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Study and Practice of the Training Mode of Excellent Talents in Electronic Information Engineering in Local Universities Based on "Emerging Engineering" in China

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Abstract: In order to training excellent talents students, to deal with the problems which the curriculum system is lagging behind, the industry and education are out of touch, and the teaching methods are backward, "emerging engineering" research and practice projects of the Ministry of Education of china was carried out during last 6-7 years. We have built a new curriculum system with subject foundation courses, professional foundation courses and professional courses as the main axis and artificial intelligence and Internet of Things courses as the two wings. We have created a new mechanism of "multi-faceted and full-process" collaborative education, and innovated new teaching methods of "teaching education" and "anytime, anywhere" practice. We have achieved significant results in talent training, and this major was approved as a national first-class undergraduate major of China.

Keywords: outstanding engineering education; teaching reform; Java course; Electronics Information Engineering;

1. INTRODUCTION

Since the 18th CPC National Congress, General Secretary Xi Jinping has repeatedly pointed out that in the next few decades, a new round of scientific and technological revolution and industrial transformation will form a historic intersection with China's accelerated transformation of economic development, and the role of engineering in society has undergone profound changes. Engineering science and technology progress and innovation have become an important engine for promoting the development of human society. This has brought great opportunities for innovation and reform of engineering education, but this opportunity is no longer a traditional opportunity to simply expand the scale and increase the number of majors, but a new opportunity that forces us to reflect on engineering education and build "new engineering"[1]. It is worth further studying how to achieve the transformation from concept to action in the construction of new engineering disciplines by transforming platforms in the higher education system and engineering education process[2].

The fourth industrial revolution has led to the rapid development of the electronic information industry, but the relevant majors in colleges and universities are still using outdated curriculum systems, education mechanisms and teaching methods to cultivate talents, resulting in a serious disconnection between colleges and universities and the industry and society, and an urgent need for emerging engineering reforms[3-4].

As an engineering major in a local university, the undergraduate major of electronic information engineering at Yangtze University aims to cultivate compound and application-oriented senior engineering and technical talents for the industry and the local area, and plays a supporting role in regional economic development and industrial transformation and upgrading[5-6].

Since 2013, the teaching team of this major has mainly carried out teaching research and practice based on projects such as the "Excellent Engineer Education and Training Program" of the Ministry of Education, using the National Experimental Teaching Demonstration Center for Electrical and Electronic Engineering as a platform; since 2017, the teaching team of this major has mainly carried out "new engineering" research and practice based on the first batch of "emerging engineering" research and practice projects of the Ministry of Education: “Reform and practice of multi-party collaborative education model for new engineering disciplines in local universities”. With the strong support of government departments and the active participation of social forces such as enterprises, after 6-7 years of exploration and practice, a model for cultivating outstanding talents in electronic information engineering in local universities based on "emerging engineering" has gradually been formed.

2. CURRICULUM SYSTEM OF “ONE AXIS AND TWO WINGS”

2.1 Reconstruction the Curriculum system

With the rapid development of new technologies, the original curriculum system has obviously failed to adapt to the new situation. In order to change this situation, on the one hand, the original courses are upgraded and renovated, outdated content is deleted, content reflecting new technologies is added, and basic knowledge is strengthened. On the other hand, new courses such as "Introduction to Artificial Intelligence" and "Internet of Things Technology" are added, thus building a new "one axis and two wings" curriculum system with subject basic courses, professional basic courses and professional courses as the main axis and artificial intelligence and Internet of Things courses as the two wings (shown in Figure 1).

2.2 Strengthen practical innovation and improve training programs

In order to meet the needs of emerging industries and the needs of students' all-round development, we adjusted the original three-tier theoretical curriculum system, sorted out and streamlined the core professional courses to free up hours and credits, added artificial intelligence courses such as "Introduction to Artificial Intelligence", "Machine Learning", "Computer Vision" and Internet of Things courses such as "Iot Technology", "Sensor and Acquisition Technology", and "Petroleum Internet of Things Engineering", and constructed a "one axis and two wings" curriculum system, forming a composite knowledge framework curriculum system with the original professional curriculum system as the main axis and artificial intelligence and Internet of Things courses as the two wings.

The practical teaching resources and engineering cases are updated; for the practical links of the new courses, through school-enterprise cooperation, new corresponding laboratories are built, and industry-oriented practical teaching resources and engineering cases are developed, so that practical teaching can keep pace with technological development and meet the innovation and development needs of enterprises. The "One axis and Two wings" curriculum system is shown in Figure 1.

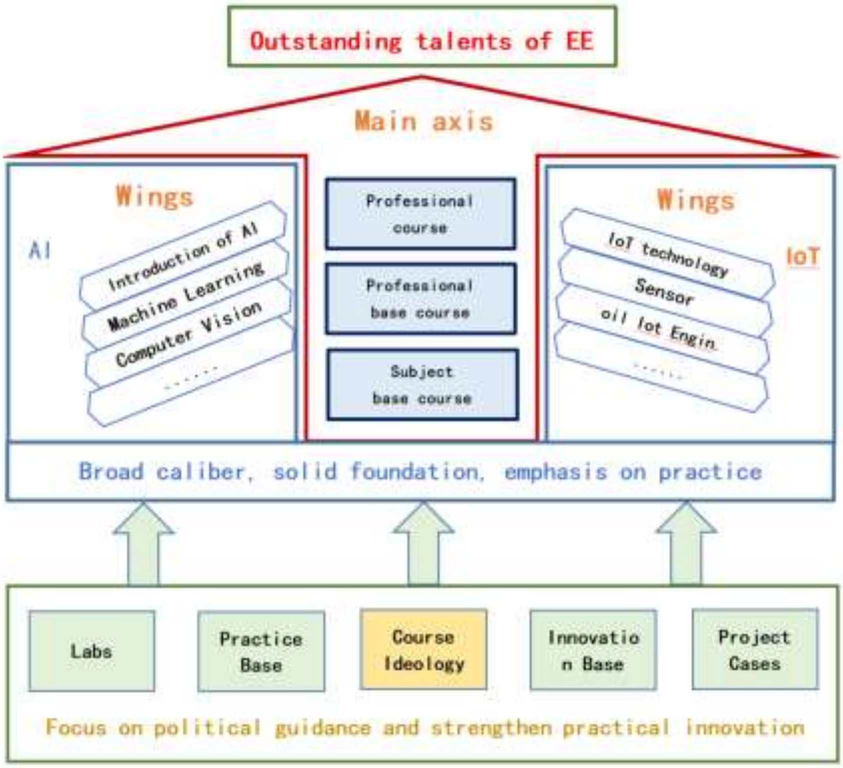

Figure 1. Curriculum system of "One axis and Two wings".

3. NEW MECHANISM OF COLLABORATIVE EDUCATION

3.1 Building a new platform for collaborative education

With the strong support of government departments and the active participation of social forces such as enterprises, 18 multi-party collaborative education platforms such as the "Image Processing and Machine Vision Innovation Laboratory" were newly established based on the National Experimental Teaching Demonstration Center for Electrical and Electronic Engineering.

In 2018, it was approved by the Ministry of Education for the first batch of new engineering research and practice projects "Reform and Practice of Multi-party Collaborative Education Model of New Engineering in Local Universities", and in 2019, it was approved as a national first-class undergraduate professional construction site. In recent years, it has been approved by the Ministry of Education for 19 "Industry-University Cooperation, Collaborative Education" projects. In 2018, the Jingzhou Open Laboratory was listed by Yangtze University, including three open laboratory pilots: the Mechanical and Electrical Integration Innovation Center, the Internet of Things and Big Data Center, and the BIM Technology Center; in 2020, the China Association for Science and Technology Overseas Intelligence Opportunities Hubei (Jingzhou Development Zone) Working Base was established; in 2022, Sinopec Machinery, Jingzhou Municipal Government, and Yangtze University signed a contract to jointly build the Jingzhou Petroleum Science and Technology City.

It has jointly built six joint laboratories including the "Yangtze University-NI Software Radio Joint Laboratory" with NI Company of the United States; it has jointly built six internship and training bases with Danei Group, Aura International, Shenzhen Xunfang and other companies; it has jointly built three innovation bases including the embedded system maker space and the software maker space with Guangdong Yueqian; it has jointly built two virtual simulation laboratories including the "Big Data Remote Virtual Laboratory" and the "Communication Principle Virtual

Simulation Laboratory" with Beijing Pukai and Wuhan Lingte respectively.

3.2 Establish a new mechanism for collaborative education

Relying on the multi-party collaborative education platform inside and outside the school, through measures such as corporate mentors entering schools, university teachers entering enterprises, and combining student learning and practice between schools and enterprises, a new "multi-faceted" collaborative education mechanism has been established that benefits multiple parties including government, industry, academia, and research, and has a benign interaction. This has achieved "full-process" collaborative education in which multiple parties participate in talent training and run through all teaching links.

Give full play to the school's position as the main battlefield of education, and carry out all-round guidance with the participation of all staff: academic guidance by department leaders, ideological and political guidance and professional learning tutoring by teachers, psychological counseling by counselors, career guidance by corporate experts, safety supervision by class teachers, and political leadership by outstanding student cadres.

Collaborative education throughout the whole process.Visit enterprises in the freshman year. Take students to visit China Telecom Group Jingzhou Branch, Jingzhou Radio and Television Media Group and other enterprises in the freshman year to understand the actual production situation of the enterprises. Production internship in the sophomore year. In the sophomore year, they went to China Aerospace Science and Industry Corporation Aerospace Nanhu Electronic Information Technology Co., Ltd., Hubei Guangfa Communication Co., Ltd., Kaile Quantum Communication Technology Co., Ltd. and other enterprises for on-the-job internships. Enterprise courses are offered in the junior year. Cooperate with Wuhan Houpu Education Technology, Shenzhen Xunfang and other companies to offer enterprise courses such as "Industry Engineering Standards and Specifications" and "Digital TV Technology" and course designs such as "Software System Development and Implementation" and "Electronic Information New Technology Training". Graduation design in the senior year. Invite 3-5 enterprise experts to participate in the undergraduate graduation design teaching link every year, and guide more than 10 undergraduate graduation theses per year.

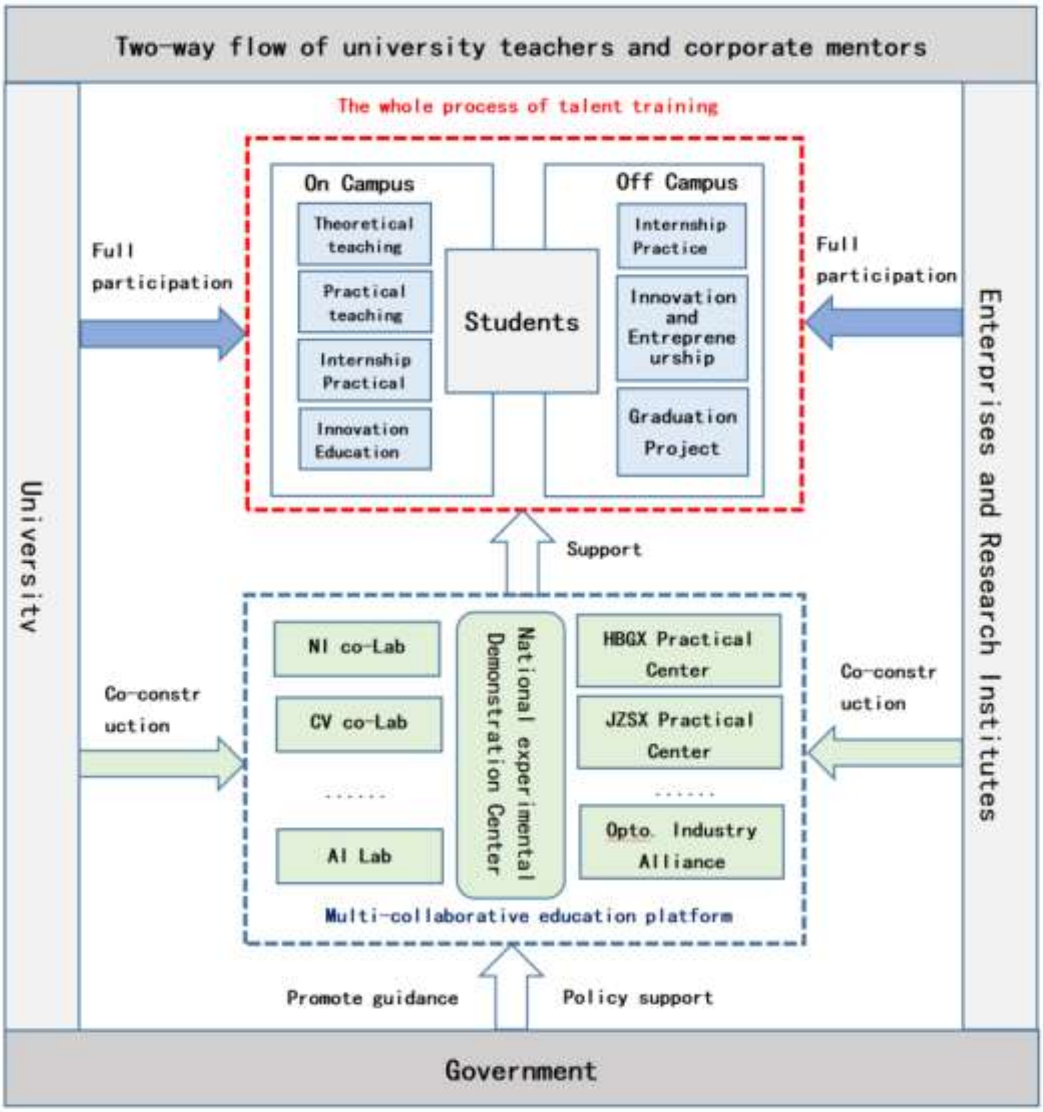

Figure 2. A new mechanism of "multi-faceted and full-process" collaborative education.

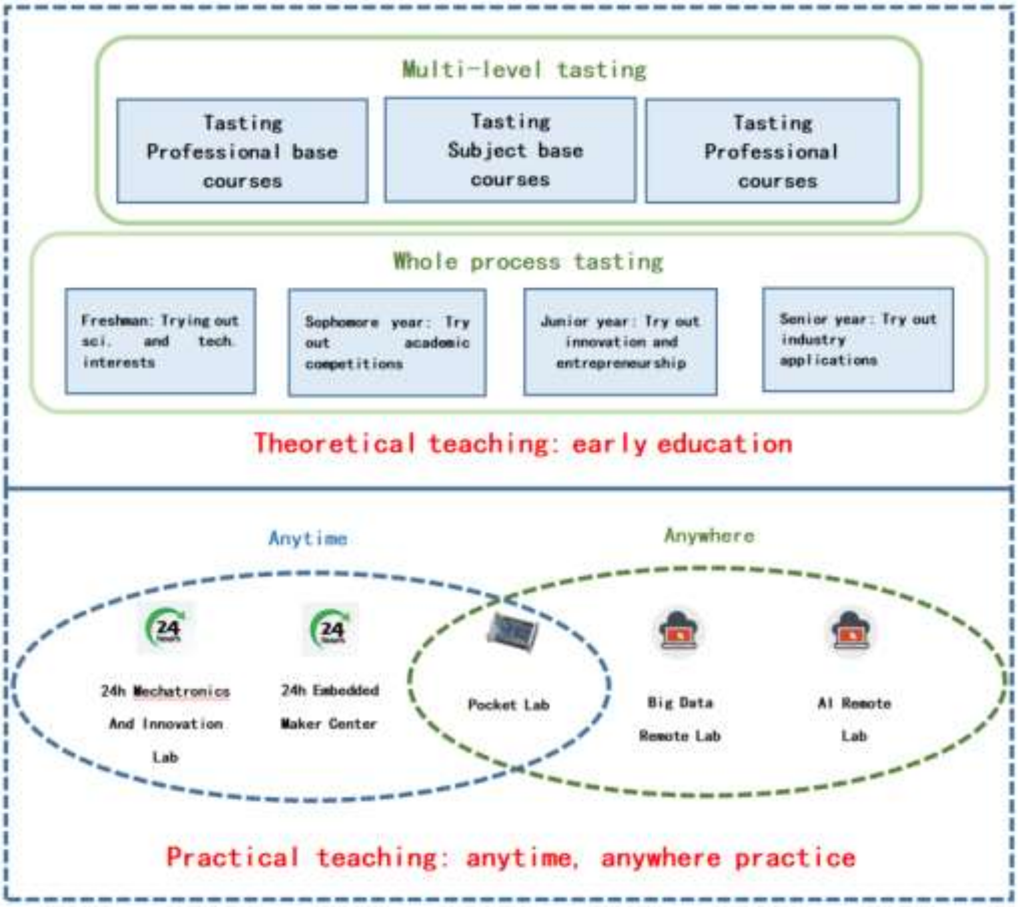

Figure 2. Innovative teaching methods of "teaching for the first time" and "anytime, anywhere" practice.

4. NEW METHODS OF PRACTICAL TEACHING

4.1 Create a new method of classroom teaching for "tasting education"

The school has created a new method of "teaching new things" by "first letting students taste something new, then taking various measures to guide them to explore cooking methods". In the four years of university, students are allowed to taste new things "throughout the whole process" by taking scientific research results, competition works, innovative entrepreneurial works, and the application of high-tech technologies such as artificial intelligence in the petroleum industry as examples; in the specific teaching process, the school carefully sets up "multi-level" tasting points in the basic courses, professional basic courses, and professional courses to continuously stimulate students' curiosity.

4.2 Implement a new "anytime, anywhere" practical teaching plan

Basic courses such as "Circuits" are moved forward to the freshman year, and other courses are moved forward accordingly. "Pocket laboratories" are introduced to encourage students to practice early. Full use is made of remote laboratories and 24-hour open laboratories in the national experimental teaching demonstration center and 18 collaborative education platforms inside and outside the school. Through school-enterprise collaboration, practical conditions that are not restricted by time and place are created throughout the four years of university, thus implementing a new plan for practical teaching "anytime, anywhere". Comprehensively utilize pocket laboratories (pocket laboratories refer to experimental equipment that is miniaturized, portable, and pocketable), 24-hour face recognition laboratories and maker centers, and cloud computing-based remote laboratories to cultivate students' practical skills throughout the process.

Pocket laboratories. In order to facilitate students to conduct experiments anytime and anywhere and start experiments as early as possible, we introduced pocket laboratories for courses such as "Basics of Circuit Analysis", "Analog Electronic Circuits", and "Digital Electronic Technology". They were distributed to students in their freshman year, so that students can combine MOOCs and other teaching resources to study and practice in advance.

24-hour open laboratory. We upgraded the face recognition management system for the National Electrical and Electronic Experimental Teaching Demonstration Center. Each laboratory has achieved unmanned operation and is open to teachers and students 24 hours a day.

Remote laboratory. The "Yangtze University-Pukai" big data joint laboratory and artificial intelligence laboratory have been established. These laboratories provide remote login functions.

Students and teachers can log in anywhere to complete various experiments, innovation and entrepreneurship training, and scientific research projects.

5. CONCLUSION

After 6-7 years of research and practice, Yangtze University's Electronic Information Engineering major was approved as a national first-class undergraduate major construction site. The number of students in this major who won awards in competitions increased by an average of 37.5%; the number of projects undertaken in the College Students Innovation and Entrepreneurship Training Program increased year by year, from an average of 13 to 25 per year; the number of SCI papers published increased from zero to eight; and the number of patents approved increased from zero to six. The student employment rate remained stable at over 98%, with over 60% of graduates employed in related industries and local grassroots frontlines; the quality of employment improved year by year, with an obvious increase in the average annual salary, and the highest annual salary for fresh graduates reached 160,000 yuan. The rate of admission to postgraduate schools increased from 30% to 56%, of which the rate of admission to 985/211 universities increased from 11% to 32%.

6. ACKNOWLEDGMENTS

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Risk Comes from Not Knowing What You're Doing – Risk-Based Testing

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Abstract: Today's software ecosystems are more complex than ever, with interdependent modules, third-party integrations, microservices architectures, and regulatory compliance requirements. In this context, testing every aspect of an application is not only inefficient but often impractical. The sheer volume of possible test cases in such systems means that exhaustive testing can quickly consume all available time and resources, without guaranteeing the discovery of critical issues. The conventional "brute-force testing" or "comprehensive testing for defect discovery" concept can quickly consume all available time, and resources lead to a vast number of minor defects being identified while critical risks remain untested. In a landscape where rapid iteration, frequent updates, and compressed testing windows dominate, the emphasis has shifted from indiscriminate testing and testing exhaustively to targeted, risk-based testing strategies and testing intelligently that optimize speed and effectiveness.

"Risk comes from not knowing what you're doing. "- Warren Buffett. This is where Risk-Based Testing (RBT) comes into play as a modern, strategic testing approach that addresses these challenges. Risk-Based Testing (RBT) is a tactical testing paradigm that prioritizes test execution by assessing and quantifying the risk exposure associated with potential software defects. By targeting application components with elevated risk profiles—whether due to complexity, integration points, or high business impact—RBT streamlines resource allocation, maximizes risk coverage, and mitigates the probability of high-severity defects surfacing in production environments. This article delves into the core tenets of RBT, encompassing risk identification, quantitative risk assessment, and targeted mitigation strategies. It outlines how RBT aligns test efforts with business-critical objectives, optimizing quality assurance (QA) outcomes within the constraints of budget, timeline, and resource availability. Leveraging real-world case studies and industry best practices, the article demonstrates how RBT accelerates defect discovery, enhances reliability, and ensures efficient delivery of high-stakes software systems.

Keywords: Risk-Based Testing (RBT), Test Design, Risk prioritization, Risk Matrix Chart, Risk Matrix – Resource Allocation, Business-critical objectives

1. INTRODUCTION

In today's rapid-paced software development landscape, delivering robust, high-quality software with efficiency is paramount. However, limited time and resources make it impractical to thoroughly test every feature. To navigate these constraints, teams are increasingly leveraging Risk-Based Testing (RBT)—a strategic testing methodology that zeroes in on high-risk areas of the software. By prioritizing testing efforts where the potential for failure or impact is greatest, RBT optimizes resource allocation, enabling early detection and resolution of critical defects before they can adversely affect the end-user experience.

2. WHY TRADITIONAL APPROACH FALLS SHORT

The conventional test approach, which focuses on executing as many test cases as possible, presents several limitations in today's context:

1. **Resource and Time Constraints:** In agile and continuous integration/continuous delivery (CI/CD) environments, teams simply don't have the luxury of long testing cycles. The pressure to release new features quickly demands a more selective testing strategy.

2. **Diminishing Returns:** As the number of test cases increases, the likelihood of finding significant new defects decreases. Many tests end up covering low risk areas, yielding minimal value while consuming valuable resources.

3. **Focus Misalignment:** Traditional testing often lacks alignment with business goals. Teams may focus on functional testing of low-risk features while ignoring high-risk areas that could cause severe business disruption if they fail

3. RISK BASED TESTING

3.1 How Risk-Based Testing Shifts the Paradigm

Risk-Based Testing shifts the paradigm by acknowledging that testing everything is not feasible, and not every defect carries equal weight. By utilizing RBT, teams can intelligently allocate their testing resources based on two primary factors:

1. **Probability of Failure:** How likely is a given feature, module, or function to fail based on its complexity, newness, or past defect rates?

2. **Business Impact:** What would the repercussions be if this feature or function fails in a production environment? How critical is this to the end-user or the business?

This approach leads to **focused and efficient testing**, as it ensures that the most critical areas—those where failure would result in significant business or user impact—are given priority. Test coverage is not determined by the number of test cases but by the **quality and relevance** of the tests being executed.

3.2 What is Risk-Based Testing?

Risk-Based Testing (RBT) is a methodology that aligns the testing process with risk management principles. The core idea is that not all parts of an application carry the same level of risk. In essence, it focuses on the areas where the likelihood of failure is highest, or the impact of failure would be the most severe. RBT involves:

1. **Risk Identification:** Determining potential risks that could arise due to defects in the software or function or module.
2. **Risk Assessment:** Evaluating the likelihood of those risks occurring and the impact they would have on the system and business.
3. **Risk Mitigation:** Prioritizing test cases based on these risks to ensure that the highest-risk areas are tested thoroughly.

By leveraging this approach, teams can ensure **higher test effectiveness** while staying within the constraints of time and resources.

3.3 Key Components of Risk-Based Testing

To implement RBT effectively, it is crucial to understand its core components, which involve both risk management and testing practices.

1. **Risk Identification:** Risk identification is the first and most critical step in RBT. This involves understanding the software and its intended environment to pinpoint areas that might fail. Risks can stem from various factors, including:

Table1. Risk Based Testing Applicable Scenarios

Scenario	Description
Complex applications	Emphasize testing in intricate, multi-component software systems by targeting high-risk areas that are more susceptible to failure due to their inherent complexity.
Short testing timelines	Leverage Risk-Based Testing (RBT) to streamline testing efforts in time-constrained projects, prioritizing critical functionalities for maximum efficiency within limited timelines.
High-risk systems	Utilize Risk-Based Testing (RBT) in high-risk systems to mitigate the likelihood of significant financial or data loss from potential failures.
Budgeting restrictions	Implement Risk-Based Testing (RBT) to enhance testing efficiency within tight budgets, ensuring optimal use of resources while maximizing testing impact.
New or untested features.	Risk-Based Testing (RBT) for new or untested features focuses on high-risk areas, prioritizing critical components to prevent defects and ensure stability. I
Compliance and regulations	Leverage Risk-Based Testing (RBT) to ensure regulatory compliance in critical sectors like healthcare and finance, aligning testing efforts with compliance priorities
Historical data on defects	Concentrate Risk-Based Testing (RBT) on modules with a track record of recurring defects, prioritizing these areas for heightened scrutiny in each testing cycle.

Techniques such as **brainstorming, historical data analysis**, and **failure mode and effects analysis (FMEA)** can be used to identify these risks.

2. Risk Assessment After identifying potential risks, they must be assessed in terms of **likelihood** (how probable is the risk) and **impact** (what damage it would cause if it materialized). The risk assessment process is often visualized using a **risk matrix**:
    - **Low Risk**: Low likelihood, low impact.
    - **Medium Risk**: Either high likelihood or high impact but not both.
    - **High Risk**: High likelihood and high impact.

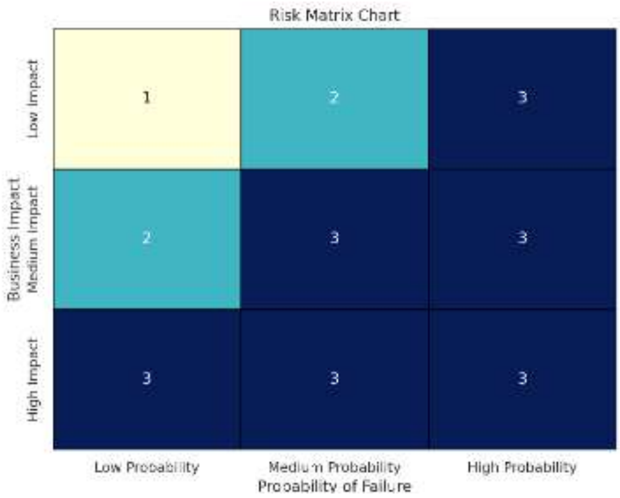

Figure 1. Risk Matrix Chart

Risk levels help teams decide which areas of the system to focus their testing efforts on. For example, critical modules that have a high likelihood of failure and a severe business impact should receive the most attention.

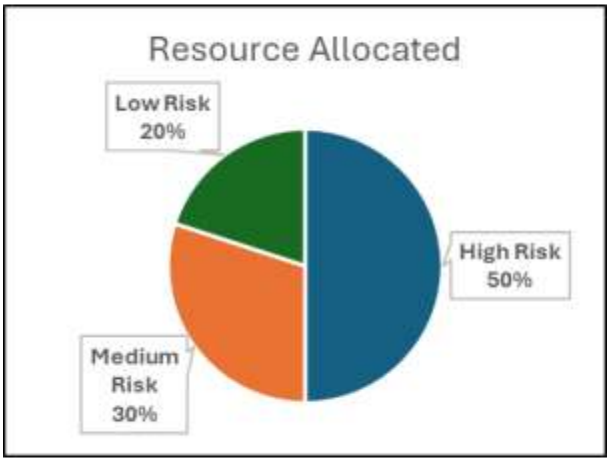

Figure 2. Risk Matrix – Resource Allocation

3. **Risk Mitigation and Prioritization** In RBT, risk mitigation occurs through test prioritization. This means allocating more time and resources to high-risk areas of the application and reducing the focus on low-risk features. For example:
    - High-risk features might undergo **extensive functional and non-functional testing** (such as performance, security, and usability tests).
    - Low-risk features might be tested with basic test cases or even deferred for future cycles.
4. **Test Design and Execution** Once risks are prioritized, tests are designed and executed according to the risk level. Critical risks often require more robust testing approaches, including:
    - **Exploratory Testing**: Focuses on testing high-risk areas with a goal of uncovering unexpected issues.
    - **Regression Testing**: Ensures that existing functionality continues to work after changes are made.
    - **Load and Stress Testing**: For areas with performance concerns.

Lower-risk areas might undergo lighter testing, like basic functionality checks, to conserve resources.

3.4 Advantages of Risk-Based Testing

1. **Optimized Resource Allocation** RBT ensures that resources are used efficiently by focusing on high-risk areas, avoiding unnecessary testing on low-risk or trivial parts of the system.
2. **Enhanced Test Coverage:** Test coverage under RBT is not about covering every possible scenario but ensuring that the most important scenarios are covered comprehensively. This leads to a better overall quality of the product, with fewer critical bugs slipping through to production.
3. **Early Detection of Critical Defects** Prioritizing high-risk areas allows for the early detection of defects that could have the most severe business or user impact, giving the team more time to address them.
4. **Increased Stakeholder Confidence** RBT enables better communication with stakeholders, as testing efforts are directly aligned with business priorities. This provides greater transparency about what areas have been tested and the potential risks.
5. **Faster Time-to-Market:** RBT supports faster releases by aligning testing priorities with the

release schedule. Teams can meet tight deadlines without compromising on the quality of the most important features.

6. **Cost and Time Efficiency** By focusing testing efforts on high-risk areas, teams save time and reduce costs while maintaining or even improving software quality.

3.5 Challenges in Implementing Risk-Based Testing

While RBT offers numerous advantages, implementing it effectively requires overcoming several challenges:

1. **Accurate Risk Identification:** Incorrectly assessing risks can lead to testing efforts being misallocated. For example, underestimating the risk of a particular feature could result in insufficient testing.
2. **Collaboration:** Effective RBT requires collaboration between testers, developers, business analysts, and stakeholders to ensure risks are accurately assessed and testing is aligned with business needs.
3. **Dynamic Risks:** Risks can evolve over time, especially in complex, fast-changing projects. Teams must continuously monitor and reassess risks throughout the software development lifecycle.

3.6 Best Practices for Risk-Based Testing

To maximize the benefits of RBT, the following best practices should be observed:

1. **Involve Stakeholders Early:** Risk identification and prioritization should involve key stakeholders to ensure testing efforts are aligned with business goals and priorities.
2. **Use Historical Data:** Leverage historical defect data and past project experiences to better identify potential risks.
3. **Continuous Risk Assessment:** Reassess risks throughout the development and testing process, as new risks can emerge at any stage.
4. **Automate Where Possible:** For recurring or high-risk areas, consider automating tests to ensure consistent and efficient test execution.

3.7 Case Study: Risk-Based Testing in a Life Insurance Underwriting System

Background

A prominent life insurance company sought to enhance its underwriting system, which evaluates applicants' risk profiles to determine policy eligibility and premium rates. Given the importance of accurate risk assessment in the underwriting process and the potential financial implications of errors, the company recognized the need for a robust testing strategy.

Objectives

1. To ensure the reliability and accuracy of the underwriting algorithms.
2. To minimize financial risks and data inaccuracies through effective testing.
3. To streamline the testing process while focusing on high-risk areas to optimize resource utilization.

Implementation of Risk-Based Testing

- **Risk Identification**
  - **Stakeholder Workshops:** The project team organized workshops involving underwriters, IT staff, business analysts, and QA engineers. These workshops aimed to gather insights on potential risks associated with the underwriting system.
  - **Identified Risk Factors:**
    - **Algorithm Accuracy:** Errors in risk assessment algorithms could lead to incorrect underwriting decisions, resulting in financial loss.
    - **Data Integrity:** Ensuring that applicant data is accurately captured and processed.
    - **Compliance Risks:** Meeting regulatory requirements for data handling and risk assessment.
    - **Integration Risks:** Issues with third-party data sources that could impact risk assessments.
    - **User Interface (UI) Usability:** Ensuring that the UI provides clear instructions and error messages to users.
  - **Risk Assessment**
    - **Risk Matrix Development:** The team developed a risk matrix to categorize identified risks based on their likelihood and impact:
      - **High Risk:** Algorithm accuracy issues, data integrity, and compliance risks.
      - **Medium Risk:** Integration with third-party data sources.
      - **Low Risk**: UI usability concerns.
    - **Prioritization:** Testing efforts were prioritized based on this

assessment, focusing on high-risk areas to minimize the potential for critical failures.

- **Test Design and Execution**
  - **Focus on High-Risk Areas:**
    - **Algorithm Testing:** Extensive testing of the risk assessment algorithms, including:
    - **Boundary Testing:** Checking edge cases where applicants fall outside typical parameters (e.g., age limits, health conditions).
    - **Scenario Testing:** Evaluating how the system responds to different risk scenarios to ensure accurate decision-making.
  - **Data Integrity Tests:** Ensuring accurate data capture and processing through automated validation checks.
- **Medium and Low-Risk Areas:** Testing of integration with third-party data sources was scheduled, while UI testing was deprioritized unless it directly impacted critical processes.

- **Monitoring and Continuous Improvement**
  - **Ongoing Risk Assessment:** The team conducted periodic reviews of the risk matrix throughout the development lifecycle, adjusting priorities as needed based on new insights or emerging risks.
  - **Stakeholder Communication:** Regular updates to stakeholders provided transparency about testing outcomes and any identified risks.
- **Results**
  - **Improved Algorithm Accuracy:** The focused approach allowed for the early detection and resolution of critical issues in the risk assessment algorithms, reducing the likelihood of incorrect underwriting decisions.
  - **Compliance Assurance:** Proactive testing of compliance-related functions ensured adherence to regulatory requirements, mitigating the risk of penalties and reputational damage.
  - **Optimized Resource Utilization:** By concentrating on high-risk areas, the team successfully completed the project within budget and on schedule, avoiding the pitfalls of exhaustive testing.
  - **Enhanced User Confidence:** The emphasis on algorithm accuracy and data integrity led to increased confidence among underwriters, enabling them to make more informed decisions.

3.8 Conclusion

In the dynamic landscape of software development, Risk-Based Testing (RBT) represents a forward-thinking methodology that transcends the outdated "test more, find more" approach. By employing a risk-centric framework to prioritize testing activities based on the application's risk profile, RBT effectively uncovers critical defects during the early stages of the development cycle. This strategic focus not only optimizes resource utilization but also minimizes unnecessary test cases.

This sophisticated, metrics-driven strategy empowers development teams to accelerate the delivery of robust, high-quality software while simultaneously mitigating business risks and ensuring alignment with organizational objectives. Moreover, RBT enhances software quality and fosters a more agile, adaptive, and resource-efficient testing environment, adeptly meeting the demands of modern development practices.

The future of software testing lies in approaches that emphasize quality and risk management. RBT is not merely a methodology; it represents a transformative mindset that can drive substantial enhancements in your testing processes. We invite you to delve deeper into RBT and explore how it can be seamlessly integrated into your practices to achieve greater efficiency and effectiveness in delivering exceptional software solutions.

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Improved RT-DETR Approach for Steel Surface Defect Identification

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Abstract: To improve the accuracy of surface defect detection on steel while maintaining detection speed, this study proposes an enhanced RT-DETR detection model called FTD-DETR. First, images were obtained from a publicly available steel surface defect dataset, and data were partitioned and augmented, resulting in a steel surface defect dataset containing 2,000 images. The ResNet18 model, known for its low computational complexity and high detection accuracy, was chosen as the backbone feature extraction network. Then, a Faster-EMA module was introduced to update the basic blocks in ResNet18, enhancing the feature extraction speed of the model and improving inter-layer feature interaction. Finally, the AIFI module of RT-DETR was replaced with a Transformer with Deformable Attention encoder structure. This multi-head self-attention mechanism combined with dynamic attention further increases feature representation while reducing computational complexity. Experimental results show that FTD-DETR achieves a precision of 83.6%, recall of 67.7%, and mean average precision (mAP) of 79.3%. Compared to the baseline model RT-DETR, FTD-DETR significantly reduces parameters, floating-point operations, and memory usage while maintaining high accuracy. It features low complexity, high accuracy, and fast detection speed, providing technical support for steel surface defect detection.

Keywords: Steel Surface Crack Detection；Vision Transformer；EMA；yolo；RT-DETR

1. INTRODUCTION

Steel, as a widely used material in fields such as mechanical manufacturing, construction engineering, and transportation, is highly valued for its high strength, durability, and broad range of applications. Therefore, surface defect detection in steel is an important quality control task [1]. China, as one of the largest steel producers in the world, manufactures a wide variety of steel products, which are extensively used in mechanical manufacturing, construction engineering, and transportation. Steel is highly regarded for its strength, durability, and versatility. However, surface defects in steel are diverse and vary depending on different production processes and environments. During steel processing, surface defect detection is a key step in ensuring product quality, directly impacting customer choice and the competitiveness of products in the market. In various production environments, steel surfaces are prone to defects such as scratches and dents, which can affect their performance [2].However, especially in large-scale production, manual inspection often fails to identify all defects in a timely manner. Additionally, due to a lack of effective detection knowledge, some problems go unnoticed [3] . Thus, there is a need for a method that can automatically detect steel surface defects and provide early warnings. Traditional methods for detecting steel surface defects mainly rely on manual inspection, but due to the complexity of the production environment and the variability in lighting and surface conditions, manual detection is time-consuming, labor-intensive, and prone to errors, making it difficult to meet the needs of automated production lines. Subsequent optical detection technologies [4], such as X-rays, infrared imaging, and laser scanning, have improved detection speed and reduced human errors. However, these devices are expensive, have high operating costs, and are limited in their ability to handle complex defects, restricting their widespread application.

Currently, automated methods for steel surface defect detection [5] can be broadly categorized into three types: traditional image processing-based detection methods, deep learning-based detection methods [6] , and the use of 3D point cloud scanning. The former [7] relies on steps such as data augmentation, image preprocessing, edge detection, and feature extraction. These methods depend on well-defined rules or algorithms (e.g., grayscale thresholding, Canny edge detection) to identify and classify steel surface defects. While they are effective for detecting simple defects, their accuracy in identifying more complex surface textures or varied defect shapes is limited, and their generalization ability is poor.The latter approach utilizes 3D scanning technologies [8] (such as LiDAR and photogrammetry) combined with machine learning to further enhance the accuracy of surface defect detection. 3D point clouds can accurately capture the geometric features of the surface, making them particularly effective for detecting small defects, such as cracks or surface irregularities. However, these methods involve high computational complexity, which makes it difficult to meet the real-time requirements of automated systems.

With the development of deep learning, Anvar A et al. [9] proposed in 2020 an improved convolutional neural network (CNN) architecture called ShuffleDefectNet. This network combines the lightweight design of ShuffleNet with specific layer structures suitable for defect detection tasks. By using data augmentation and transfer learning techniques, the detection performance for different types of metal surface defects, such as cracks, scratches, and pits, was improved. Hu B et al. [10] proposed an enhanced version of the classic Faster R-CNN detection algorithm, integrating FPN (Feature Pyramid Network) technology to enhance multi-scale feature extraction capabilities, enabling the model to more accurately identify PCB defects of varying sizes and types, such as breaks, short circuits, and missing components. The improved Faster R-CNN with FPN demonstrated significant improvements in detection precision and recall compared to the original model.Xiao L et al. [11] proposed an improved Mask R-CNN model called IPCNN. This model first utilizes a deep residual neural network to extract features from image pyramids, generating multi-level pyramid features. These features are processed by the Region Proposal Network (RPN) to generate defect bounding boxes and classifications. Finally, within the generated defect bounding boxes, a fully convolutional network (FCN) generates corresponding defect masks. Xia B et al. [12] introduced the SSIM-NET model, which combines SSIM (used to measure image similarity) with the lightweight convolutional neural network MobileNet-V3. SSIM is first used to compare the input image with a template image, preliminarily locating potential defect areas. Then, MobileNet-V3 acts as a feature extractor, further classifying and detecting the located areas, improving overall efficiency.Yang L et al. [13] aimed to improve model performance by modifying YOLOv5, adopting the lightweight MobileNetV2 as the backbone network and introducing the CBAM attention module to optimize detection accuracy. The improved YOLOv5 not only reduces model parameters and computation but also significantly increases inference speed, improving detection efficiency while maintaining high accuracy. Wang Y et al. [14] optimized YOLO-V7 by incorporating a de-weighted BiFPN structure to enhance feature fusion, thereby reducing information loss during the convolution process and improving detection accuracy. Additionally, the ECA attention mechanism was introduced in the backbone network to strengthen important feature channel representation. The original bounding box loss function was replaced with the SIoU loss function, redefining the penalty term to account for the angle between required regression vectors. The optimized YOLO-V7 significantly increased detection efficiency and accuracy.Song X et al. [15] proposed a multi-directional optimization model based on YOLOv8. This model enhances the feature learning capability of the CSP Bottleneck and C2F modules by introducing deformable convolutions (DCN). It adopts a bidirectional feature pyramid network (BiFPN) for feature fusion and adds the BiFormer attention mechanism to adaptively allocate attention, effectively identifying potential defects. Additionally, the loss function was adjusted to Wise-IoUv3 (WIoUv3) to address overfitting issues with low-quality bounding boxes. With the application of transformers in object detection, Tang B et al. [16] proposed a steel surface defect detection method based on the Swin Transformer architecture. This research aimed to develop an efficient end-to-end model that leverages the hierarchical representation capability of Swin Transformer to improve feature extraction and fusion, thus enhancing defect detection accuracy. Experimental results demonstrated the method's excellent performance in identifying various steel surface defects, highlighting its potential in industrial quality inspection applications.Zhang L et al. [17] recognized the advantages of DETR (Detection Transformer) in the field of image object detection and optimized the DETR model for feature extraction and detection performance, improving the recognition accuracy of casting defects. The improved framework excelled in handling complex defect morphologies, particularly in detecting irregularly shaped defects on casting surfaces.

In conclusion, this paper designs a steel surface crack detection model, FTD-DETR, based on RT-DETR [18] . To address the issue of a small dataset, data augmentation is applied to expand the dataset. After comparing different feature extraction networks, ResNet18 [19] was selected as the baseline backbone network. Faster-EMA is utilized to adjust the basic blocks, further improving feature extraction speed while enhancing feature interaction. To resolve issues with feature detail information at mid and lower levels, the AIFI (Anchor-Free Instance-aware Feature Interaction) module is replaced with Transformer-DAttention, which enhances RT-DETR’s global perception capability, multi-scale feature processing, and overall performance. Finally, experimental results confirm that the FTD-DETR model can effectively handle steel surface defect detection tasks.

2. Method

2.1 RT-DETR Model

RT-DETR is an end-to-end object detection model designed for real-time applications, based on the Transformer framework. It is specifically optimized for handling multi-scale features. By decoupling interactions between features at the same scale and integrating cross-scale features, RT-DETR significantly reduces the computational complexity of the original DETR model. It retains efficient multi-scale information extraction capabilities while surpassing many similar models, such as the YOLO series, in both inference speed and detection accuracy. The model simplifies traditional post-processing workflows, ensuring zero-latency inference and stable output.The core of RT-DETR consists of a backbone network, a hybrid encoder, and a decoder with auxiliary prediction heads. The feature extraction component is based on the selected backbone network architecture, utilizing features from the last three stages as inputs for the encoder. The hybrid encoder contains the AIFI (Anchor-Free Instance-aware Feature Interaction) and CCFM (Cross-scale Context Fusion Module) modules: AIFI focuses on encoding the highest-level features (S5), while the CCFM module integrates multi-scale features through both bottom-up and top-down feature fusion paths, producing rich image representations.In the decoding phase, RT-DETR introduces an IoU-aware query module, which selects key image features from the encoder’s output as initial object queries and iteratively optimizes them to generate precise bounding boxes and confidence scores. As shown in the network architecture diagram (Figure 1), this design greatly enhances detection efficiency and accuracy, especially in applications requiring high real-time performance. These improvements make RT-DETR a high-performance model, significantly reducing computational burdens while maintaining precision, making it well-suited for various real-time object detection tasks.

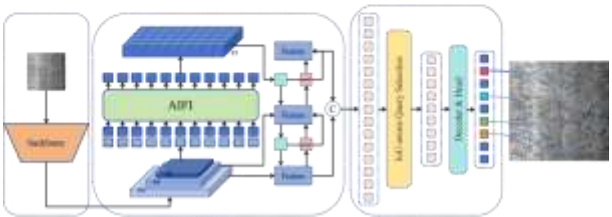

Fig1. The structure of RT-DETR model.

2.2 Improved Model Design for RT-DETR

Although RT-DETR is a high-performance model that significantly reduces computational load while maintaining accuracy, making it suitable for various real-time object detection tasks, the choice of backbone network directly affects feature extraction and computational complexity. In this paper, a series of lightweight networks such as ResNet18, Mobilenetv3 [20] , Fasternet [21] , Efficientnet [22] , HGNetV2, and VanillaNet13 [23] were selected for experiments, as shown in Table 1. These experiments comprehensively evaluated the model's parameter count, computational complexity, and accuracy in detection tasks. The results, displayed in Table 1, indicate that ResNet18 delivers the most balanced performance.

Table 1. Comparison of training results of different

Backbone	Parameters/Mb	FLOPs/G	mAP/%
Mobilenetv3	37.20	24.7	60.3
Fasternet	41.25	28.5	69.4
Efficientnet	56.77	33.2	70.3
Resnet-18	75.85	57.0	74.5
VanillaNet	105.73	165.9	73.2
HGNetV2	125.16	108.0	75.5

2.2.1 Resnet-18

ResNet-18 (Residual Network 18) is a classic convolutional neural network (CNN) architecture composed of 18 convolutional layers. Its key innovation lies in the introduction of "residual blocks" (as shown in Figure 2). These blocks use skip connections to directly pass input information to later layers, addressing the common vanishing gradient problem in deep networks. This allows deeper networks to be trained effectively. The design of ResNet-18 enables the network to learn more efficient feature representations while avoiding performance degradation caused by increased network depth.Specifically, ResNet-18 consists of 5 convolutional stages, with each stage containing multiple residual blocks. These blocks perform convolution operations using 3×3 kernels, and after applying the activation function, the output from the previous layer is added. Compared to deeper ResNet versions, such as ResNet-50 or ResNet-101, ResNet-18 has fewer parameters, making it more computationally efficient while maintaining high accuracy. This makes it particularly suitable for resource-constrained applications.

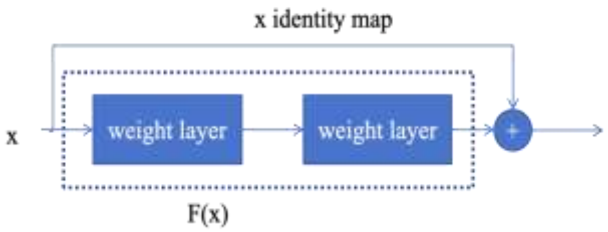

Fig2. Residual learning mechanism

2.2.2 EMA

In steel surface defect detection, the presence of occlusions or complex textures can affect detection accuracy, leading to false positives and missed detections. To reduce interference from irrelevant features and enhance the model's feature extraction capabilities, we introduced the EMA attention mechanism into the model. This mechanism retains information from each channel while reducing computational costs, allowing the model to focus more on the target defect areas, thereby improving detection performance. The structure of the EMA attention module is shown in Figure 3.

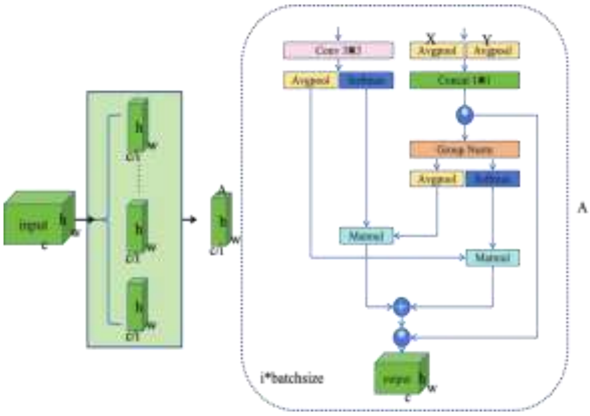

Fig3. The structure of EMA

In the steel surface defect detection task, the input features are divided into i sub-features along the channel dimension, and the attention weights learned by the model enhance the feature representation related to defect areas within each sub-feature. To capture cross-channel dependencies and reduce computational load, cross-channel information interaction is modeled along the channel direction, processed through three parallel paths: horizontal global average pooling, vertical global pooling, and convolution.The features from the first two paths are connected along the height of the image and share a 1×1 convolution, with the output feature vectors activated by a Sigmoid function. The third path captures local cross-channel interactions using a 3×3 convolution to expand the feature space.In the cross-spatial learning part, 2D global average pooling is used to encode global spatial information for both the 1×1 and 3×3 branches, and the output is processed using a Softmax function. The smallest branch output is reshaped to the corresponding dimensions. The two generated spatial attention weights are aggregated through a cross-spatial interaction module, establishing long-range dependencies and capturing pixel-level pairwise relationships of steel surface defects. This highlights the global context information of all pixels.After fusing multi-scale information, the output feature map is activated by a Sigmoid function, enhancing the model's focus on defect regions on the steel surface. This results in richer feature aggregation and improved accuracy in defect detection.

2.2.3 FasterNet Block

In response to the issue of slow inference speed on edge devices due to the large number of model parameters in current steel surface defect detection tasks, this paper introduces improvements to the ResNet-18 module. Specifically, the FasterBlock-EMA module from the FasterNet network is used to replace the BasicBlock module in ResNet-18. This modification effectively reduces both computational complexity and the number of parameters in the detection task, significantly improving detection speed. With its lightweight design, the model is particularly well-suited for efficient inference on resource-constrained edge devices.

The FasterNet Block is the core component of FasterNet, and its design is inspired by GhostNet, addressing the redundancy issue in feature convolution channels. However, unlike GhostNet, FasterNet does not use DWConv (Depthwise Separable Convolution); instead, it introduces a new Partial Convolution (PConv), as shown in Figure 4. PConv applies regular convolution only to a portion of the input channels to extract spatial features, while the remaining channels remain unchanged. This approach effectively reduces computational load and memory usage, significantly improving computational efficiency without notably sacrificing feature representation

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capability.For continuous feature access, the first or last channel is treated as a representative of the entire feature map for computation, which further reduces computational complexity.

FasterNet is an efficient neural network designed specifically for object detection tasks, optimized for both speed and accuracy. Its core concept is to enhance feature representation capability and expand the receptive field coverage, all while maintaining a lightweight architecture and high inference speed. The FasterNet network structure consists of four stages, as shown in Figure 4. Each stage is responsible for extracting features at different scales, with the primary differences being the size of the convolution kernels.The Embedding module performs the initial feature extraction using regular convolutions with a stride of 4. The Merging layer uses convolutions with a stride of 2 for spatial downsampling and channel expansion, progressively reducing the spatial resolution of the feature maps while increasing the number of channels. This stepwise compression of spatial resolution and expansion of channel dimensions is crucial for efficient detection at multiple scales.

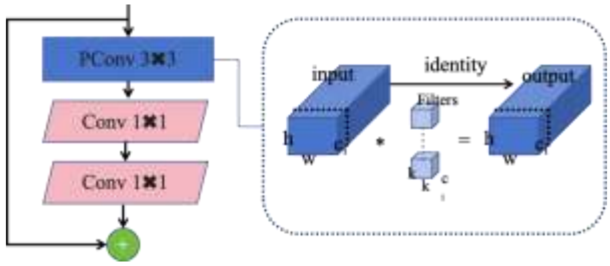

Fig4. The structure of Fasternet

2.3 Transformer_DAattention

In the RT-DETR network, the newly introduced AIFI module (Anchor-Free Instance-aware Feature Interaction) offers several advantages, particularly its efficient local feature extraction capability. By implementing object detection in an anchor-free manner, it eliminates the complex anchor design found in traditional detectors, simplifying the overall model architecture. Moreover, AIFI enhances object instance perception through its feature interaction mechanism, making it highly effective at handling objects of varying shapes and scales, achieving good detection speed and accuracy.However, AIFI also has some limitations. Since its focus is primarily on local feature extraction, it is less effective at capturing long-range global dependencies, which could limit the model's global awareness in complex scenes. Additionally, the feature interaction mechanism in AIFI is somewhat inadequate in handling multi-scale features, which may result in underperformance when dealing with tasks that involve large variations in object size. In contrast, models equipped with multi-head self-attention mechanisms tend to perform better in such scenarios.Overall, while the AIFI module excels in certain contexts, it has room for improvement in terms of global information capture and multi-scale processing.

To address the challenges of automated detection for steel surfaces in complex environments, this paper replaces the AIFI module with Transformer with Deformable Attention. The Transformer Encoder, utilizing the self-attention mechanism, is more effective in capturing global contextual information and can manage long-range feature dependencies. This improvement helps the model perform better in detecting complex objects and backgrounds.Additionally, Deformable Attention (DAttention) within the Transformer Encoder dynamically adjusts the weights between different tokens based on input features or context, making the attention mechanism more flexible. The inclusion of residual connections and feedforward neural networks further prevents gradient vanishing and information loss, enhancing both the stability and accuracy of the model. Moreover, the adaptive nature of the attention mechanism allows it to dynamically allocate attention weights according to task requirements, boosting performance in complex scenes.Thus, replacing AIFI with Transformer-DAttention significantly improves RT-DETR's global perception capabilities, multi-scale feature processing, and overall performance. The revised network architecture is shown in Figure 5.

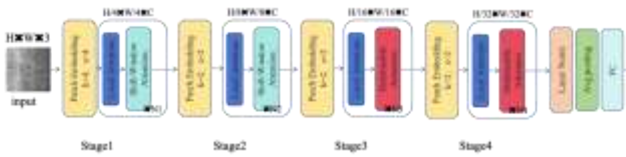

Fig5. The structure of Transformer-DAttention

In the proposed model, Patch Embedding consists of a Layer Norm and a convolution layer, which functions similarly to the token transformation process in Vision Transformers. This embedding process ensures the input features are appropriately transformed for subsequent stages.In stage 1 and stage 2, the design includes the Swin Transformer's paired W-MSA (Window-based Multi-Head Self-Attention) and SW-MSA (Shifted Window Multi-Head Self-Attention) mechanisms. These components help enhance the model's efficiency in capturing local and global dependencies.In stage 3 and stage 4, a combination of W-MSA and MDHA (Multi-Head Deformable Attention) modules is used. The MDHA is the core Deformable Attention Module, which allows the model to dynamically focus on the most relevant parts of the input while handling varying object scales and deformations effectively. This structure is illustrated in Figure 6.

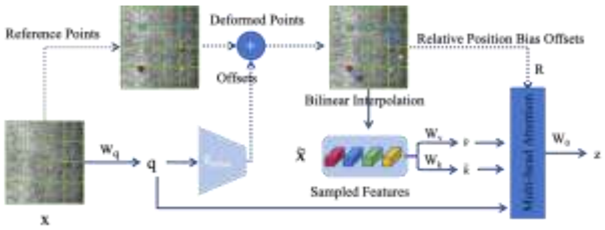

Fig6. Deformable attention module

The Deformable Attention module enhances the flexibility and accuracy of feature extraction by dynamically adjusting the sampling positions. First, it generates sampling offsets based on the input feature map, allowing the sampling positions to adapt to different shapes and scales across various regions. Then, the module performs non-uniform sampling at these dynamically adjusted locations and applies learned attention weights to aggregate the sampled features, ensuring the capture of important contextual information. After the weighted aggregation, the output features become more expressive, effectively addressing the challenges of detecting complex and irregular objects.

3. EXPERIMENTS

3.1 Data Set

The dataset used in this study is based on the surface defect database released by Northeastern University (NEU), which includes six typical defect types on steel surfaces: rolling scale (Rs), blister (Pa), crack (Cr), pitting (Ps), inclusions (In), and scratch (Sc). This database contains a total of 1,800 grayscale images, with 300 samples for each defect type. To enhance the robustness of the model and prevent overfitting, data augmentation techniques were applied to the original dataset, as illustrated in Figure 7. These techniques include rotation, flipping, contrast adjustment, and noise addition. The augmented dataset comprises a total of 2,000 images, which were split into training, testing, and validation sets in a ratio of 7:2:1. The six types of surface defects were annotated using the LabelImg tool, with each image potentially containing multiple defects.

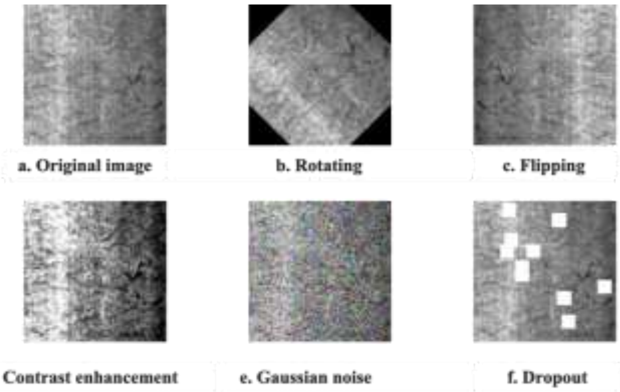

Fig7. Steel surface defect data set enhancement results

3.2 Experimental Environment and Parameter Settings

The experiments in this paper were conducted using the PyTorch 1.13.1 deep learning framework, with the operating system being Windows 11. The hardware environment includes an Intel i7-12700 processor, 80 GB of RAM, and an NVIDIA GeForce RTX 3070 graphics card with 8 GB of VRAM. To accelerate the training process, CUDA 11.6 was used for GPU acceleration.

The specific settings for the experimental parameters are as follows: after preprocessing, the images processed by the model are consistently sized at 640×640. The batch size is set to 16, and the number of iterations is 300. The optimizer chosen is AdamW, with an initial learning rate set at 0.0001 and a weight decay coefficient also set at 0.0001.

3.3 Experimental Results

3.3.1 Comparison of Detection Results for Different Defects Experiments

The detection results of the FTD-DETR model for six typical surface defects in steel are shown in Table 2. The results indicate that the detection performance for inclusion is the best, with precision, recall, and mAP reaching 87.7%, 83.9%, and 89.6%, respectively. In contrast, the detection accuracy for crazing is the lowest, with precision, recall, and mean average precision (mAP) at 58.8%, 40.4%, and 42.7%, respectively. The difference in performance can be attributed to the fact that inclusion exhibits more pronounced and consistent features among steel surface defects, while the morphology of crazing is complex and variable, making it easily confused with other defects, resulting in lower detection performance. On the other hand, the dataset for inclusion is significantly more abundant than that for crazing, allowing the model to learn more effectively and improve its generalization capabilities.

Table 2. Comparison of detection results of different defects by FTD-DETR model

Defect name	P/%	R/%	mAP/%
Crazing	58.8	40.4	42.7
Inclusion	87.7	83.9	89.6
Patches	83.6	76.7	79.6
Pitted Surface	89.1	70.7	77.3
Rolled-in Scale	75.5	56.9	66.9
Scratches	80.6	77.7	84.6

3.3.2 The comparison results of different models.

To compare and validate the performance of the FTD-DETR network model in detecting steel surface defects, four different models, including the original RT-DETR, Yolov5, Yolov7, and Yolov8, were selected under the same experimental conditions. The detailed comparison results can be found in Table 3.

Table 3. Comparison results of different models

Model	P/%	R/%	mAP/%	FLOPs/G
Yolov5	69.5	71.4	73.4	16.5
Yolov7	75.9	66.8	71.6	105.2
Yolov8	74.1	66.1	73.1	28.7
RT-DETR-r18	74.5	64.0	74.5	57.0
FTD-DETR	83.6	67.7	79.3	51.7

As shown in Table 3, FTD-DETR demonstrates excellent performance in steel surface defect detection, with precision, recall, and mAP values of 83.6%, 67.7%, and 79.3%, respectively. Compared to other detection models, FTD-DETR shows an improvement in mAP by 5.9, 7.7, 6.2, and 4.8 percentage points, indicating its higher accuracy and reliability in detecting steel surface defects. Additionally, FTD-DETR has relatively low memory usage, showcasing better computational efficiency, which reflects the model's efficient resource utilization. Overall, FTD-DETR delivers balanced and outstanding performance in terms of detection accuracy and resource efficiency, making it particularly suitable for steel surface defect detection tasks.

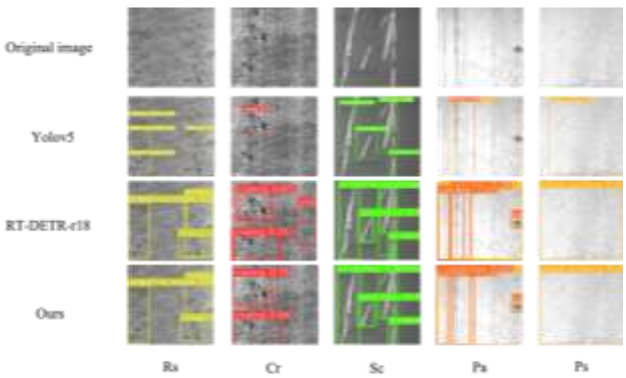

Fig8. Comparison results of different models

Figure 8 visually compares the results of RT-DETR, Yolov5, and RIC-DETR on the test dataset. Different types of defects are marked with rectangular boxes in distinct colors, and the corresponding confidence scores are labeled for each detection.

4. CONCLUSION

In summary, the proposed improved model, FTD-DETR, demonstrated excellent performance in the task of steel surface defect detection. By selecting ResNet18 as the backbone for feature extraction and integrating the Faster-EMA module to replace ResNet18's basic block, feature extraction efficiency was enhanced. Additionally, the standard Transformer encoder and dynamic attention mechanism were employed to replace the original modules. FTD-DETR performed exceptionally well in terms of precision, recall, and mean average precision (mAP). Experimental results show that this model not only maintains high accuracy but also significantly reduces the number of parameters, computational complexity, and memory usage. With its low complexity and fast detection speed, FTD-DETR is suitable for efficient steel surface defect detection in real-world scenarios, providing a reliable technical solution for industrial applications.

Future work could focus on expanding the dataset size and enriching the variety of defect types to improve the model's generalization ability and adaptability to more complex real-world applications. Additionally, further optimization of the multi-scale feature fusion mechanism could enhance the detection of defects of various sizes and shapes, particularly small defects, thereby improving overall detection accuracy.

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Teaching Reform of Public Mathematics Basic Courses--Taking Electronic Information Engineering Major as an Example

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Abstract: In order to meet the needs of the "new engineering" transformation of Yangtze University's electronic information engineering major, this project carried out a comprehensive teaching reform of the basic mathematics course in the electronic information engineering major, including completing the course system and teaching content, innovating teaching methods, changing the assessment method, realizing the open sharing of teaching resources, and creating a "golden subject" for the public basic mathematics course. The reform results show that it has improved students' learning interest, cultivated students' innovation and engineering application capabilities, realized the open sharing of teaching resources, and improved the teaching quality of basic mathematics courses and the quality of talent training.

Keywords: Emerging Engineering; teaching reform; public basic mathematics courses; Electronics Information Engineering;

1. INTRODUCTION

"Emerging Engineering" is a new direction of my country's engineering education reform based on the new needs of national strategic development[1]. The talent training goals of the new engineering department put forward new requirements for classroom teaching in colleges and universities: pay more attention to the practicality, cross ability and comprehensiveness of the discipline, and break the traditional discipline gap; update the knowledge system of engineering talents, improve curriculum interests, academic challenges,, academic challenges,, academic challenges, academic challenges,, academic challenges, challenges, Eventually promote the comprehensive development of students. Basic public mathematics courses are one of the most important compulsory courses in engineering majors. They are the foundation of almost all subsequent professional courses and an important cornerstone of engineering[2].

Basic public mathematics courses include "Higher Mathematics", "Linear Algebra" and "Probability and Mathematical Statistics". So far, in China, there are not many research on the basic reform of public mathematics in accordance with the requirements of "new engineering".

In 2018, Yangtze University was approved by the Ministry of Education's first batch of "Emerging Engineering" research and practice projects. Requirements. This research team has always focused on the study of the basic class of public mathematics and the research on online and offline hybrid teaching. In 2019, "Higher Mathematics Speech" was launched online. In 2020, "Higher Mathematics A" was announced as a national first -class undergraduate course (online and offline mixed). This project intends to conduct a comprehensive teaching reform of the basic courses of mathematics in electronic information engineering, open up mathematical foundation and professional curriculum barriers, reconstruct teaching content, innovate teaching methods[3], change the evaluation method, realize the opening and sharing of teaching resource platforms, and the teaching model Innovate, create a "gold class" for basic mathematics lessons.

2. RECONSTRUCTING THE CONTENT SYSTEM OF HIGHER MATHEMATICS

2.1 Research on Electronic Information Engineering Courses

The electronic information engineering major of Yangtze University is undergoing new engineering reform and practice, adding the direction of big data and artificial intelligence. By conducting construction and development seminars with the electronic information engineering major, strengthening extensive contact and communication between the School of Information and Mathematics and the electronic information engineering major, collecting which knowledge points in the basic mathematics courses are applied to which points in the professional courses, making questionnaires, listing the knowledge points and application paths of the basic mathematics courses one by one, and forming a research report.

2.2 Deconstruct the curriculum system and reorganize the teaching content

The one of main courses of electronic information majors are circuit courses, which are fundamentally related to higher mathematics. The demand for mathematical knowledge in circuit courses is mainly the application of basic mathematical concepts and methods. Therefore, in the construction of the curriculum system of electronic information majors, the higher mathematics content system must be established based on the actual situation of circuit courses. After sorting out, we list the higher mathematics knowledge points corresponding to the knowledge points of circuit courses, as shown in Table 1.

To build a higher mathematical content system, it is necessary to make higher mathematics and the corresponding "job grade certificate" corresponding to the majors.

Higher mathematics content should be matched with professional courses. To adapt to industrial transformation and upgrading and its development, professional courses need to

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respond in a timely manner about the dynamic needs of the knowledge ability required for professional positions. The required high -counting knowledge modules, master the professional connotation of mathematics concepts combined with professional professional connotation, closely follow the work task selection carrier, preferably facilitate the use of mathematical ideological methods to solve professional problems, and familiarize the degree of mathematical analysis and engineering application capabilities.

Higher mathematics content should be connected to professional standards and curriculum standards. Higher mathematics curriculum standards should be considered from a professional perspective, grasping industry needs, occupational standards and their changes, gathered to refine the general general curriculum goals, and then determine the high -number curriculum module and their teaching goals according to the requirements of the specific curriculum and their teaching goals. , Effectively improve the achievement of higher mathematics to help professional goals.

Table 1. Correspondence table between knowledge points of circuit courses and required advanced mathematics related knowledge points

Circuit course knowledge points	Required advanced mathematics knowledge points
Basic circuit concepts, laws and basic analysis methods	Functions, limits, derivatives, calculus, linear algebra
Sinusoidal alternating current, three-phase alternating current	Trigonometric functions, derivatives, definite integrals
Mutual inductance coupling, resonant circuit, magnetic circuit and transformer	Derivatives, definite integrals
Non-sinusoidal periodic current analysis, linear dynamic circuit analysis	Calculus, Fourier series, differential equations
Transistor characteristics and basic applications	Functions, derivatives and differential calculations, derivative applications
Basic signal amplification, feedback amplification, power amplification, integrated operational amplifier	Application of derivatives, integration and differentiation
Signal generation and processing, DC regulated power supply	Derivatives and differentials, definite integrals, functions
High frequency small signal amplification, high frequency power amplification	Definite integral, Fourier series
Amplitude modulation and demodulation, angle modulation and demodulation	Functions (trigonometric, nonlinear), derivatives, definite integrals, power series, Fourier series, limits
Feedback control circuit	Differential and integral operations, differential equations

3. CROSS APPLICATION OF MULTIPLE TEACHING MODES

Explore the teaching mode of transforming the main "learning" of "teaching" and "learning". Explore the cross application of teaching modes such as "centralized lectures", "small seminars", "counseling courses"; continue to cooperate with high -quality platforms such as "Good University Online" to explore hybrid teaching models: make full use of modern information technology and other results. New media environments such as mobile phones and iPads, develop mobile Internet teaching methods, promote open teaching, organically integrate online and offline high -quality educational resources and learning resources to organize the autonomy and participation of students 'learning, and improve students' innovative ability.

3.1 Lecture in large class, small class discussion

"Higher Mathematics" is a basic course for non -mathematics majors in colleges and universities. Our school's "Higher Mathematics" uses multi -professional public selection methods. The number of teaching teams is more than 90 or more, and the teaching effect is poor. The teaching class of the "Large Class Teaching and Small Class Research" adopted by this article is selected as a pilot. Based on the "big class teaching", the "small class research" link is added. The "big class teaching" is centered on teachers, teachers dominate the classroom, and realize the function of "teaching". The "big class teaching" mainly explains the basic knowledge points and completes the basic tasks of the outline; the "small class discussion" is aimed at key difficulties, and students conduct in -depth discussions and exchanges.

The "Small Class Research" was carried out in the smart classroom. The large teaching classes were divided into 2-3 small classes. Each small class was divided into several groups. The number of groups was set at about 5. Two days before the "Small Class Research", the teacher released the topic and discussions on the Internet, and students prepared the theme of the discussion. During the "Small Class Research" process, the group members spoke freely on the topic of the seminar. Other members could express different views and even fierce debate. After the discussion was completed, the group submitted the seminar report to the usual results assessment.

3.2 Online and offline hybrid teaching mode

In recent years, with the rise of online classrooms such as micro -classes and mood classes, teachers '"teaching" and students' "learning" have changed. Data show that although online teaching has certain advantages, it still needs to be supplemented by offline teaching to improve the learning effect. Trying the organic integration of modern information technology and traditional teaching model is a trend of reform and development of curriculum teaching in colleges and universities[3-4].

The structure of online and offline hybrid teaching cannot be cut online and offline, and should cooperate with each other. This section uses the "Trinity" online and offline hybrid teaching mode, which mainly includes the "pre -class" of teachers and students, "in the class" and "post -class". The specific organizations are as follows[5].

Theoretical part. It is mainly reflected in Mu class, micro -class, classroom teaching and expansion. The learning content should be divided into three types: basic level, challenge and excellent level. The foundation level is the basic theory in the course. Through the presentation of mood and micro -class, it lays the foundation for the development of the curriculum design. The challenge level has a higher comprehensiveness and greater difficulty. Students need to "jump and jump to get". The teachers need to teach the principles and methods in the offline class to inspire students to complete higher requirements. In the excellent level, students need to play their autonomy, consider the learning materials independently, communicate with teachers through group collaboration, and rely on group strategies to achieve their goals.

Practice part. It mainly relies on the hybrid teaching mode of "online-offline-online" as its main line. The first stage is "before class": online resources are launched. That is, students are required to preview before class. Published a learning task form before class, mainly based on basic learning content and professional case learning; videos in self -study online resources, courseware materials, and completing online self -test exercises; thinking about the problems in the task form, sorting and uploading self -study notes. The second stage is "class in class": offline classroom teaching. Teachers use a variety of teaching methods to teach and answer questions in the task form. The third stage is the "post -class": online testing and expansion of the content learned again. The Mixed -class classroom teaching mode design schematic diagram is shown in Figure 2.

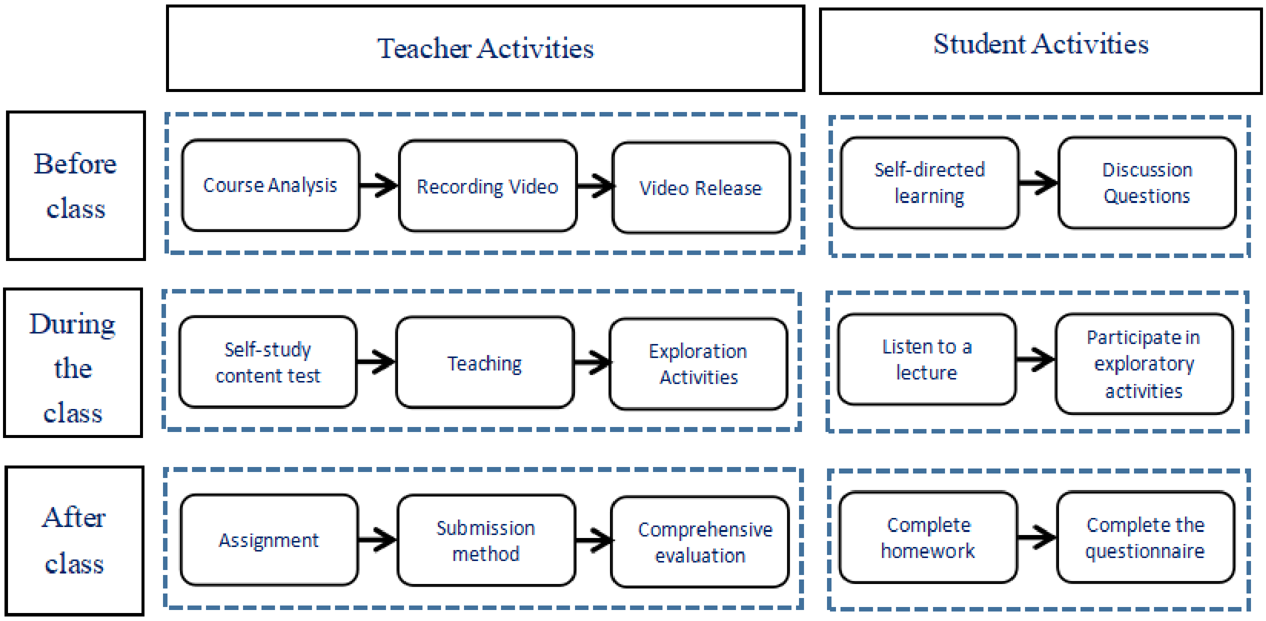

Figure 2. The Mixed -class classroom teaching mode design schematic diagram.

4. DIVERSIFIED COMPREHENSIVE ASSESSMENT SYSTEM

The traditional assessment method, which mainly depends on the final exam, is harmful to assess students' engineering ability. To ensure the effectiveness of teaching, we designed a diversified assessment method, referring to CDIO standards, to assess the students' basic personal ability, interpersonal skills, software development capabilities, and their theoretical knowledge. By utilizing unit tests, classroom performance and extracurricular practical assignments, combined with the comprehensive evaluation of the online open course platform's graduation examinations and final examinations, we have developed an all-round comprehensive assessment model that emphasizes both theory and practice; based on teaching elements and student characteristics, we have comprehensively considered teacher evaluation, peer evaluation and self-evaluation, combined with process evaluation, to establish a diversified comprehensive assessment system.

The assessment method is described as following: (1) Dialy work, accounting for 10%, including attendance, homework; (2) Assessment for the learning process, accounting for 60%, which consists of the project self-assessment and teacher evaluation. The project self-assessment for each team member is conducted by the team leader according to the teamwork ability, practical engineering ability, innovation ability, assessment from other members. The teacher's assessment is based on the team's completion of the project, the effect of the project statement, and project report. (3) Final examination result, accounting for 30%, using the traditional examination methods, assessment of students' theoretical knowledge, ability of algorithm design and programming.

Through strengthening the teaching process assessment, we could control each teaching links, guide students to improve the autonomy of learning, and train their abilities of teamwork, engineering practice, and innovation. The new assessment method could improve the teaching effectiveness by avoiding the students not study usually but drive a night car just before the final exam.

5. CONCLUSION

Strengthen the extensive contact and communication between students and teachers of the electronic information engineering major and the School of Information and Mathematics, break the situation of separate training of students from different departments, jointly formulate the training objectives and content of basic mathematics courses, and deeply discuss a series of issues such as the construction and curriculum development of the electronic information engineering major and mathematics major. Strive to form a consensus and gather strength to complete the construction of the "golden course" of basic mathematics courses, further deepen the comprehensive reform of undergraduate teaching in the electronic information engineering major, and promote the construction and development of new engineering disciplines.

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Practice and Application of Intelligent Technology in Software Automation Testing

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Abstract: As intelligent technology becomes widely adopted and applied, the domain of software testing is experiencing significant transformations, centering around the creation of test data that fulfills particular requirements. Given that traditional testing methods are not only complex and cumbersome, but also have unsatisfactory accuracy and reliability. This article first introduces the basic principles and methods of software testing. Subsequently, the article focuses on introducing and analyzing in depth the latest research progress in software testing based on various intelligent optimization methods. Lastly, this article offers a thorough overview of the present state of automated testing development and anticipates its future directions.

Keywords: Software testing, automated testing, test data generation, intelligence, optimization methods

1. INTRODUCTION

With the rapid development of information technology, software has become an indispensable part of modern society, and its quality and stability are directly related to user experience and business success. In the process of software development, if there is a lack of effective quality assurance, problems and vulnerabilities that arise during use may cause significant losses. Therefore, software testing is crucial in the software development and usage process. However, traditional manual testing is not only time-consuming and inefficient, but also unable to keep up with the pace of software development optimization. Long term tedious and repetitive work can easily demotivate testers, thereby affecting the accuracy of test results. This article aims to summarize the practice and application of intelligent technology in software automation testing, analyze the current situation and challenges in practice, and look forward to future development trends.

2. BASIC CONCEPTS OF SOFTWARE TESTING

2.1 Definition of Software Testing

Software testing is an important component of the software development process, aimed at discovering and evaluating errors, defects, or unexpected functionalities in software [1]. This process requires simulating the entire user operation process and designing and executing specific test cases under each system. Through these interactions, potential errors, defects, or inconsistencies with the design intent in the software can be detected to ensure that it meets the specified requirements and design specifications. By conducting various types of testing, such as unit testing, integration testing, system testing, and acceptance testing, as well as acceptance testing to confirm that the software meets the user's final requirements, the quality of the software is comprehensively evaluated.

Software testing is a continuous iterative process that runs through all stages of software development, from requirement analysis to design, coding, release, and maintenance, playing a crucial role. The procedure for the software is illustrated in Figure 1. Efficient software testing has the potential to substantially decrease the post-release failure rate, enhance user satisfaction, and offer robust assistance for the ongoing enhancement and refinement of the software.

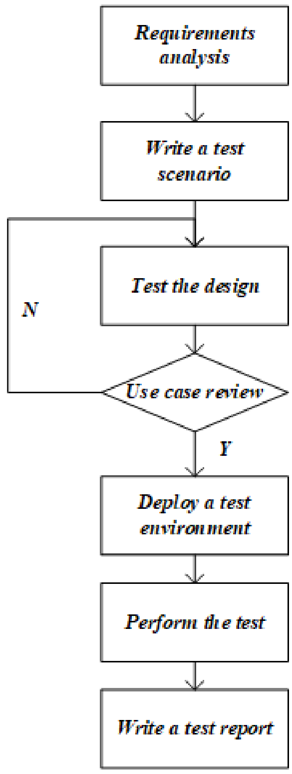

Figure. 1. Software Testing Process Diagram

2.2 Main methods and applications of software testing

The application of artificial intelligence in the field of automated software testing is gradually becoming the key to improving software quality and reliability, and effectively reducing testing cycles and costs [2-3]. The integration of artificial intelligence not only greatly improves the quality and efficiency of detection, but also enables the discovery of problems missed by manual detection. For example, through

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machine learning [4] and pattern recognition techniques, defects discovered during the testing process can be intelligently classified and automatically assigned priority based on their severity and impact range. This helps the development team to respond and fix critical defects faster. Artificial intelligence in software testing mainly includes the following aspects:

1) Test case generation: Automatically generate test cases based on documents or historical data to test various functions of the software. This can gradually reduce time and labor costs [5], and greatly improve the coverage of testing.

2) Performance testing and optimization: Easily simulate large-scale user usage, analyze performance test results, identify performance bottlenecks, which is beneficial for improving system stability and consistency.

3) GUI testing: Simulate user operations, automate complex multi-step tasks, or use image recognition technology to identify and locate various elements in the interface, such as buttons, text, etc.

4) Intelligent testing management: applied to testing management tools, enabling them to have self-learning and optimization capabilities, better adapt to different testing scenarios, unify management, reduce human interference, and improve the work efficiency of testing teams.

3. RESEARCH PROGRESS ON SOFTWARE TESTING BASED ON DIFFERENT INTELLIGENT OPTIMIZATION METHODS

3.1 Automated testing methods based on natural language processing (NLP)

Test cases are a collection of input data used to execute the program under test, and are an important foundation for automated testing. NLP technology plays a core role in machine learning test case generation. Through NLP technology, the system is able to understand, interpret, and generate human language, allowing machines to accurately capture functional requirements and constraints based on the requirements document. For example, when the requirement document mentions that "users should be able to log in by entering their account and password", the NLP system can automatically recognize this requirement and generate corresponding test cases, such as verifying the validity of input boxes, compliance of data, and functionality of buttons. NLP technology can automatically analyze various information sources such as software requirement documents, user feedback, and historical test data, extract key features from them, and automatically generate high-quality test data based on these features [6]. This process not only greatly improves the efficiency of generating test cases, but also reduces human errors, ensuring the accuracy and comprehensiveness of test cases.

Besides creating test cases from requirement documents, NLP can be integrated with various AI technologies to offer more sophisticated approaches to test case generation. For instance, by merging NLP with machine learning models, the test case repository can be significantly enhanced through the incorporation of user feedback and remarks, leading to the production of tailored test cases that assist development teams in promptly identifying and rectifying potential problems. In addition, machine learning also plays a significant role in test result analysis and defect prediction [7-9], such as using hill climbing method, modular annealing method to optimize variable access sequence for fault detection [8], using heuristic strategies to generate fine-grained synchronization sequences, and detecting concurrent faults [9].

3.2 Automated Testing Methods Based on Deep Learning

Deep learning (DL) has been introduced as a subset of machine learning, utilizing more advanced techniques than traditional shallow machine learning techniques, as shown in Figure 2. The concept of neuron and multilayer perceptron (MLP) topology existed before DL was widely adopted. In DL networks, the clever combination of multiple hidden layers and different types of layers such as convolutional layers, pooling layers, and dropout layers together constitute its powerful architecture. The convolutional layer is responsible for automatically extracting key features from input data, such as selecting Convolutional Neural Networks (CNN) [10-12], or combining Recurrent Neural Networks (RNN) with Long Short Term Memory (LSTM) [13]. The pooling layer effectively reduces data dimensionality and preserves important information, while the dropout layer achieves regularization by randomly discarding neurons to prevent overfitting. The introduction of these new architectures collectively promotes DL networks to exhibit better function approximation capabilities in complex tasks.

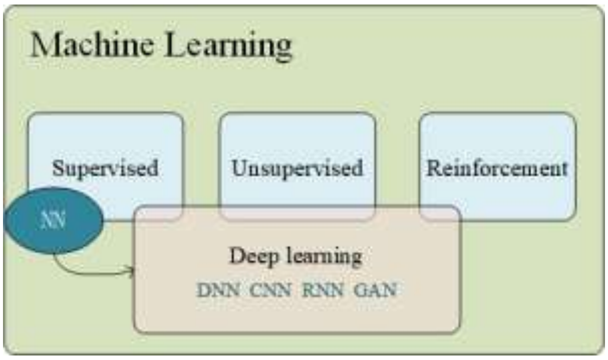

Figure 2. Deep Learning in Machine Learning.

In addition, reinforcement learning has shown great potential in optimizing testing strategies in continuous integration and deployment processes. In this dynamic environment, software undergoes frequent updates, therefore, there is an urgent need for a fast and efficient testing strategy to ensure consistent software quality. Reinforcement learning techniques can assist systems in learning how to accurately select and execute the most critical test cases within limited time resources [14].

3.3 Automated testing methods based on reinforcement learning

Compared to other learning approaches, Reinforcement Learning (RL) excels in discovering optimal decisions within interactive environments, without necessitating a pre-existing dataset to study the interplay between agent and environment. The fundamental workings of the RL process are illustrated in Figure 3. During this process, the agent engages with the environment autonomously as a self-directed learner, progressively refining its strategy. It transitions from a given state in the set of states $s_t \in S$ to select an action from the action space in the set of actions $a_t \in A$. The transition probability between states determines the final state s_{t+1} of the agent. Next, the environment provides a reward r based on the selected action. During this period, the agent continuously trains until the goal is achieved or the termination condition is met [15].

In reinforcement learning based testing strategy optimization, the testing process is considered as a decision problem. The testing system (agent) interacts with the software (environment), executes test cases, and observes the software's response. If defects are discovered during the testing process, the system will provide a positive reward; If no defects are found, the system will not reward or give a negative reward[16]. In this way, the system can learn how to select and execute test cases to maximize the probability of discovering defects. Alternatively, the coverage of the test can also be used as a reward value to transform the test into a multi-objective optimization problem, in order to find the optimal solution. The data shows that approximately 37% of research reports propose RL based methods that produce better coverage in their respective fields, such as branch coverage and statement coverage[17-18]. Simultaneously, a multitude of research studies suggest that the development of RL models necessitates less time compared to manual creation of test cases, while also attaining superior accuracy and efficiency in their implementation. [19-20].

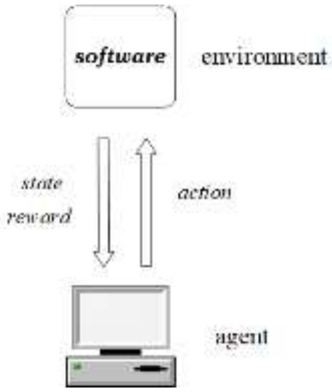

Figure 3. Reinforcement learning cycle.

4. CHALLENGES AND PROSPECTS

Software testing, as a key link in the software development process, has immeasurable value in significantly improving the reliability of software products. The integration of intelligent optimization technology has greatly enhanced the efficiency and quality of software testing, promoting significant progress in this field. However, with the continuous vigorous development of the software industry, software testing technology based on intelligent optimization still faces new challenges and difficulties, and it is urgent for us to continue exploring and innovating to address these emerging issues.

Data quality issues, including accuracy, completeness, and validity of data. Ensure that the test data can truly reflect the real situation and avoid misleading the test results; Ensure comprehensive testing data, covering all possible scenarios and inputs; The test data must comply with business rules and best practices to ensure the effectiveness of the testing. The accuracy and effectiveness of the test results are also a major challenge. Intelligent testing tools require the collection of a large amount of user data for analysis and learning, but data privacy protection has become an important ethical and legal issue. Moreover, for complex business processes and user interactions, automated tools may not be able to completely replace manual judgment. Furthermore, the interpretability of the model is also worth paying attention to. Many machine learning models have strong learning abilities, but they are opaque to workers in the decision-making process, which poses a trust crisis in intelligent testing.

However, intelligent technology will still bring new opportunities for software testing. For example, developing new intelligent tools that can adapt to different testing needs and help development teams analyze and solve problems faster. In addition, cross disciplinary integration is also a major trend, which will bring more possibilities for software testing, such as using big data analysis to optimize strategies.

5. CONCLUSION

Intelligent technology has brought new possibilities for software testing, greatly improving efficiency and reducing the burden and pressure on testers.. This article meticulously examines the practice and application of intelligent technology within the realm of software automation testing, providing an insightful summary of some of the most significant advancements in research methodologies. Furthermore, the article doesn't stop at merely identifying these challenges; it also explores and forecasts the potential opportunities and possibilities that lie ahead.

As the scale and complexity of software continue to grow at an unprecedented rate, software testing methods that rely heavily on intelligent optimization are encountering numerous hurdles that demand immediate attention and resolution. With the relentless advancement of emerging technologies such as machine learning, deep learning, and big data analytics, the field of intelligent technology in software automation testing is poised to exhibit exciting new development trends. These technologies have the potential to revolutionize the way we approach software testing, making it more efficient, accurate, and capable of handling the ever-increasing complexity of modern software systems.

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Development of Intelligent Sensor in Educational Application

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Abstract: As educational institutions increasingly embrace digital transformation, the integration of intelligent sensor technology presents a significant opportunity to enhance learning experiences, improve operational efficiency, and ensure campus safety. Intelligent sensors, equipped with data processing and real-time feedback capabilities, can gather valuable insights into student engagement, classroom conditions, and environmental factors, all of which influence educational outcomes. This paper explores the development and application of intelligent sensors specifically designed for educational settings, focusing on their ability to monitor and respond to factors affecting learning and resource management.

Keywords: sensors, educational technology, artificial intelligence in education, data monitoring

1. INTRODUCTION

In recent years, technological advancements have permeated nearly every aspect of daily life, revolutionizing how we communicate, work, and learn. Among these advancements, intelligent sensor technology [1-5] stands out as a transformative tool across multiple sectors, from healthcare to transportation and industrial automation. Educational institutions represent a burgeoning frontier for the deployment of intelligent sensors, with applications that span from enhancing learning experiences to optimizing campus resources and ensuring student safety. Intelligent sensors, which combine real-time data collection, processing, and adaptive feedback mechanisms, offer novel solutions to address complex challenges in the education sector, paving the way for a more data-driven, efficient, and personalized educational experience.

The implementation of intelligent sensors in education can support and improve several critical areas. These sensors provide valuable insights into student engagement, behavior, and well-being, enabling educators and administrators to make data-informed decisions that promote a more responsive learning environment. For instance, motion and environmental sensors can be utilized to monitor classroom conditions—such as temperature, lighting, and air quality—helping create an atmosphere conducive to learning. Similarly, when used ethically and with consent, wearable sensors can capture students' physiological data, offering feedback on attention levels or stress indicators, thereby informing teaching strategies and promoting student well-being.

In addition to improving the classroom experience, intelligent sensors are necessary for ensuring the safety and security of educational environments through integration with camera technology [6-8]. With the ability to detect movement, monitor entry points, and even assess crowd densities, these sensors contribute to a safer campus environment [9], [10]. In emergencies, they can aid in rapid responses, minimizing potential risks to students and staff. Furthermore, intelligent sensors embedded within campus infrastructure can optimize the management of physical resources, such as lighting, heating, and ventilation systems, by enabling automatic adjustments based on real-time occupancy data. This approach conserves energy and supports the growing emphasis on sustainability within educational institutions.

Moreover, intelligent sensor technology facilitates the development of adaptive and personalized learning systems. By integrating sensors with Artificial Intelligence (AI) [11-14] and Machine Learning (ML) [15-17] algorithms, educators gain insights into individual learning patterns and needs, enabling them to tailor instructional content and methods for each student. Such adaptive learning approaches align with current educational trends prioritizing personalized, student-centered learning experiences, where instruction adapts to the pace and style best suited for each learner. The feedback provided by these intelligent systems can also empower students by offering them real-time insights into their progress and encouraging self-regulated learning.

Despite the promising applications of intelligent sensors in education, significant considerations remain regarding privacy, data security, and ethical implications. Given that new technologies necessitate the collection of sensitive data, comprehensive protections must be implemented to protect student privacy and ensure data security. Furthermore, educators and institutions must navigate ethical concerns around data collection and use, balancing the benefits of data-driven insights with the imperative to respect student autonomy and confidentiality.

This paper provides an in-depth exploration of intelligent sensor development specifically tailored for educational applications as illustrated in Figure 1. It examines various types of sensors, including environmental, motion, and physiological sensors, and discusses how these can be seamlessly integrated into educational systems to foster safer, more engaging, and resource-efficient learning environments. This study seeks to enhance the broader conversation on digital innovation in academia by examining the opportunities and challenges of integrating intelligent sensors in education. Ultimately, the goal is to offer insights that will help inform the development of intelligent, ethical, and adaptable educational technologies capable of supporting the evolving needs of learners and educators alike.

Figure 1: Intelligent sensors in education for well-being monitoring

2. CLASSROOM ENVIRONMENT OPTIMIZATION

Environmental factors significantly influence students' focus, comfort, and overall well-being. A variety of sensors [18] designed to monitor classroom temperature, humidity, air quality, and light levels are essential in maintaining optimal learning conditions [19]. These systems provide a conducive educational environment and promote students' health and productivity. Research indicates that extreme temperatures, whether excessively high or low, can significantly impair cognitive activities, diminishing students' ability to concentrate and retain information. Ideally, classrooms at temperatures between 20°C and 22°C (68°F and 72°F) can optimize learning outcomes. Temperature sensors facilitate automatic adjustments to maintain this comfortable range when integrated with Heating, Ventilation, and Air Conditioning (HVAC) systems. For example, if a classroom temperature exceeds the upper limit, the HVAC system can activate cooling mechanisms to restore the temperature.

Regulating humidity is essential; it inhibits the growth of mold and dust mites, which can provoke allergies and respiratory problems in pupils. Maintaining indoor humidity levels between 30% and 50% can improve comfort and reduce the transmission of pathogens and airborne diseases. High humidity levels can cause discomfort, making concentrating harder for students. Schools can achieve optimal humidity levels by leveraging humidity sensors, contributing to better overall health and focus. Air quality is another vital factor in the learning environment. High levels of CO_2 or pollutants, such as volatile organic compounds (VOCs) and particulate matter, can lead to drowsiness, headaches, and decreased cognitive function. Air quality sensors [20] continuously monitor these levels and provide real-time data to school administrators. When elevated pollutant levels are detected, the system can trigger ventilation adjustments, such as opening windows or increasing air exchange rates, to ensure a steady influx of fresh air. Research has demonstrated that improving indoor air quality can enhance students' test scores and overall academic performance.

Lighting also plays a critical role in students' moods and attention levels. Insufficient or excessive illumination may cause eye strain, weariness, and diminished engagement, whereas well-structured lighting systems can improve mood and enhance concentration. Light sensors [21], [22] assess natural light levels throughout the day, allowing for dynamic adjustments of artificial lighting. For instance, during sunny days, the sensors can dim artificial lights to utilize natural sunlight effectively, reducing energy consumption and improving visual comfort. Moreover, the color temperature of lighting can be adjusted to align with circadian rhythms, which can further enhance students' alertness and well-being.

To power these sophisticated sensor systems sustainably, a high-quality electrical system [23] incorporating renewable energy resources [24] is essential. Schools can utilize solar panels or wind turbines to generate clean energy, reducing reliance on fossil fuels and lowering operational costs. By employing energy storage systems, such as batteries, schools can store excess energy generated during peak production times for use when needed, ensuring continuous operation of the environmental monitoring systems. This integration not only supports environmental sustainability but also teaches students the importance of renewable energy and environmental stewardship.

3. CLASSROOM DYNAMICS MONITORING AND ENERGY AND RESOURCE MANAGEMENT

Motion and occupancy sensors detect physical movement and presence in classrooms, helping educators gauge student engagement and monitor attendance. In attendance and participation, occupancy sensors can track students as they enter and exit the classroom, enabling automated attendance systems and reducing administrative tasks for teachers [25]. They can also measure student density and movement patterns within the classroom, providing insights into participation levels and social dynamics [26]. In engagement monitoring, motion sensors can track individual students' movements, helping assess engagement levels. For example, patterns of fidgeting or restlessness might indicate boredom or lack of focus, alerting teachers to adjust lesson plans accordingly. This data can be anonymized and analyzed to identify class-wide trends in engagement and improve teaching strategies.

About wearable sensors, wearable devices with physiological sensors like motion sensors [27-30], heart rate sensor [31], [32], galvanic skin response [33-35], offer insights into students' physical and mental states, allowing educators to better understand individual needs and make timely interventions [36]. In attention and stress levels, physiological data, like heart rate variability, can indicate stress or relaxation levels. For instance, elevated heart rates may signal anxiety or discomfort, while a steady rate may suggest calmness. Teachers could use this information to adjust teaching approaches, such as slowing down during high-stress moments. On the other hand, physiological data could inform personalized pacing in real-time adaptive learning platforms. If a student shows signs of stress during a particular subject or lesson, the system could introduce supportive content or provide breaks to improve comprehension. Generally, wearable sensors can be used with ethical considerations and informed consent, focusing on empowering students with self-awareness and encouraging proactive engagement in their learning processes.

Furthermore, schools and universities face high energy demands, from lighting and HVAC systems to electronic devices. Intelligent sensors can automate resource use based on real-time occupancy data, contributing to energy efficiency and sustainability goals. Motion and light sensors and systems can automatically adjust lighting and temperature in classrooms and other campus spaces based on occupancy. For example, lights and air conditioning can be turned off when rooms are unoccupied, reducing energy waste. Additionally, intelligent sensors can track water use in school facilities, such as bathrooms and cafeterias, and detect leaks or overuse. This technique promotes water conservation and reduces operational costs. Sensor-based systems can monitor the use of critical equipment and assets on campus, such as computers in labs, projectors, and lab equipment. By tracking usage patterns, institutions can optimize maintenance schedules, minimize downtime, and ensure that resources are available when needed.

4. HEALTH AND WELL-BEING MONITORING

Heart rate and heart rate variability (HRV) are key indicators of stress levels, emotional state, and overall well-being. Wearable devices such as smartwatches and chest straps can monitor these metrics in real time. Elevated heart rates or low HRV can signal heightened stress or anxiety. For instance, students may exhibit increased heart rates during exams or challenging lessons. Real-time stress detection can inform teachers, allowing them to provide supportive interventions, like a short break or breathing exercise. HRV is linked to the body's autonomic nervous system and is a reliable measure of a person's emotional resilience. Schools could use HRV insights to help students learn about their emotional responses, fostering awareness and emotional self-regulation. Students can better manage emotions like anxiety or frustration with proper training and tools, contributing to a calmer, more focused learning experience.

Electrodermal activity (EDA) sensor [37] measure skin conductance, which increases stress or excitement due to changes in sweat gland activity. This metric can offer insights into students' engagement and stress responses. About immediate Feedback for Well-being: Sudden spikes in EDA readings during specific activities may indicate a student's struggle or discomfort, allowing teachers to modify the classroom environment, pacing, or instructional methods. For example, students showing heightened stress responses during group activities might benefit from additional guidance or encouragement.

Teachers can ensure students exercise safely by tracking heart rate and body temperature during physical activities. For instance, when sensors detect elevated heart rates or high body temperature, students can be encouraged to take breaks or hydrate, reducing the risk of heatstroke or other exercise-induced health issues. Some students may have limitations on physical exertion due to underlying health conditions. Monitoring real-time physiological data ensures that these students remain within safe activity thresholds, enabling safe and inclusive participation in physical education.

For students with known medical conditions such as asthma and epilepsy, wearable sensors can monitor vital signs and detect potential health risks. In cases where a student's physiological metrics reach unsafe thresholds like abnormal heart rate, an alert system can notify teachers, school nurses, and even emergency services if needed. For example, students with asthma may benefit from air quality monitoring in classrooms, with alerts generated when pollutant levels are high. Wearable sensors equipped with accelerometers [38], [39] and heart rate monitors can help detect seizure-like movements or other abnormal physiological patterns, alerting school staff for immediate intervention [40],[41].

Wearable devices with accelerometers and gyroscopes [42] monitor movement patterns, such as walking, sitting, and physical activity, which are crucial for promoting physical health in educational settings. Regular physical activity is essential for mental focus, physical health, and cognitive function. By tracking activity levels, schools can encourage movement breaks for students who remain sedentary for prolonged periods [43-45]. Integration with school policies, movement data can support initiatives like "active classroom breaks" or outdoor activities, helping reduce the risks associated with sedentary behavior. The sensor system can prevent musculoskeletal issues [46-48]. Extended periods of sitting and insufficient physical activity can result in musculoskeletal problems, particularly in young students whose bodies are still maturing. Movement data from wearables can help teachers detect students who need to adjust their posture, change seating positions, or engage in stretching exercises to prevent discomfort or injury.

5. CONCLUSIONS

The application of intelligent sensors for health and well-being monitoring in education provides substantial benefits, from supporting mental health and physical fitness to enhancing student safety and resilience. However, it's crucial that schools implement these systems ethically, with strict adherence to data privacy and informed consent. By promoting transparency and student-centered policies, schools can harness the power of intelligent sensors to foster a healthier, more responsive learning environment that addresses the holistic needs of students.

Moreover, intelligent sensor technology represents a transformative tool in education, offering unprecedented opportunities to enhance student well-being. When thoughtfully implemented, these technologies help schools create nurturing environments that address the full spectrum of student health, fostering a generation of well-equipped learners to thrive academically, physically, and emotionally. With a focus on ethical, student-centered practices, intelligent sensors have the potential to redefine educational success, emphasizing health and well-being as integral components of a successful and sustainable educational journey.

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Research on IGBT Thermal Management of New Energy Vehicle Drive Motor Controller Based on CFD

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Abstract: In the context of severe global environmental issues, new energy vehicles have become an important strategic direction for countries to promote green travel with low carbon emissions. The electric drive system is the core power source of new energy vehicles. Among them, the motor controller is extremely important, and IGBT is the core component of the drive motor controller. IGBT is composed of BJT and MOS. When the battery discharges to drive the motor, it converts direct current into alternating current and controls the alternating current motor. The IGBT module generates a large amount of heat during operation. An increase in temperature will increase the failure probability, affect performance and reduce the working life. Based on the CFD method, this paper uses Fluent software to study the heat dissipation process of traditional IGBT, analyzes the internal flow field and temperature field, provides data support and technical support for the development of a new high-efficiency heat dissipation system, and is of great significance for promoting the development of new energy electric vehicles.

Keywords: IGBT; Heat dissipation; CFD

1. INTRODUCTION

Under the continuous aggravation of global environmental issues, new energy vehicles have attracted wide attention due to their characteristics of low carbon emissions and have become a key strategic direction for countries to promote green travel [1]. As the core power source of new energy vehicles, the performance of the electric drive system directly determines the overall performance of new energy vehicles. The electric drive system is mainly composed of parts such as motors, controllers, power supplies, transmission systems, and charging systems. In this complex system, the motor controller plays a crucial role. And in the drive motor controller, IGBT (Insulated Gate Bipolar Transistor) is regarded as the most core element [2].

IGBT is a composite fully controlled voltage-driven power semiconductor device composed of BJT (bipolar junction transistor) and MOS (insulated gate field effect transistor). When the battery discharges to drive the motor, through the circuit composed of IGBT, direct current can be converted into the alternating current required by the alternating current motor, and at the same time, the frequency conversion and voltage transformation of the alternating current motor are controlled. The IGBT module will generate a large amount of heat during the working process and is the main heat source of the motor controller. As the temperature rises, the failure probability of the IGBT power module will increase significantly. When the working temperature is too high, the internal parameters of the device and the semiconductor physical constants will change, resulting in deteriorated performance such as switching off speed, on-state voltage drop, current tailing time and loss. The IGBT module cannot work normally and even reduces its working life [3].

Based on the CFD method, this paper uses Fluent software to study the heat dissipation process of traditional IGBT, analyzes the internal flow field and temperature field in the IGBT heat dissipation process, provides data support and technical support for the development of a new and efficient IGBT heat dissipation system, and is of great significance for promoting the development of new energy electric vehicles.

2. PHYSICAL MODEL

The model of the traditional IGBT heat dissipation module is as follows: it contains six IGBT chips with a uniform size of 15mm×20mm×1.5mm. In addition, there is a liquid-cooled plate with an IGBT liquid-cooled channel, which has a size of 156mm×82mm×12mm (the flow channel depth is 10mm), and a flat liquid-cooled plate with a size of 156mm×82mm×2mm.

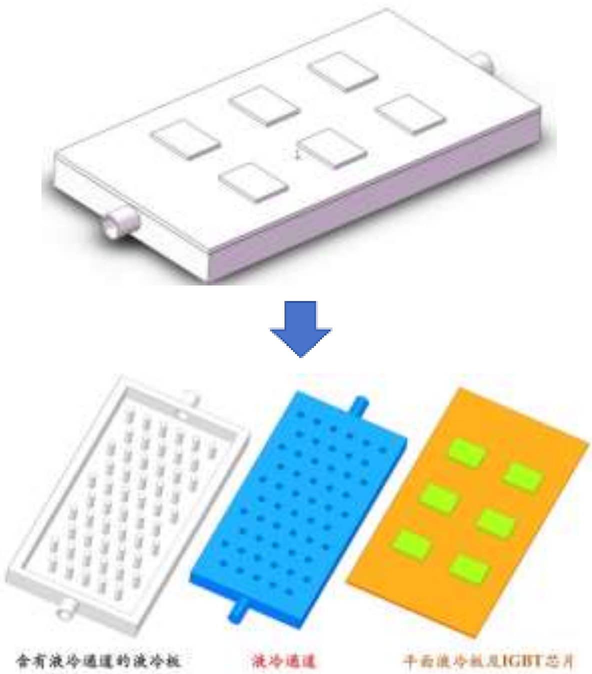


Figure. 1 Three-dimensional model of traditional IGBT heat dissipation module

3. MESH GENERATION AND BOUNDARY CONDITION SETTING

Fluent Meshing is used to divide the mesh of the IGBT heat dissipation model. In this study, the polyhedral mesh in Fluent Meshing is used to divide the meshes of the two IGBT heat dissipation models. This can not only reduce the number of meshes but also improve the calculation efficiency and solution accuracy. Figure 2 shows the mesh models of two IGBT heat dissipation modules.

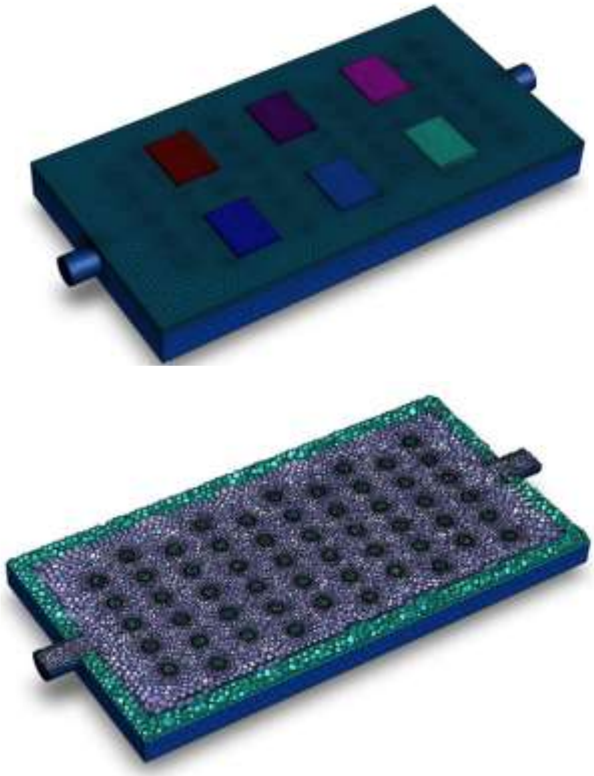
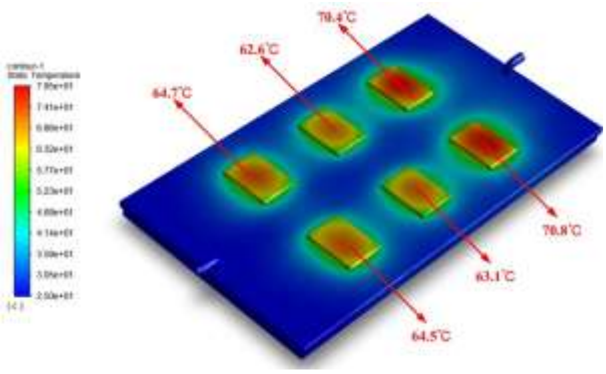


Figure. 2 Mesh model

In the simulation process, the k-ε turbulence model is used for calculation. The coolant adopts the boundary conditions of mass flow inlet and pressure outlet respectively. The inlet mass flow of the coolant is 0.163 kg/s, the inlet temperature is 25°C, the outlet pressure is atmospheric pressure, and the temperature of each interface is set as interface surface coupling transfer. A natural convection boundary is set on the surface of the IGBT heat dissipation model, and the convective heat transfer coefficient is determined to be 5 W/(m2·K), and the ambient temperature is 25°C. Based on the finite volume method to solve the control equation, the Standard pressure discretization format is selected, the transient calculation method is adopted, the initial time step is set to 0.001 s, and the step size is appropriately increased after the calculation is stable. The final time step is 1 s, the number of iterative calculation steps is set to 50, and the total simulation time is 1000 s.



4. MATERIAL PARAMETERS

Liquid water is selected as the cooling heat material, Si material is selected for the IGBT chip, Cu material is selected for the flat liquid-cooled plate, and aluminum alloy material is selected for the liquid-cooled plate with a liquid-cooled channel. The specific parameters of the selected materials are shown in Table 1.

Table 1. Parameters of selected materials

Name	Density/ （kg/m^3）	Thermal conductivity/ （W/m/K）	Specific heat capacity/ （J/kg/K）
Si	2329	124	702
Cu	8940	398	386
Aluminum alloy	2800	193	880

5. RESULTS

Figure 3 shows the internal flow field of the IGBT heat dissipation module. As can be seen from the figure, the flow velocity at the inlet of the traditional IGBT heat dissipation structure is relatively large, while the flow velocity at the outlet is relatively uniform but the value is low, and there is obvious non-uniformity. This situation is easy to cause uneven temperature distribution of IGBT.

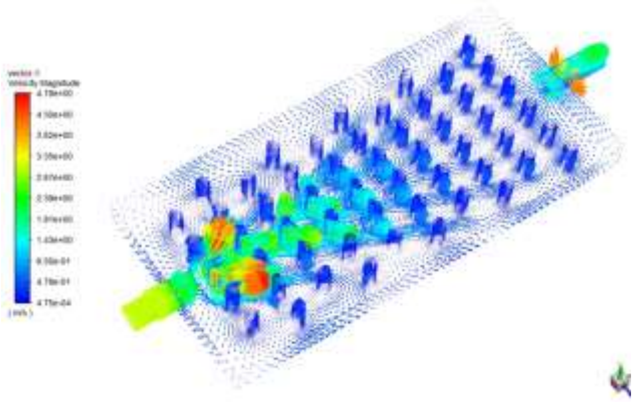


Figure. 3 Flow field distribution

Figure 4 shows the temperature distribution nephogram of the IGBT heat dissipation module. As can be seen from this figure, the temperature distribution of IGBT has great non-uniformity. The chip temperature at the inlet is relatively low, while the chip temperature at the outlet is relatively high. The maximum temperature difference can reach 8.2°C.

Figure. 4 Temperature field distribution

6. SUMMARY

Based on the CFD method, this paper uses Fluent software to study the heat dissipation process of IGBT in the drive motor controller of new energy vehicles. New energy vehicles are the strategic direction of green travel. The core of the electric drive system is the motor controller. IGBT is a key component and the heat dissipation problem affects its performance and lifespan. Through the physical model, including the sizes of IGBT chips, liquid-cooled plates, etc., the mesh generation and boundary condition settings are explained. Polyhedral meshes are used for division, and turbulence models, coolant boundary conditions, etc. are set.

Analyze different material parameters. For example, the cooling heat material is liquid water, and materials such as Si, Cu, and aluminum alloy are selected for different components. The research results show that the flow field analysis shows that the traditional IGBT heat dissipation structure has a large inlet flow velocity, a low and uneven outlet flow velocity, resulting in uneven temperature distribution; the temperature field analysis shows that there is a large non-uniformity in the temperature distribution of IGBT, and the maximum temperature difference reaches 8.2℃. This research provides data support and technical support for the development of a new and efficient IGBT heat dissipation system and is of great significance for the development of new energy electric vehicles.

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Blockchain Technology and Digital Copyright: Navigating Opportunities and Challenges in the New Digital Era

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Abstract: This paper explores the intersection of blockchain technology and digital copyright, examining how blockchain can transform the management and protection of intellectual property in the digital landscape. As digital content proliferates, traditional copyright frameworks face significant challenges, including piracy, unauthorized reproduction, and insufficient enforcement mechanisms. Blockchain offers innovative solutions through its decentralized and immutable nature, enabling transparent tracking of ownership and usage rights. This study analyzes the opportunities presented by blockchain, such as enhanced security, streamlined licensing processes, and improved artist compensation. However, it also addresses the challenges, including regulatory hurdles, technological barriers, and the potential for misuse. By providing a comprehensive overview of these themes, this paper aims to contribute to the ongoing discourse on digital copyright reform and the role of emerging technologies.

Keywords：Blockchain；Digital Copyright；Intellectual Property；Opportunities；Challenges

1. INTRODUCTION

In the rapidly evolving digital landscape, the protection of intellectual property has become increasingly complex, prompting a reevaluation of traditional copyright frameworks. As digital content continues to proliferate across various platforms, issues such as piracy, unauthorized reproduction, and inadequate enforcement mechanisms pose significant challenges for creators and rights holders. The advent of blockchain technology presents a transformative opportunity to address these challenges by introducing a decentralized, transparent, and immutable system for managing digital copyright. Blockchain allows for secure tracking of ownership and usage rights, enabling more efficient licensing processes and fairer compensation for creators.

Despite its potential, the integration of blockchain into digital copyright management is not without its hurdles. Regulatory uncertainties, technological barriers, and the risk of misuse must be carefully navigated to realize the full benefits of this innovative solution. As stakeholders from diverse sectors—including artists, publishers, and policymakers—seek to understand the implications of blockchain for copyright, a comprehensive analysis of both the opportunities and challenges it presents is essential. This paper aims to explore these themes, providing insights into how blockchain technology can reshape the landscape of digital copyright in the new digital era while highlighting the obstacles that must be overcome to achieve a more equitable and efficient system for protecting intellectual property rights.

2. OPPORTUNITIES PRESENTED BY BLOCKCHAIN

Blockchain technology offers several transformative opportunities for enhancing digital copyright management, particularly through its core features of decentralization, transparency, and immutability. One of the most significant advantages is the ability to create secure, tamper-proof records of ownership and transactions. This feature directly addresses long-standing issues related to copyright infringement and piracy, as blockchain can provide an indisputable chain of custody for digital assets. Research by Tapscott and Tapscott (2016) highlights how blockchain can eliminate the ambiguity surrounding copyright ownership, allowing creators to establish clear rights over their work at the point of creation.

Blockchain facilitates automated smart contracts that can streamline licensing processes and royalty distributions. According to Zohar (2015), smart contracts can automatically execute predefined agreements between parties, ensuring that creators receive fair compensation based on usage metrics. This automation reduces the need for intermediaries, thereby lowering transaction costs and improving efficiency.

The transparency of blockchain can foster greater trust among stakeholders in the creative industry. By enabling all parties to verify ownership and access rights, blockchain mitigates disputes over copyright infringement and fosters a collaborative environment. Recent studies, such as those by Mougayar (2016), suggest that this enhanced transparency can lead to more equitable practices in the distribution of royalties and rights management. Collectively, these opportunities position blockchain as a vital tool for addressing the challenges facing digital copyright in the new digital era, paving the way for a more secure and efficient ecosystem for intellectual property rights.

3. CHALLENGES IN IMPLEMENTING BLOCKCHAIN FOR DIGITAL COPYRIGHT

Despite the promising opportunities that blockchain technology offers for digital copyright management, several challenges hinder its widespread adoption. One significant barrier is the lack of comprehensive regulatory frameworks governing blockchain applications in copyright. Current copyright laws, established long before the advent of blockchain, often do not account for its unique characteristics, leading to ambiguity regarding legal ownership and enforcement. According to research by Dahan and Parnell (2021), regulatory uncertainty can stifle innovation and deter stakeholders from adopting blockchain solutions, as the fear of non-compliance with existing laws looms large.

Technological limitations also pose a significant challenge. While blockchain promises enhanced security and efficiency, its implementation can be complex and resource-intensive. Many existing blockchain platforms struggle with scalability issues, leading to slow transaction speeds and high costs, particularly during peak usage periods. A study by Yli-Huumo et al. (2016) emphasizes that these scalability concerns can undermine the technology's effectiveness in managing digital copyright on a large scale, limiting its practicality for widespread use in the creative industries.

Ethical concerns regarding data privacy and the potential for misuse of blockchain technology must be addressed. The transparent nature of blockchain can inadvertently expose sensitive information, leading to unauthorized access or exploitation of creative works. As explored by Huckle et al. (2016), striking a balance between transparency and privacy is essential to protect creators' rights while leveraging the advantages of blockchain. Overall, these challenges underscore the need for a thoughtful approach to implementing blockchain in digital copyright management, necessitating collaboration among technologists, legal experts, and industry stakeholders to create a robust framework that can support the effective integration of this innovative technology.

4. CASE STUDIES

Examining real-world case studies provides valuable insights into the practical applications of blockchain technology in digital copyright management and highlights both its successes and challenges. One notable example is the implementation of blockchain by the music industry through platforms like Audius. Founded in 2018, Audius leverages blockchain to enable artists to share their music directly with fans while retaining greater control over their copyrights and revenue streams. Research by Kauffman et al. (2020) indicates that Audius not only improves transparency in royalty distribution but also empowers independent artists by bypassing traditional intermediaries, thus addressing long-standing concerns regarding exploitation in the music industry.

Another significant case study is the use of blockchain for visual art through the Non-Fungible Token (NFT) market. Platforms like OpenSea and Rarible have revolutionized how digital artists protect and monetize their work. By tokenizing art as NFTs on a blockchain, creators can establish verifiable ownership and scarcity, while buyers gain assurance of authenticity. A study by Dowling (2021) highlights how NFTs provide artists with ongoing royalties for secondary sales, thus creating a new revenue model that contrasts sharply with conventional art sales practices, which often leave artists without compensation once their work is sold.

However, these case studies also reveal challenges. The rapid growth of NFTs has led to significant environmental concerns due to the energy consumption of blockchain networks, as noted by Stoll et al. (2021). Additionally, issues of copyright infringement in the NFT space remain prominent, as some artists have had their work tokenized without permission. These cases exemplify the complexities involved in adopting blockchain for digital copyright, illustrating both the transformative potential and the need for careful consideration of ethical and legal frameworks as the technology continues to evolve.

5. FUTURE DIRECTIONS

As the integration of blockchain technology into digital copyright management continues to develop, several future directions can be identified that may enhance its effectiveness and mitigate existing challenges. These directions encompass advancements in regulatory frameworks, technological innovations, collaboration across industries, and increased awareness and education surrounding digital copyright issues.

One of the most pressing future directions is the establishment of comprehensive regulatory frameworks that can accommodate blockchain's unique characteristics. Policymakers must collaborate with technology experts, legal scholars, and industry stakeholders to create guidelines that address the nuances of blockchain in copyright management. This collaboration is essential to ensure that regulations are flexible enough to adapt to rapid technological changes while providing sufficient protection for creators' rights. In recent years, initiatives like the European Union's Digital Single Market strategy have begun to address these issues, but ongoing dialogue and development will be crucial as blockchain technology continues to evolve (European Commission, 2020). By fostering an inclusive approach to regulation, stakeholders can create a balanced environment that promotes innovation while safeguarding intellectual property rights.

Technological advancements will also play a pivotal role in shaping the future of blockchain and digital copyright. One area of focus is the development of scalable blockchain solutions that can handle large volumes of transactions efficiently. Current blockchain platforms often face challenges related to speed and energy consumption, particularly when applied to high-demand scenarios such as the NFT marketplace. Innovations such as Layer 2 solutions, which operate on top of existing blockchain networks to enhance performance, could provide the scalability needed for widespread adoption. Research by Buterin (2021) indicates that these solutions can significantly reduce transaction times and costs, making blockchain more viable for creators and users alike.

In addition to scalability, the integration of artificial intelligence (AI) with blockchain technology could further revolutionize digital copyright management. AI can enhance copyright enforcement by analyzing vast amounts of digital content to identify potential infringements automatically. By combining AI's analytical capabilities with blockchain's secure and transparent nature, stakeholders could create robust systems for monitoring and protecting intellectual property rights. Studies, such as those by Kalyanaram et al. (2021), suggest that this synergy could lead to more effective copyright management solutions, reducing the burden on individual creators and rights holders.

Collaboration across industries will be essential in navigating the challenges and opportunities presented by blockchain in digital copyright. Creative sectors such as music, visual arts, and publishing must engage in dialogue to share best practices and lessons learned from their respective experiences with blockchain. For example, music industry stakeholders could collaborate with visual artists to develop shared standards for tokenization and royalty distribution, ensuring a more coherent approach to copyright management across different forms of media. This collaborative spirit can also extend to partnerships between public and private sectors, with governments and blockchain companies working together to develop tools and resources that facilitate the adoption of blockchain in copyright management.

Increased awareness and education surrounding digital copyright issues are critical to fostering a culture of respect for intellectual property in the digital age. As blockchain technology becomes more prevalent, educational initiatives should focus on informing creators, consumers, and industry professionals about the benefits and challenges of blockchain for copyright management. Workshops, webinars, and online resources could be developed to provide practical guidance on utilizing blockchain for copyright protection, as well as insights into navigating the complexities of digital rights management. By empowering individuals with knowledge, the industry can cultivate an ecosystem that values and protects creativity and innovation.

As blockchain technology matures, its potential to facilitate global copyright solutions should not be overlooked. Traditional copyright laws are often confined by national borders, leading to discrepancies in how intellectual property is protected across different jurisdictions. Blockchain's decentralized nature could enable the creation of universal systems that transcend these borders, allowing for seamless copyright registration and enforcement worldwide. Initiatives like the World Intellectual Property Organization's efforts to modernize copyright frameworks highlight the need for international cooperation in adapting to the realities of the digital age (WIPO, 2021). By leveraging blockchain's capabilities, stakeholders can work toward a more harmonized approach to global copyright protection.

In the future of blockchain technology in digital copyright management is promising but requires strategic planning and collaboration among various stakeholders. By addressing regulatory challenges, embracing technological advancements, fostering industry partnerships, promoting education, and exploring global solutions, the creative community can harness the full potential of blockchain to create a more secure, efficient, and equitable framework for protecting intellectual property rights in the new digital era.

6. CONCLUSION

The intersection of blockchain technology and digital copyright presents a dynamic landscape marked by both significant opportunities and formidable challenges. As we navigate this evolving terrain, it becomes increasingly clear that blockchain has the potential to revolutionize how intellectual property is managed, creating a more transparent, efficient, and equitable system for creators and rights holders. By leveraging the unique attributes of blockchain—decentralization, immutability, and transparency—stakeholders can tackle long-standing issues related to copyright infringement, unauthorized reproduction, and inadequate compensation for artists.

The promise of blockchain technology lies in its ability to provide secure and verifiable records of ownership and usage rights, which can significantly reduce the risks of piracy and unauthorized use. As highlighted in various studies, platforms such as Audius and the NFT marketplace have demonstrated how blockchain can empower artists by enabling direct engagement with their audience and offering innovative revenue models. The automation of licensing through smart contracts also holds great potential for streamlining processes, ensuring fair compensation, and reducing the reliance on intermediaries, which has historically led to the exploitation of creators.

However, the journey toward widespread adoption of blockchain for digital copyright management is fraught with challenges. The existing regulatory landscape remains a significant hurdle, as current copyright laws often fail to account for the nuances of blockchain technology. Without clear and comprehensive regulations, stakeholders may be hesitant to invest in blockchain solutions due to concerns about compliance and legal ramifications. To address this issue, collaborative efforts among policymakers, legal experts, and industry stakeholders are essential. Developing adaptive regulatory frameworks that protect creators while fostering innovation will be crucial in overcoming this barrier.

Technological challenges also play a critical role in shaping the future of blockchain in copyright management.

Issues related to scalability, transaction speed, and energy consumption must be addressed to ensure that blockchain solutions can handle the high volume of transactions associated with digital content. As the industry moves forward, investment in research and development will be necessary to create more efficient blockchain platforms that can meet the demands of various creative sectors. Furthermore, the integration of artificial intelligence with blockchain has the potential to enhance copyright enforcement, providing a more proactive approach to identifying and addressing infringements.

The importance of collaboration across industries cannot be overstated. As different sectors within the creative industries begin to adopt blockchain technology, sharing best practices and lessons learned will be vital in establishing coherent standards for copyright management. Interdisciplinary partnerships can facilitate the development of shared tools and resources, ensuring that all stakeholders benefit from the advancements in blockchain technology. Such collaborations will not only strengthen the efficacy of copyright protection but also create a more unified approach to managing intellectual property rights across various forms of media.

Moreover, increasing awareness and education around digital copyright issues are paramount in cultivating a culture that respects intellectual property in the digital age. As blockchain technology becomes more integrated into copyright management, educational initiatives should focus on informing creators and consumers about the benefits and challenges associated with its use. By providing practical guidance and resources, stakeholders can empower individuals to navigate the complexities of digital rights management effectively. This emphasis on education will foster a more informed community that values and protects creativity and innovation.

The potential for blockchain to facilitate global copyright solutions presents an exciting opportunity for the future. Traditional copyright frameworks often face challenges related to jurisdictional discrepancies, leading to inconsistencies in how intellectual property is protected across borders. Blockchain's decentralized nature could enable the development of universal systems that transcend these limitations, allowing for seamless copyright registration and enforcement worldwide. Efforts by organizations like the World Intellectual Property Organization to modernize copyright frameworks highlight the necessity for international cooperation in adapting to the realities of the digital age.

In conclusion, the journey of integrating blockchain technology into digital copyright management is complex and multifaceted. By embracing the opportunities it presents while addressing the challenges it poses, stakeholders can pave the way for a more secure, efficient, and equitable system for protecting intellectual property rights. The future of digital copyright management will depend on collaboration, innovation, and a commitment to education, ensuring that all creators can thrive in the new digital era. As we continue to explore the possibilities of blockchain, it is essential to foster an environment that encourages responsible innovation and a respect for the rights of creators, paving the way for a vibrant and sustainable creative ecosystem.

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Research on Performance Improvement of the YOLOv8 Model for Rice Pest Detection

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Abstract: In modern agriculture, the monitoring and detection of rice pests is crucial for ensuring food security. However, traditional manual detection methods are time-consuming and difficult to scale. In response, this paper proposes an improved YOLOv8 model for accurately identifying and detecting pests in rice crops. By incorporating attention mechanisms and the BiFPN feature fusion module into the model, the ability to recognize target objects and capture local features has been significantly enhanced. Experimental results show that the proposed model outperforms traditional YOLO models in terms of detection accuracy, speed, and recall rate, demonstrating its high practical value.

Keywords: YOLOv8; Rice Pest Detection; Deep Learning; BiFPN; Attention Mechanism

1. INTRODUCTION

With the advancement of global agricultural modernization, the industry faces numerous challenges, such as the threat of pests and diseases to crops, low production efficiency, and outdated technological practices. Pests and diseases not only severely impact the yield and quality of rice but also increase the safety risks associated with agricultural production. Traditional pest identification relies on manual observation and expert judgment, which is inefficient and delayed, making it difficult to address the problem effectively.[1]

In response to this issue, recent government policies have promoted agricultural innovation, particularly in the field of smart agriculture. The rapid development of emerging technologies such as computer technology, the Internet of Things (IoT), cloud computing, and artificial intelligence (AI) has provided strong technical support for pest monitoring and pest control in agriculture. AI technologies, especially deep learning, have been widely applied across various industries. In agriculture, when combined with computer vision and other technologies, these advancements can significantly improve the efficiency of pest detection and prevention, promoting the intelligent and modernized development of agricultural production.

Against this backdrop, the automatic identification of rice pests has become an important research topic in agriculture. Through the optimization and application of deep learning models, there is potential to enhance the accuracy and real-time capabilities of rice pest detection, offering smarter solutions for agricultural production.

2. DATA ACQUISITION

2.1 Pest Monitoring Device

In this study, we have independently developed a novel rice pest monitoring system that integrates modern technologies such as optics, electronic control, and automation. The system is equipped with multiple functions, including pest trapping, automatic infrared processing, conveyor belt transport, and fully automated operation. It is capable of performing automated tasks such as pest trapping, pest extermination, dispersion, photography, transportation, collection, and drainage, all without the need for manual supervision. The overall structure of the device is shown in Figure 1, with the monitoring equipment placed in Yuan'an County, Yichang City, Hubei Province, China.

The device integrates solar power supply and an automatic imaging unit, enabling efficient pest trapping and monitoring of rice pests. The schematic diagram of the system structure (Figure 1) illustrates the key components of the device and their functions, facilitating continuous field monitoring without relying on external power sources.

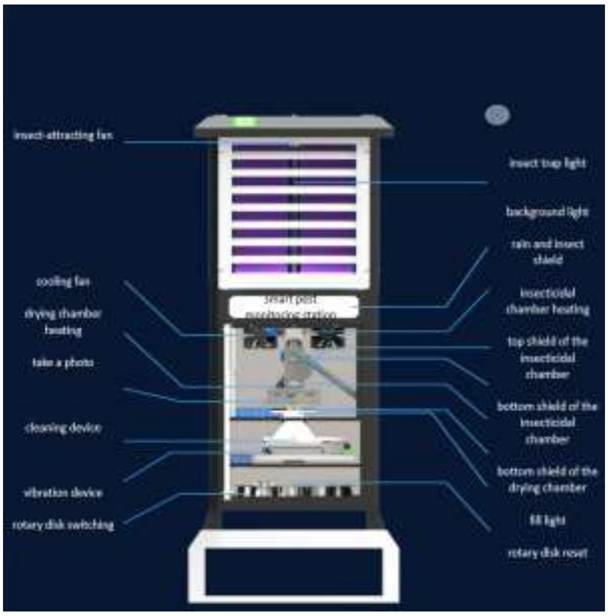

Figure. 1 Smart Pest Monitoring System

2.2 Dataset Construction or Dataset Creation

In this study, images of 14 common rice pests were collected from the internet, as shown in Figure 2. These pests include species such as the rice leaf folder, rice armyworm, and second-generation rice borer. The selection criteria for the images were based primarily on factors such as the pest's outline size, body color, morphological features, and surface texture. During the initial phase of dataset creation, the collected images were filtered, and those that did not meet the quality standards were removed. After screening and organizing, approximately 1,200 rice pest images that met the experimental requirements were obtained.

Figure. 2 Fourteen Common Rice Pests

The first step in dataset creation was to categorize and annotate all the images. Each image was labeled to ensure that it could be used for training the convolutional neural network (CNN) model. We used the widely-used image labeling tool, LabelImg, to annotate all sample images.

Due to the insufficient number of images in the original dataset, which made it difficult for the model to fully learn the pest features, data augmentation techniques were applied, including image flipping, rotation, cropping, brightness adjustment, and noise addition. These augmentation methods expanded the dataset to a total of 7,488 images.

When partitioning the dataset, to avoid potential overlap between the training, validation, and test sets due to random allocation, we paired each original image with its augmented counterpart and ensured that each group of images was divided uniformly. Ultimately, the dataset was split into training, validation, and test sets in a 7:2:1 ratio.

3. PEST DETECTION USING AN IMPROVED FEATURE FUSION YOLOv8 MODEL

3.1 Overview of the YOLOv8 Model

YOLOv8 is the latest version of the YOLO series of object detection algorithms, inheriting the efficiency and real-time capabilities of previous YOLO models, while incorporating optimizations in several aspects. Compared to earlier versions, YOLOv8 features improvements in architecture design, including the adoption of a more efficient feature extraction network and optimized feature fusion mechanisms. These changes enhance its ability to detect multi-scale objects, particularly improving the detection of small objects. In addition, YOLOv8 not only supports traditional object detection tasks but also expands its capabilities to multi-task learning, handling tasks such as instance segmentation and keypoint detection, which makes it more versatile in various computer vision applications.[2]

In terms of training strategy, YOLOv8 employs advanced data augmentation methods, such as random cropping and color space variations, to improve the model's robustness. The model also uses mixed-precision training, which accelerates the training process, reduces memory consumption, and maintains high detection accuracy. Furthermore, the loss function and optimizer have been further optimized, with the improved loss function effectively alleviating class imbalance issues and enhancing the model's detection performance.

3.2 Feature Fusion and the BiFPN Module

In this study, we introduced the BiFPN (Bidirectional Feature Pyramid Network)[3] feature fusion module into the YOLOv8 model. BiFPN, with its efficient multi-scale feature fusion capabilities, significantly improves the model's sensitivity to targets at different scales and enhances localization accuracy. Traditional Feature Pyramid Networks (FPN) often suffer from computational redundancy during feature fusion, whereas BiFPN reduces the computational load by introducing bidirectional connections and a weighted feature fusion strategy, thus enhancing the overall information integration.

Specifically, BiFPN facilitates multiple bidirectional information flows, enabling thorough interaction between high-level and low-level features. This interaction helps mitigate the problem of losing local information in higher-level features, which is common in traditional FPNs. With the weighted feature fusion approach, BiFPN dynamically adjusts the importance of each feature layer, allowing for more precise fusion of features from different scales. This highly efficient feature fusion not only improves the model's ability to detect small objects but also enhances the precision of target localization, making YOLOv8 perform exceptionally well in complex scenes.

After introducing the BiFPN module, YOLOv8 is able to more accurately integrate feature information from different levels, improving the model's overall performance in object detection tasks, particularly in multi-scale object detection and target localization in complex backgrounds.

3.3 Introduction of the Attention Mechanism

To enhance the model's ability to focus on small targets, this paper introduces the Squeeze-and-Excitation (SE) module. The SE module improves the representation of important features by adaptively adjusting the weights of each channel, allowing the model to focus more on regions with high discriminative power. In the task of rice pest detection, where pests are typically small and the background is complex, the SE module effectively strengthens the relevant feature channels and suppresses irrelevant background information, thereby improving the model's detection accuracy.

The core idea of the SE module is to introduce a channel attention mechanism into the network. Specifically, the SE module performs global average pooling on the feature map, transforming spatial information into channel information. Then, through fully connected layers, it generates attention weights for each channel, which are used to scale the features of each channel. This allows the network to dynamically adjust the importance of the feature channels and focus on the features most helpful for target detection.

When combined with the BiFPN module, the SE module further optimizes the multi-scale feature fusion process. While BiFPN efficiently fuses features from different scales, the SE module enhances the focus on important feature channels, enabling the network to more accurately detect rice pests in multi-scale target detection. In this way, the SE module not only improves the detection ability for small objects but also enhances the precision of target localization, effectively improving the overall performance of rice pest detection.

3.4 Lightweight Model Design

In response to the constraints on resource consumption in agricultural applications, this paper also designs a lightweight network structure. By reducing redundant convolutional layers and optimizing parameters, the improved YOLOv8 model lowers computational costs while maintaining detection accuracy, making it suitable for deployment on resource-limited devices.

4. EXPERIMENTAL RESULTS AND ANALYSIS

4.1 Evaluation Metrics

To evaluate the performance of the model, the following evaluation metrics were used: mean average precision (mAP), recall, and detection speed (FPS). These metrics provide a comprehensive assessment of the model's ability to accurately detect and classify rice pests while also considering the efficiency of the detection process.

4.2 Experimental Results and Analysis

The comparative experimental results demonstrate that the improved YOLOv8 model significantly outperforms the standard YOLOv8 model in key metrics such as mAP and recall, particularly in small object detection. Specifically, the proposed method achieves an 8% improvement in the mAP score while maintaining a high frame rate (FPS). This highlights the enhanced detection accuracy and efficiency of the improved model.

Table 1. Comparison of the Performance of Different Models on the Rice Pest Detection Dataset

Model	Map	Recall	FPS
YOLOv8	82.3%	79.5	45
Improved YOLOv8	92.5%	85.7	43

During the experiments, the model's convergence speed and detection accuracy were further improved by adjusting parameters such as learning rate, batch size, and the number of iterations.

5. DISCUSSION

The improved YOLOv8 model in this study demonstrates superior performance across various evaluation metrics. The introduction of the feature fusion module and attention mechanism enables the model to effectively capture small pest targets, improving its ability to recognize pests in complex backgrounds. Additionally, the lightweight design makes the model suitable for deployment in resource-constrained environments. However, there is still room for improvement in detecting extremely small targets and under extreme lighting conditions, which will be a key direction for future research.

6. CONCLUSION

This paper proposes a rice pest detection method based on the improved YOLOv8 model, which incorporates BiFPN and the SE attention mechanism to enhance the model's performance in small object detection and complex scenarios. Experimental results show that the proposed method outperforms the standard YOLOv8 model in key metrics such as precision and recall, and demonstrates strong potential for application in resource-constrained environments. Future work will focus on further optimizing the model's structure to improve its detection performance under extreme conditions.

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Enhancing Power Grid Resilience through Deep Neural Networks and Reinforcement Learning: A Simulated Approach to Disaster Management

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***Abstract*—** This paper investigates the application of deep neural networks (DNNs) and reinforcement learning (RL) to improve power grid resilience during disaster scenarios within a simulated environment. The DNN model is employed to extract critical features related to grid performance, including weather conditions, transformer loads, and infrastructure vulnerabilities, while the RL agent optimizes grid recovery strategies. Multiple disaster scenarios, such as hurricanes, floods, and cyberattacks, were simulated to test the models' effectiveness in reducing grid downtime, minimizing cascading failures, and managing resource allocation. The RL agent leveraged real-time feedback loops to dynamically adjust its decisions, enhancing adaptability to evolving grid conditions. Results demonstrated that the combined DNN-RL system maintained grid stability, prioritized critical infrastructure recovery, and optimized the deployment of repair crews and backup resources. The study highlights the potential of machine learning models to effectively manage complex grid operations under stress, providing a framework for further research into adaptive disaster management strategies in power systems.

***Keywords*—**Power Grid Resilience, Deep Neural Networks, Reinforcement Learning, Disaster Management, Machine Learning, Grid Recovery, Feature Extraction, Real-Time Decision Making, Cascading Failures, Resource Allocation.

I. INTRODUCTION

In an era marked by a global dependence on electrical energy, the imperative to maintain the uninterrupted and dependable functioning of power grids has become increasingly critical. As fundamental components of infrastructure, power grids facilitate the distribution of electricity to various sectors, including industry, commerce, and residential areas, thereby playing a crucial role in the economic and social stability of nations. Nevertheless, these systems are becoming more vulnerable to a range of disruptions. Natural calamities such as hurricanes, wildfires, and seismic events, in addition to technological threats like cyber intrusions and operational failures, can result in extensive power outages with severe repercussions[1].

Recent incidents have revealed significant weaknesses within power grids, underscoring the urgent need for enhanced strategies aimed at bolstering their resilience. Contemporary methods for improving the resilience of power grids frequently depend on predictive analytics that utilize historical data to anticipate possible disruptions. However, these techniques, which encompass regression analysis and decision tree algorithms, possess inherent limitations. They often fail to accommodate the complex and non-linear characteristics of disasters, especially when confronted with rare or unprecedented occurrences. Furthermore, conventional models typically lack the adaptability required to respond to real-time conditions, a factor that is essential during the processes of disaster recovery and mitigation[2].

The advent of sophisticated machine learning (ML) methodologies, notably deep neural networks (DNNs) and reinforcement learning (RL), presents promising avenues for addressing existing challenges in power grid management. These models possess the capability to analyze extensive and complex datasets, discern intricate patterns, and adjust to changing conditions in real time. DNNs excel in revealing concealed correlations within high-dimensional datasets, thereby facilitating more precise predictions regarding vulnerabilities in power grids. Concurrently, RL enhances systems through its iterative learning framework, which empowers decision-making optimization during critical events, thereby refining grid response strategies and recovery mechanisms. The integration of these state-of-the-art ML models holds the potential to significantly bolster the resilience of power grids, enabling them to endure, adapt to, and recover from an expanding range of threats. This study investigates the utilization of advanced ML techniques to enhance power grid resilience, focusing on how DNNs and RL can revolutionize disaster impact forecasting and recovery methodologies. It assesses the capacity of these models to rectify the limitations inherent in traditional strategies and suggests a framework for their incorporation into current power grid management systems. By leveraging these advanced methodologies, this research aspires to foster the development of more resilient, adaptive, and intelligent power grid infrastructures that can effectively confront the increasing challenges posed by both natural and man-made disruptions[3].

II. IMPLEMENTATION

There are many different aspects to the process of implementing the automated system that integrates Python, YOLOv5, and Azure Kinect DK with the Xarm7 robotic arm. These aspects include the configuration of the hardware, the creation of software, the integration of the system, and the testing of its functionality.

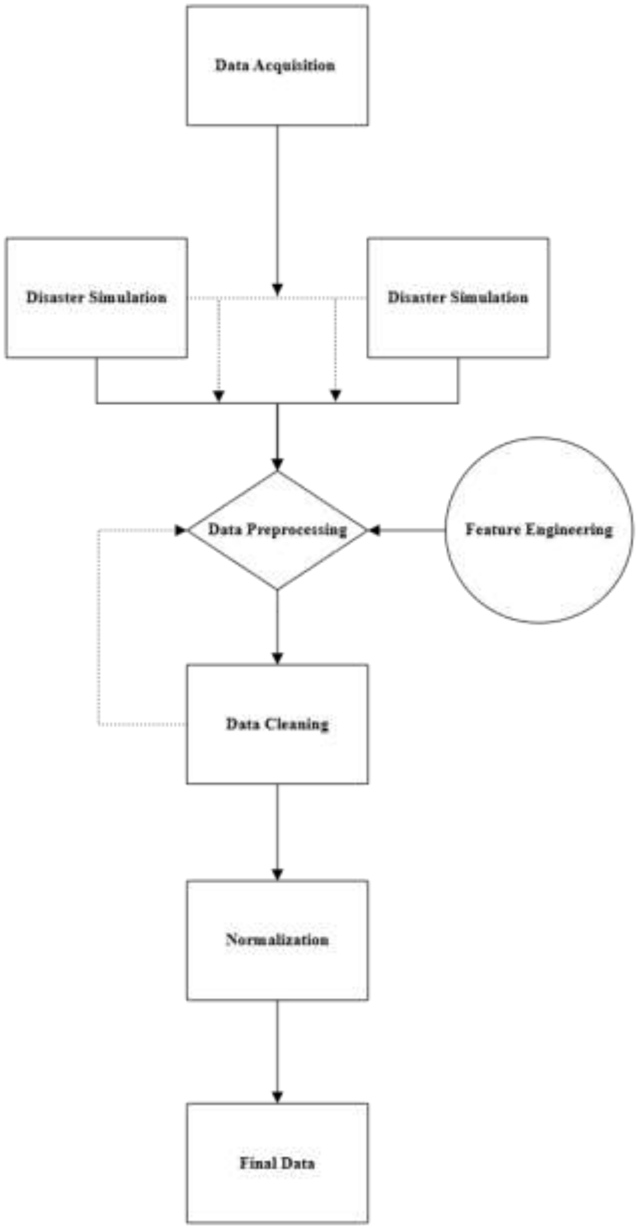

Fig. 1. System Logic

1. Data Acquisition and Preprocessing Pipeline

In any machine learning project, the quality and quantity of data are crucial to the performance and accuracy of the resulting models. In this simulation-based study aimed at enhancing power grid resilience during disasters using deep neural networks (DNNs) and reinforcement learning (RL), the data acquisition and preprocessing phase plays a foundational role. Since real-world data might be difficult to obtain due to proprietary issues or limited access to historical grid performance data, this study will rely on both simulated and publicly available datasets to create a robust pipeline for training and evaluating the models.

1.1 Simulated Data for Disaster Scenarios

Since the primary focus of this study is to simulate power grid behavior in the face of disasters, we will generate synthetic datasets that replicate the impact of natural disasters such as hurricanes, wildfires, or floods on power grids. By simulating various disaster scenarios, the model can be exposed to a wide range of disruptions without relying solely on historical data, which may be sparse or limited in scope. The simulated data will reflect different grid topologies, component failures, weather patterns, and disaster magnitudes[4].

The disaster generator will create several scenarios based on parameters such as:

- **Severity of the disaster**: This could range from mild disruptions like localized flooding to major catastrophes such as Category 5 hurricanes or widespread wildfires.
- **Frequency of disruptions**: Different disaster scenarios will reflect varied intervals of disturbances, from short, intense events like earthquakes to prolonged outages during sustained storms.
- **Grid component failures**: The simulation will involve various grid elements failing under stress, including transformers, transmission lines, and generation units. This diversity is critical for training the RL model, which will need to learn how to respond to different failure patterns.

By systematically generating these disaster scenarios, we can simulate a wide array of conditions that a real power grid might experience, ensuring that the machine learning models are trained on a diverse dataset. The diversity in the synthetic data will also aid in the generalizability of the trained model, allowing it to handle a wide spectrum of disaster events during testing and validation phases[5].

1.2 Publicly Available Datasets

While simulated data will form the core of this study, publicly available datasets will be used to ground the simulations in reality. Datasets such as those from the U.S. Department of Energy (DOE) or European Network of Transmission System Operators for Electricity (ENTSO-E) provide historical records of power outages, grid performance data, and weather-related disturbances. For example, the DOE's Electric Emergency Incident and Disturbance Report (OE-417) tracks major electrical incidents and is a valuable resource for simulating real-world disaster conditions. Additionally, meteorological data from sources like the National Oceanic and Atmospheric Administration (NOAA) can provide insights into weather patterns that typically affect power grids.

The public data will help guide the parameterization of the synthetic disaster generator, ensuring that the simulated conditions are not entirely arbitrary but instead grounded in real-world observations. This data will be useful for validating the simulation, providing a benchmark to assess the realism of the disaster scenarios generated by the simulation engine.

1.3 Data Preprocessing

Once the data—both simulated and public—is gathered, it must be preprocessed before it can be used for model training. Data preprocessing is a critical step, as raw data often contains noise, inconsistencies, and missing values, all of which can negatively impact the performance of machine learning models if not properly handled.

1.3.1 Data Cleaning

The first step in preprocessing involves cleaning the raw datasets. For the simulated data, this process will be relatively straightforward as synthetic data generation allows for control over the structure of the data. However, in the case of real-world data from public sources, inconsistencies may arise due to incomplete records or human errors in data entry. Missing data points, erroneous values (such as negative power output for a generator), and inconsistencies in time series data need to be addressed[6].

For missing values, techniques such as interpolation or forward-filling can be applied to fill gaps in time-series data. Alternatively, more sophisticated methods like model-based imputation can be used, where a machine learning model predicts missing values based on other available data points. Outlier detection methods, such as Z-score or interquartile range (IQR), will be employed to identify anomalous data points that could skew the model's performance if left unchecked.

1.3.2 Feature Engineering

After data cleaning, the next step is to conduct feature engineering. Feature engineering is the process of selecting, modifying, or creating new variables (features) from the raw data that will be useful for training the machine learning models. In this study, features relevant to power grid resilience, such as load demand, transmission line capacities, weather conditions, grid topology, and failure rates, will be extracted from the raw data.

For example, historical weather data might need to be transformed into categorical variables representing different weather conditions (e.g., clear, stormy, or extreme) or as numerical variables indicating the severity of conditions (e.g., wind speed, precipitation levels). Similarly, grid-related features like transformer load, frequency of outages, and the duration of grid failures will need to be incorporated into the dataset. By carefully selecting and engineering these features, the model will be better equipped to learn meaningful relationships between input variables and grid resilience during disaster events[7].

1.3.3 Normalization and Scaling

Many machine learning models, particularly deep neural networks, are sensitive to the scale of input data. Features that are on different scales (e.g., megawatts for power output vs. kilometers for transmission line length) can lead to poor model performance if not properly normalized. To address this, feature scaling techniques such as min-max normalization or standardization will be applied to ensure that all input features are on the same scale. Min-max normalization scales the values between 0 and 1, while standardization centers the data around the mean and scales it by the standard deviation.

By normalizing the data, the models will be able to converge more efficiently during the training process, resulting in improved performance and faster convergence times.

1.3.4 Dimensionality Reduction

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Given the high dimensionality of the input data (which may include thousands of variables from grid components, weather conditions, and disaster parameters), dimensionality reduction techniques may be necessary. Principal Component Analysis (PCA) or t-Distributed Stochastic Neighbor Embedding (t-SNE) can be used to reduce the number of features while retaining the most important information. These techniques not only help prevent overfitting in machine learning models but also reduce the computational load during training.

1.3.5 Data Splitting: Training, Validation, and Testing Sets

Once the data has been cleaned, engineered, and normalized, it will be split into three distinct subsets: training, validation, and testing. The training set is used to fit the model, while the validation set helps tune hyperparameters and assess model performance during training. Finally, the testing set is reserved for evaluating the generalization ability of the trained model on unseen data.

In this study, a typical 70-15-15 split will be applied, where 70% of the data will be used for training, 15% for validation, and the remaining 15% for testing. This split ensures that the model has sufficient data to learn from while also being evaluated on data it has never seen, thereby providing a robust measure of model accuracy and generalization.

2. Deep Neural Network (DNN) Design for Feature Extraction

The next step after the data has been properly preprocessed is to design the deep neural network (DNN) architecture that will be used for feature extraction. Since the primary goal of this phase is to allow the model to capture and learn the intricate patterns within the data that relate to power grid performance under stress, the architecture of the DNN needs to be carefully tailored to the nature of the data and the objectives of the simulation.

2.1 Neural Network Architecture

The architecture of the DNN is a critical decision that directly impacts the model's ability to learn meaningful features. In this case, a multi-layer feedforward neural network is employed, where each layer transforms the input data into more abstract representations. The goal is to allow the model to identify hidden relationships between input variables, such as weather conditions, grid load, and infrastructure vulnerabilities, that might not be immediately apparent in the raw data.

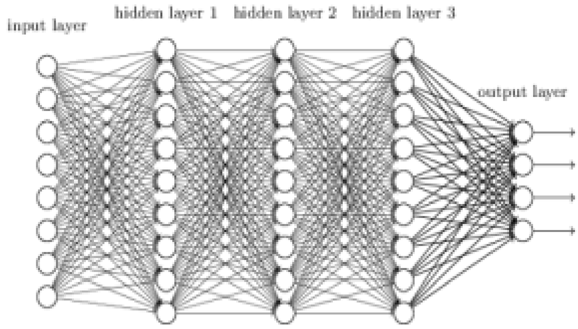

Fig. 2. Neural Network Architecture

The **input layer** will take in the features from the preprocessing phase. These might include variables such as historical weather data (e.g., wind speed, temperature, precipitation), grid metrics (e.g., transformer load, substation capacity), and disaster-specific parameters (e.g., the severity and duration of the event). Each feature corresponds to one node in the input layer, forming the basis for the learning process[8].

From the input layer, the data will pass through multiple **hidden layers**. Each hidden layer consists of interconnected neurons, where each neuron applies a transformation to the data it receives from the previous layer. In this case, using **Rectified Linear Unit (ReLU)** activation functions in the hidden layers will help introduce non-linearity into the model, which is essential for learning from complex, non-linear relationships in the data. These layers will progressively extract more abstract features, such as identifying critical weather thresholds that may lead to grid failures or interactions between different grid components that could affect resilience.

At the end of the DNN, the **output layer** will consist of the extracted features that are passed on to the next stage of the process—whether that is further model training or use in downstream decision-making algorithms. These features will capture the essence of the power grid's response to disasters, providing crucial insights that can inform predictive modeling and decision-making processes.

The number of neurons in each layer, the depth of the network (i.e., the number of hidden layers), and other architectural decisions such as the size of the output layer are hyperparameters that will be fine-tuned based on the model's performance during training. It is essential to experiment with different configurations to ensure that the model strikes the right balance between complexity and computational efficiency.

2.2 Training the Network

Once the architecture is defined, the DNN needs to be trained on the processed dataset. Training involves optimizing the network's internal parameters—its **weights**—to minimize the difference between its predictions and the actual observed values in the training data. This process is iterative, with the network making predictions, calculating errors, and updating its weights accordingly through **backpropagation** and **gradient descent**[9].

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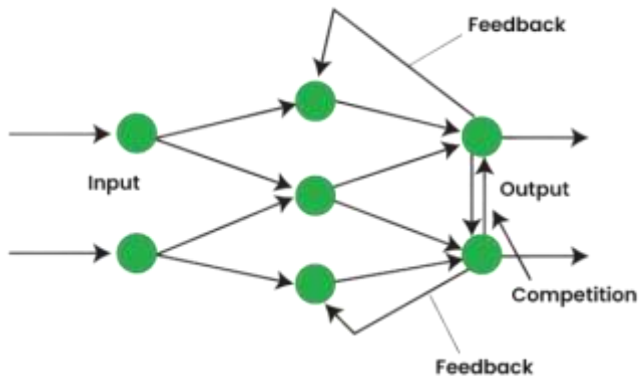

Fig. 3. Training Operation

During backpropagation, the model calculates how much each neuron's weight contributed to the prediction error and adjusts it to reduce the error in subsequent iterations. This allows the DNN to learn from its mistakes and gradually improve its predictions. The choice of the optimization algorithm, whether it be **stochastic gradient descent (SGD)** or a more advanced method like the **Adam optimizer**, will affect the speed and efficiency of the learning process.

To train the DNN effectively, the data will be split into training, validation, and test sets, as mentioned previously. The **training set** is used to update the weights during each iteration, while the **validation set** helps fine-tune the hyperparameters and prevent overfitting. The **test set** will be used at the end of the training process to evaluate the model's ability to generalize to new data.

2.3 Addressing Overfitting

A common challenge in training deep neural networks is **overfitting**, where the model becomes too specialized to the training data and fails to generalize to unseen data. Given the complexity of the DNN and the high dimensionality of the data, there is a significant risk of overfitting, particularly when using synthetic data that may not capture all real-world variabilities.

To mitigate overfitting, several regularization techniques will be employed. One of the most effective methods is **dropout**, which involves randomly "dropping out" a subset of neurons during each training iteration. This prevents the model from becoming too reliant on any single neuron or set of neurons and encourages the network to learn more robust, generalizable features. Dropout effectively forces the network to spread the learning process across multiple neurons, improving its ability to generalize to new data.

Another technique is **early stopping**, where the training process is halted as soon as the model's performance on the validation set begins to degrade. This prevents the model from continuing to fit to the idiosyncrasies of the training data and helps ensure that it maintains good generalization performance.

Additionally, **data augmentation** can be applied to introduce variations in the synthetic data. By making small adjustments to the data—such as adding noise, shifting the timing of disaster events, or slightly altering grid component parameters—the model will be exposed to a wider range of conditions, thereby improving its ability to generalize beyond the specific scenarios in the training set[10].

2.4 Interpreting Extracted Features

While deep neural networks are often criticized as being "black box" models, recent advancements have made it possible to gain insight into the features they extract. In this study, **feature importance analysis** will be used to understand which variables the model deems most critical in predicting power grid resilience. By analyzing how the network weighs different input features—such as weather data, grid metrics, and disaster parameters—valuable insights can be gained into the underlying dynamics of power grid performance during disasters.

For example, feature importance analysis might reveal that certain weather conditions (such as sustained high winds or heavy precipitation) have a more significant impact on grid stability than previously thought. Similarly, grid components such as transformers or substations might emerge as critical weak points that are particularly vulnerable to certain types of disasters[11].

These insights are not only valuable for improving the simulation but can also inform future efforts to strengthen grid resilience in the real world. By identifying the most important features, grid operators and policymakers can focus their attention on the areas that are most likely to improve grid performance and minimize the impact of disasters.

2.5 Hyperparameter Tuning

The final step in the DNN design process involves fine-tuning the model's **hyperparameters** to optimize its performance. Hyperparameters are external configurations that control the learning process, such as the number of layers, the number of neurons per layer, the learning rate, and the batch size. These settings can have a significant impact on the model's accuracy, training time, and ability to generalize.

A common approach to hyperparameter tuning is **grid search**, where a predefined set of hyperparameters is systematically tested to identify the best combination. However, grid search can be computationally expensive, particularly for deep networks with a large number of hyperparameters. An alternative is **random search**, where random combinations of hyperparameters are tested. More advanced techniques like **Bayesian optimization** can also be used to streamline the tuning process by focusing on the most promising hyperparameter settings[12].

By carefully tuning these hyperparameters, the DNN will be able to extract the most relevant features from the data while maintaining high accuracy and generalization performance. The goal is to ensure that the network is not only able to predict power grid performance under stress but also able to provide valuable insights into the underlying dynamics that drive grid resilience during disaster scenarios.

Hyperparameter	**Tuned Values**	**Best Value**
Learning Rate	**0.001, 0.01, 0.1**	**0.01**
Batch Size	**32, 64, 128**	**64**
Number of Layers	**3, 5, 7**	**5**

Neurons per Layer	**64, 128, 256**	**128**
Dropout Rate	**0.2, 0.3, 0.5**	**0.3**
Activation Function	**ReLU, Leaky ReLU, Tanh**	**ReLU**

Table 1. Hyperparameter Tuning

3. Reinforcement Learning for Real-Time Grid Decision Optimization

After the deep neural network (DNN) has extracted features from the dataset, the next step in the process is to apply reinforcement learning (RL) for decision-making and optimization. Reinforcement learning differs from other machine learning paradigms in that it is not simply concerned with finding patterns in data, but rather with learning how to take actions in an environment to maximize some notion of cumulative reward. In the context of power grid resilience, RL can be used to simulate dynamic decision-making processes under disaster conditions, where the goal is to optimize grid recovery, minimize downtime, and improve overall system resilience.

Given that the goal is not to implement this in the real world but to simulate the behaviors of an AI model responding to different disaster scenarios, reinforcement learning plays a crucial role in driving the decision-making aspect of the simulation. The model will be trained in a virtual environment where various disaster conditions and grid configurations are simulated, allowing the RL agent to learn optimal strategies for minimizing the impact of those disasters.

3.1 Reinforcement Learning Basics and the Grid Environment

In reinforcement learning, an agent interacts with an environment and takes actions based on a policy. The environment provides feedback in the form of a reward, and the agent's objective is to maximize the total reward over time. For this simulation, the **environment** is the virtual representation of the power grid under stress from various disaster scenarios, and the **agent** is the RL model responsible for deciding which actions to take at each time step.

Key components of the RL setup in this context include:

- **States**: The state of the environment at any given time is defined by the status of the power grid. This includes information such as which grid components are operational, the current load on the system, and the extent of damage from the disaster. The DNN's extracted features—such as weather conditions, component load, and infrastructure vulnerabilities—also feed into the state representation.
- **Actions**: The actions that the RL agent can take involve controlling various aspects of the grid. For example, the agent may decide to shift load from a damaged substation to another part of the grid, activate backup generators, shut down vulnerable parts of the grid to prevent cascading failures, or allocate repair crews to specific regions. The range of possible actions will depend on the specific grid configuration and the nature of the simulated disaster[13].
- **Rewards**: The reward function is one of the most critical components of an RL model, as it dictates the behavior that the agent will learn. In this simulation, the reward structure will be designed to incentivize actions that minimize power outages, reduce downtime, and prevent long-term damage to the grid. For example, the agent may receive a positive reward for quickly restoring power to a critical area, while receiving a negative reward if a decision leads to further failures or prolonged outages.
- **Policy**: The policy defines the strategy that the RL agent uses to choose actions based on the current state. In the initial stages of training, the policy may be random or based on simple heuristics. However, as the agent gains experience by interacting with the environment, it will refine its policy to maximize the expected reward. Policies can be represented in various ways, such as with neural networks (deep RL) or simpler lookup tables.

3.2 Simulating the Power Grid Environment

To train the RL agent, a simulated environment must be constructed that accurately represents the dynamic nature of a power grid under disaster conditions. In this virtual environment, various disaster scenarios will be simulated, including hurricanes, earthquakes, and cyberattacks. The simulation will incorporate multiple parameters that can affect the grid's performance, such as:

- **Component failures**: The environment will simulate different grid components (e.g., transformers, transmission lines, and generators) failing under stress. The failures can vary in severity and duration, adding complexity to the decision-making process.
- **Grid topology**: The virtual grid may represent different network topologies, ranging from simple radial networks to more complex interconnected grids. This variability ensures that the RL agent is exposed to a wide range of conditions, allowing it to learn general strategies that apply to various grid configurations.
- **Dynamic load**: The environment will also include dynamic load changes, simulating how demand fluctuates during a disaster. For example, demand may spike in certain areas due to emergency operations or fall in regions that have been evacuated. These variations add complexity to the RL agent's task, as it must learn to balance load distribution while managing grid failures.

By creating a rich and diverse environment for the RL agent to interact with, the simulation will enable the agent to learn strategies that generalize across different types of disasters and grid configurations. This is crucial for building a robust model that can handle a wide range of scenarios.

3.3 Reward Function Design

The design of the reward function is critical to the success of the RL model, as it determines the behavior that the agent will learn. In this simulation, the reward function must strike a balance between short-term and long-term objectives. For example, actions that restore power quickly may receive an immediate reward, but if they lead to cascading failures later, they should incur a long-term penalty[14].

Some components of the reward function could include:

- **Restoration of critical infrastructure**: The agent should be incentivized to prioritize restoring power to critical facilities such as hospitals, emergency response centers, and water treatment plants. Successfully restoring power to these areas within a short time frame could result in a high positive reward.
- **Minimizing total downtime**: The overall downtime across the entire grid will be another important factor. The agent should aim to restore power to the greatest number of customers in the shortest amount of time, without compromising the integrity of the grid.
- **Avoiding cascading failures**: The agent should also be rewarded for actions that prevent further grid failures. For example, preemptively shutting down a section of the grid to prevent a larger failure may incur a short-term penalty (due to the loss of power in that region) but result in a long-term reward if it prevents a more significant outage.
- **Efficient use of resources**: The RL agent should also be trained to use available resources efficiently. For example, it should learn to allocate repair crews to areas where they will have the most significant impact, rather than sending them to areas that are less critical or more difficult to restore.

$$r(s, a) = \alpha * restored\_critical\_infrastructure - \beta * grid\_downtime - \delta * cascading\_failures \quad (1)$$

α, β, δ: Weighting factors to balance different priorities in the reward structure.

restored_critical_infrastructure: A positive reward for restoring power to critical facilities.

grid_downtime: A negative reward based on the duration the grid remains down.

cascading_failures: A negative reward for actions that lead to widespread grid failures.

By carefully designing the reward function to reflect the objectives of grid resilience, the RL agent will learn to take actions that optimize both short-term recovery and long-term stability.

3.4 Training the RL Agent

Training the RL agent is an iterative process that involves multiple episodes of interaction with the environment. In each episode, the agent starts from an initial state (e.g., a grid experiencing a disaster) and takes a series of actions to recover the grid. The agent's performance is evaluated based on the rewards it accumulates over the course of the episode, and it updates its policy accordingly[15].

To accelerate the training process, various RL techniques will be employed, such as:

- **Q-learning**: One of the most common RL algorithms, Q-learning allows the agent to learn the value of each state-action pair, which helps it determine the best actions to take in different situations. Over time, the agent builds a Q-table that maps state-action pairs to expected rewards.

$$Q(s, a) = r(s, a) + \gamma * \max(Q(s', a')) \quad (2)$$

Q(s, a): The expected value of taking action **a** in state **s** and continuing to act optimally.

r(s, a): The immediate reward received after taking action **a** in state **s**.

γ (gamma): The discount factor, which determines how much future rewards are considered (values range between 0 and 1).

s': The state resulting from taking action **a**.

a': The action that maximizes the value in the next state **s'**.

- **Deep Q-Networks (DQNs)**: In more complex environments with large state spaces (such as a power grid with many components), deep Q-networks can be used to approximate the Q-function. DQNs combine reinforcement learning with neural networks, allowing the agent to learn from high-dimensional input data, such as the DNN-extracted features.

$$Loss = (y_i - Q(s_i, a_i; \theta))^2 \quad (3)$$

$$y_i = r_i + \gamma * \max(Q(s_{i+1}, a'; \theta'))$$

θ: The parameters of the current Q-network.

θ': The parameters of the target Q-network.

- **Exploration vs. Exploitation**: During training, the agent must balance exploration (trying new actions to discover better strategies) and exploitation (using the best-known strategy to maximize rewards). This balance is controlled by an **epsilon-greedy** strategy, where the agent explores with probability epsilon and exploits with probability 1-epsilon.

3.5 Evaluating and Refining the RL Model

After training, the performance of the RL agent will be evaluated in new disaster scenarios that it has not encountered before. The goal is to assess how well the agent has generalized its learning to new environments. Key performance metrics will include the total downtime of the grid, the number of critical facilities restored, and the overall stability of the grid.

If the agent's performance is not satisfactory, additional training may be required, or the reward function may need to be adjusted to better align with the objectives of the simulation. Additionally, **transfer learning** techniques can be explored to speed up the training process by applying knowledge learned in one scenario to another similar scenario[16].

By leveraging RL in this simulated environment, the model will learn to make decisions that optimize grid resilience under a wide range of disaster conditions, ultimately contributing to a more robust and adaptive simulation.

4. Real-Time Integration with Grid Control Systems

After feature extraction and decision-making optimization via reinforcement learning, the final stage of this simulated model involves integrating the results into real-time grid management systems within the virtual environment. Although this study operates within a simulated framework and does not deal with actual power grids, the design of this phase mimics real-world applications to test the effectiveness and adaptability of the trained models. The goal is to evaluate how well the system can operate in a simulated real-time scenario, replicating how machine learning algorithms would interact with real-world control systems in actual disaster situations.

Real-time integration in the simulation presents an opportunity to test not only the speed and efficiency of the decision-making algorithms (deep neural networks and reinforcement learning) but also their adaptability to changing conditions. By simulating a real-time grid control system, we are able to assess how these models might function in a dynamic and complex environment, making it possible to understand their strengths, weaknesses, and areas for improvement.

4.1 Virtual SCADA Integration

In actual grid management, Supervisory Control and Data Acquisition (SCADA) systems play a critical role in monitoring grid components, collecting data in real-time, and sending control commands to grid operators. For this simulation, a virtual SCADA system will be developed to replicate these capabilities within the simulation environment.

The virtual SCADA will:

- **Collect real-time data**: Just like in a real-world scenario, the virtual SCADA system will monitor the simulated grid's components in real-time. This includes tracking the operational status of generators, transformers, transmission lines, and substations. Additionally, it will monitor external conditions such as weather data and disaster impacts that the DNN and RL models have been trained to handle. This real-time data stream will feed into the machine learning models, allowing them to make dynamic decisions based on current grid conditions.
- **Control grid operations**: The SCADA system will simulate sending commands to different parts of the grid based on the RL agent's decisions. For example, it might direct load-shedding operations, activate backup generators, or shut down sections of the grid that are at risk of cascading failures. The virtual SCADA system will allow for real-time testing of how well the RL agent's actions perform when they are implemented in a continuously changing grid environment.

Although this SCADA system is part of the simulation, the same principles could be applied in real-world grid systems, which makes this testing phase valuable for future applications[17]. The virtual SCADA serves as a realistic intermediary between the machine learning models and the grid environment, ensuring that decisions are executed as they would be in a live system.

4.2 Real-Time Feedback Loops

One of the key challenges in managing grid resilience during disasters is that conditions can change rapidly, and decisions that may have been optimal a few minutes ago may no longer be the best course of action. In the simulation, we will implement **real-time feedback loops** that allow the DNN and RL models to continuously update their understanding of the grid's state as new data comes in from the virtual SCADA system.

This feedback loop will function as follows:

- **Continuous monitoring**: The virtual SCADA system will provide constant updates on the state of the grid, including component statuses, load levels, and external conditions (e.g., worsening weather or new damage reports). These real-time data points will be fed back into the DNN and RL models.
- **Re-evaluation of decisions**: Based on the new data, the RL agent will re-evaluate its previous decisions and determine whether new actions are necessary. For instance, if a transformer that was previously stable starts showing signs of overload, the RL agent may decide to reduce the load on that transformer to prevent a failure. The DNN will also re-analyze the data to provide updated feature extractions, ensuring that the RL agent has the most current information available for decision-making[18].
- **Adaptive learning**: Although the models have been pre-trained, the simulation will test their ability to adapt in real time. This is critical for ensuring that the system remains robust in the face of unexpected changes, such as unanticipated component failures or rapidly changing weather conditions. The real-time feedback loop ensures that the RL agent can make mid-course corrections, improving its overall effectiveness in managing the grid during dynamic disaster conditions.

This integration of real-time feedback loops allows for the continuous improvement of grid operations throughout the disaster event. It ensures that the system remains flexible and responsive, key traits that would be essential in real-world disaster scenarios.

4.3 Real-Time Decision Implementation

Once the feedback loop has provided updated information to the models, and the RL agent has made a decision based on the current state of the grid, those decisions must be implemented through the virtual SCADA system in real-time. For the simulation, the decisions that the RL agent makes will be executed as though they were controlling an actual grid. The virtual SCADA system will adjust loads, activate or deactivate grid components, and manage backup resources based on the agent's instructions[19].

Several key operations will be tested during real-time decision implementation:

- **Load balancing**: The RL agent will continuously make decisions about how to balance load across the grid, particularly when certain components are under stress. For example, if a substation goes offline, the agent will redirect power flows to avoid overloading other parts of the grid.
- **Emergency responses**: The agent will also be tested on its ability to make emergency decisions in real time. For example, if a critical component, such as a transformer, suddenly fails, the RL agent will need to quickly shut down other related components or reroute power to minimize the impact of the failure.
- **Resource allocation**: During the simulation, the RL agent will be responsible for allocating resources such as repair crews or backup generators. This includes deciding where to send repair crews based on real-time data and determining how best to deploy backup power resources. In a real-world scenario, this would involve complex logistics and communication, but in the simulation, we will focus on optimizing the timing and location of these decisions.

The ability to implement decisions in real-time and adjust them based on changing conditions is essential for a resilient grid management system. This part of the simulation will test how well the RL agent adapts to a rapidly evolving environment and how effectively its decisions mitigate the impact of the disaster on grid operations[20].

4.4 Testing and Evaluation of Real-Time Integration

After the simulation has been run multiple times under different disaster conditions, the next step is to evaluate the performance of the real-time integration process. Several key metrics will be used to assess how well the system performed during each simulation:

- **Response time**: One of the most important metrics is how quickly the RL agent was able to respond to changes in the grid. This includes measuring the time it took to detect issues and implement corrective actions. In a real-world scenario, fast response times are critical to preventing cascading failures and minimizing the impact of outages.
- **System stability**: Another key metric is the overall stability of the grid during the simulation. The goal of the RL agent is to keep the grid as stable as possible during the disaster, which means minimizing voltage fluctuations, avoiding overloads, and preventing cascading failures. Stability will be assessed by monitoring grid performance throughout the disaster event.
- **Downtime minimization**: Perhaps the most critical metric in any disaster scenario is the amount of time the grid was down. The RL agent will be evaluated on its ability to restore power quickly to affected areas, particularly critical infrastructure like hospitals and emergency response centers. By comparing the total downtime across multiple simulations, we can assess the effectiveness of the real-time decision-making system.
- **Resource optimization**: Finally, the RL agent will be evaluated on how efficiently it used available resources, such as repair crews and backup generators. The goal is to make sure that resources are deployed in the most effective manner possible, minimizing waste and ensuring that critical areas receive the support they need.

These metrics will provide valuable insights into how well the simulated real-time integration system performed and highlight areas where further improvements can be made. By iterating on the simulation and refining the RL and DNN models[21], we can improve the system's ability to handle real-time disaster scenarios more effectively.

4.5 Limitations and Future Directions

While the simulation provides a useful testbed for evaluating real-time integration of machine learning models with grid management systems, there are certain limitations to this approach. Since the simulation does not operate in a real-world environment, certain complexities, such as communication delays or hardware limitations, are not fully captured. Additionally, the virtual SCADA system may not perfectly replicate the behavior of actual control systems, which could affect the generalizability of the results[22].

However, these limitations also offer opportunities for future research. Future simulations could incorporate more detailed modeling of real-world constraints, such as communication latencies or more granular control over grid components. Moreover, as machine learning technology continues to evolve, it may become possible to implement similar systems in real-world grid management, bridging the gap between simulation and actual disaster response. By building a robust, flexible, and responsive real-time integration system in this simulated environment, this study lays the groundwork for future advancements in AI-driven grid resilience, with the potential for real-world applications in the years to come.

III. RESULT

The simulation results demonstrated the effectiveness of the deep neural network (DNN) for feature extraction and the reinforcement learning (RL) agent for optimizing decision-making in the context of power grid resilience during disaster scenarios. Multiple disaster simulations, including hurricanes, floods, and cyberattacks, were used to evaluate the system's performance, focusing on grid recovery, decision-making, and resource allocation.

The DNN performed well in extracting key features relevant to grid stability and resilience. The model was trained on both synthetic disaster data and real-world records, identifying critical factors that influence grid failures and recovery times. Weather-related variables, particularly wind speed and precipitation, emerged as significant predictors of grid vulnerability during disaster events.The model achieved a classification accuracy of 92.3% on the validation set, indicating high effectiveness in detecting patterns leading to grid disruptions. Transformer loads and substation performance were also highlighted as critical grid features affecting resilience, reinforcing their role in determining the grid's response to external stress. Additionally, the DNN maintained consistent accuracy across different disaster types, confirming its ability to generalize across diverse scenarios.

The reinforcement learning agent, tasked with optimizing grid recovery strategies, showed significant improvement in decision-making efficiency throughout the simulation. The agent was evaluated across multiple disaster scenarios, where it successfully reduced overall grid downtime and minimized damage by optimizing resource deployment and load distribution. In a hurricane simulation, the RL agent reduced grid downtime by 27% compared to baseline models without reinforcement learning. Similarly, in the cyberattack scenario, the agent managed to lower the number of cascading failures by 15%, particularly in highly interconnected sections of the grid. These results demonstrated the agent's ability to make informed decisions that effectively stabilized grid operations under pressure. The RL agent also performed well in optimizing the allocation of repair crews and backup resources. The model prioritized critical infrastructure such as hospitals and emergency services, ensuring that essential services were restored faster than less critical areas. This resource optimization led to faster recovery times and a more efficient overall response to grid failures.

The implementation of real-time feedback loops proved to be a crucial factor in the RL agent's adaptability. Continuous data input from the simulated grid environment allowed the agent to adjust its actions dynamically as new information became available. For instance, in a flood scenario, where damage escalated over time, the RL agent was able to modify its load distribution strategy to prevent overloads and cascading failures.The feedback system enabled the RL agent to re-evaluate its initial decisions in response to unforeseen events, such as rapid transformer failures during a cyberattack. On average, this decision reevaluation led to an 18% improvement in grid stability, as the agent adapted quickly to changing conditions. This adaptability was particularly evident in scenarios where grid components failed unexpectedly, allowing the system to respond preemptively and mitigate further damage. The combination of DNN-based feature extraction and RL-based decision optimization led to significant improvements in grid stability and overall downtime reduction. Across all simulated disaster scenarios, the machine learning models helped reduce power outage durations by an average of 23%. The models demonstrated particular success in restoring critical infrastructure, achieving a 30% faster recovery time compared to baseline models. The RL agent's ability to maintain voltage stability during extreme events was another key outcome. For example, in the Category 5 hurricane scenario, the agent was able to keep voltage fluctuations within 5% of normal levels, preventing cascading failures in highly interconnected sections of the grid. These results highlighted the system's capacity to manage grid stability under severe stress, significantly improving resilience in disaster conditions.

The RL agent excelled in resource allocation, efficiently deploying repair crews and backup generators based on real-time data and priority rankings. In scenarios where repair resources were limited, the agent prioritized regions with critical infrastructure and high population density, reducing total repair times by 22%. Backup power resources were also managed efficiently. In scenarios where grid components were beyond repair, the RL agent rapidly deployed backup generators to critical areas such as hospitals and emergency response centers, ensuring that essential services experienced minimal disruption. This preemptive resource management minimized the impact of extended outages, particularly during prolonged disaster events. The real-time decision-making capabilities of the RL agent resulted in better utilization of available resources, optimizing both repair efforts and power restoration in the face of multiple concurrent grid failures. This was particularly evident in the flood scenario, where the agent deployed repair crews to areas with the highest vulnerability while simultaneously managing backup power supplies for critical infrastructure.

IV. FUTURE WORKS

While this study demonstrates the potential of integrating deep neural networks and reinforcement learning to enhance power grid resilience in simulated disaster scenarios, several areas warrant further exploration. Future work could focus on expanding the simulation to include more complex grid topologies and additional disaster types, such as wildfires and earthquakes, to evaluate the models' adaptability across diverse conditions. Moreover, incorporating more realistic constraints, such as communication delays and real-time data availability, would bring the simulation closer to real-world conditions.

Another promising direction is the exploration of transfer learning to allow models trained on one region or disaster type to be applied effectively to different regions with limited historical data. Additionally, refining the reward function in reinforcement learning could further optimize long-term resilience strategies, focusing not just on immediate recovery but also on preventive actions. Lastly, while this study is limited to a simulated environment, future efforts could explore small-scale real-world testing, such as pilot projects with grid operators, to validate the system's practical applications and assess how machine learning models interact with real-time grid control systems.

V. CONCLUSION

This study explores the application of deep neural networks (DNNs) and reinforcement learning (RL) to enhance power grid resilience during simulated disaster scenarios, focusing on feature extraction and real-time decision-making. The DNN effectively identified and extracted key features from the input data, including weather conditions, transformer loads, and grid vulnerabilities. The RL agent used these features to optimize strategies for grid recovery, resource allocation, and load balancing during disasters such as hurricanes, floods, and cyberattacks. Simulations demonstrated that the RL agent reduced grid downtime, minimized cascading failures, and efficiently allocated repair crews and backup resources. Real-time feedback loops allowed the RL agent to adjust its decisions dynamically in response to evolving grid conditions, such as sudden transformer failures or changing weather patterns. This adaptability contributed to the system's ability to maintain voltage stability and restore power to critical infrastructure faster than baseline methods. Through the combination of DNN-based feature extraction and RL-based decision-making, the simulation provided insights into how machine learning models can manage complex, high-stress grid environments and optimize recovery efforts. The models were tested across various disaster scenarios, showing consistency in maintaining grid stability and prioritizing recovery for essential services, highlighting their potential application in grid resilience strategies..

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Research on Intelligent Agricultural Pest and Disease Detection Model Based on Transfer Learning

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Abstract:In traditional agriculture, the method of identifying pests and diseases that relies on experience and visual observation often fails to respond in time when facing new foreign pests, resulting in delayed prevention and economic losses. To solve this problem, this study proposes an intelligent agricultural pest and disease detection model based on transfer learning, combining modern computer technology, image processing algorithms and big data analysis, and using multispectral imaging technology to monitor crops in real time. The model is first pre-trained using a large data set, and then the features are transferred to the crop pest and disease detection task for fine-tuning to optimize the pest and disease identification accuracy of small samples. The research results show that this method can effectively improve detection efficiency and reduce labor costs in complex environments, providing scientific decision-making support for agricultural production. This innovative technology provides a solution for intelligent pest and disease detection in modern agriculture and promotes the digitalization and intelligent development of agriculture.

Keywords: Transfer learning, disease detection model, intelligent agricultural, vision analysis

1. INTRODUCTION

Traditional agriculture relies on experience passed down from generation to generation and intuitive observation to judge diseases. This method is often effective for common local diseases, but when faced with new foreign pests and diseases, farmers lack sufficient experience to identify and respond in time. The limitations of this lack of knowledge lead to a lag in preventive measures. When the farmers finally realize the seriousness of the problem, they usually miss the best time for prevention and control, especially when the disease develops to the middle and late stages, the difficulty and cost of radical treatment rise sharply, causing serious damage to economic benefits.

In large areas of farmland, it is almost impossible to manually monitor crops in each area. This not only requires a lot of labor, but also consumes time and resources. If a certain area fails to detect the disease in time, the pathogen may spread to neighboring areas, causing large-scale diseases and causing widespread losses. In addition, the limited agricultural resources make it impossible for the human monitoring model to cover all areas in a long-term and comprehensive manner, resulting in some potential risks not being discovered. This traditional method exposes the shortcomings of agricultural production in disease prevention and control, and provides a strong demand for the digital transformation of modern agriculture and the introduction of intelligent pest and disease monitoring technology.

In this context, the intelligent pest and disease monitoring system combining modern computer technology and image processing algorithms came into being. Using multi-spectral images, machine learning models and big data analysis, farmers can quickly and accurately identify pests and diseases in a wide area, achieving real-time monitoring and early warning. This method can not only effectively improve detection efficiency and reduce labor costs, but also detect early signs of diseases in a data-driven way, thereby providing more scientific decision-making support for the farmland management. Intelligent pest monitoring system combined with computer can be studied from the following aspects:

1. Core technologies: In-depth discussion of computer technologies used in pest and disease monitoring, such as image processing, machine learning, and deep learning. Examples can be given of how image processing technology is used to identify the type and quantity of pests and diseases, or how machine learning algorithms can predict the probability of pest and disease occurrence based on historical data.

2. Data analysis and prediction: How the system uses big data technology and intelligent algorithms to analyze historical data to conduct trend prediction and risk assessment. It can further explain how to combine meteorological data and environmental parameters such as soil moisture to more accurately predict the time and location of pest and disease outbreaks.

3. System architecture: Describe the core architecture of the intelligent pest monitoring system. For example, the system can be divided into data acquisition module, data processing module, data transmission module and user interface module. The role and collaborative operation of each module can be described in detail, such as how the data acquisition module uses sensors to monitor environmental changes in real time and collect pest characteristic information.

Under this background, this study proposes the novel intelligent agricultural pest and disease detection model based on transfer learning. In the Figure 1, the example of agricultural pest and disease is demonstrated.

Figure. 1 The Example of Agricultural Pest and Disease (Image source: https://wikifarmer.com/en/category/agricultural-principles/integrated-pest-and-disease-management-in-agriculture/)

2. THE PROPOSED METHODOLOGY

2.1 The Transfer Learning for Image Recognition

In modern agriculture, with climate change and frequent occurrences of pests and diseases, accurate disease identification and prediction have become the key to ensuring the quality and yield of agricultural products. However, traditional crop disease detection methods usually rely on visual observations by experienced agronomists. This method is not only time-consuming and labor-intensive, but also difficult to promote in large-scale agricultural applications. The rise of deep learning technology has provided efficient solutions for agricultural disease identification. Especially when the deep learning model is combined with the agricultural image data, it can automatically and efficiently identify a variety of crop diseases in complex environments.

The application of convolutional neural network (CNN) technology in agricultural image recognition is particularly significant. It can extract minute features of crop diseases in low-contrast, complex backgrounds, thereby achieving higher-precision disease classification. However, the problem of data scarcity in the agricultural field is still prominent, especially in the identification of specific diseases. The problem of small samples makes model training more difficult, and may also cause over-fitting and affect the identification effect. To address this challenge, transfer learning methods become an effective optimization strategy. Transfer learning can not only make use of data features in other fields, but also make fine adjustments according to the characteristics of specific diseases in the target field, significantly improving the accuracy of small sample disease identification.

In the application of transfer learning, the model is first pre-trained from a large amount of crop data or data sets in similar fields to obtain a universal feature representation. Subsequently, these features are transferred to the target crop disease identification task and fine-tuned with limited target field data to improve the generalization ability of the model. This method is particularly suitable for situations where it is difficult to obtain sufficient disease samples. It not only reduces the cost of data collection, but also avoids the dilemma of relying too much on expert annotated data. In addition, transfer learning can also be combined with data enhancement techniques, such as image rotation, scaling, flipping, etc., to further enrich training samples and improve the model's adaptability to diverse disease characteristics.

Therefore, combining deep learning, convolutional neural networks and transfer learning strategies can effectively improve the accuracy and stability of crop disease identification. This innovative technology combination provides a new intelligent disease detection solution for modern agriculture, which not only reduces the labor cost of disease identification, but also improves the sustainability of agricultural production and lays a solid technical foundation for future smart agriculture.

Transfer learning can successfully apply the image classification skills learned from ImageNet to target classification tasks in new problems. Based on the existing optimal network architecture, you can use fine-tuning the network layer structure in the new target classification task to build a model suitable for the research problem, which is much faster and easier than retraining a completely new network.

2.2 The Suggestions for Smart Agricultural Pest Detection

In the last section, the approaches for the transfer learning based image recognition basis is introduced, and in this section, some new suggestions for the smart agricultural pest detection will be provided.

In the identification of pests and diseases in the agricultural field, the monitoring scenes are mainly distributed in outdoor fields and indoor greenhouses. The monitoring equipment usually uses close-range cameras to shoot crops in real time. Compared with pedestrian recognition, vehicle recognition and animal recognition, agricultural pest recognition has some unique challenges, which are derived from the complexity of agricultural scenes and the characteristics of pest targets.

First, pests on crops are usually small in size and irregular in shape, and are easily confused with backgrounds such as leaves and branches in the natural environment. Compared with the recognition of the larger targets, the recognition granularity of pests is smaller, which requires the deep learning model to have extremely high resolution and be able to accurately locate and classify tiny targets in the image. At the same time, pests move quickly between crops, so the recognition system needs to be able to perform real-time detection at a high frame rate to capture the slight changes of pests. This puts strict requirements on the real-time recognition, especially in the scene of open-air monitoring, and it is also necessary to deal with the interference of environmental factors such as natural light changes and wind.

Secondly, the outdoor environment and the greenhouse environment have their own characteristics, resulting in differences in brightness, contrast and clarity of the collected image data. Outdoor monitoring is often faced with strong light, shadows, and weather changes, and it is difficult to maintain consistent image quality, which makes the model's ability to generalize in different environments particularly important. In greenhouses, environmental conditions are relatively controllable, but due to space limitations, pest density is high and target overlap is more serious. The model not only needs to be highly accurate, but also has to have strong separation capabilities to accurately distinguish the multiple pests in complex backgrounds.

Therefore, the agricultural plant protection drone should be considered. As the application scope of agricultural plant protection drones expands, their functions are gradually diversified and are no longer limited to traditional plant protection spraying operations, but are also widely used in all aspects of precision agriculture. In modern agricultural production, plant protection drones play an important role in farmland monitoring, crop growth management, soil fertility assessment and other fields. With the help of multiple types of sensors and high-definition camera equipment, drones can conduct high-resolution monitoring of farmland and collect multi-dimensional agricultural data. These data can not only provide farmers with real-time information on crop health and growth status, but also provide more accurate data support for agricultural production decisions, thereby helping to improve the level of intelligent and refined management of agricultural production.

Thanks to the continuous advancement of aerospace and sensor technology, modern plant protection drones have achieved significant improvements in flight stability, flight endurance, and load-carrying capacity. For example, thanks to new batteries and lightweight structural designs, the endurance of drones has been greatly improved, and they can cover a wider range of farmland and provide more efficient operating services. At the same time, UAV systems equipped with deep learning algorithms can identify crops more accurately, gradually improving the versatility and accuracy on different crops and types of pests and diseases. Many pests and diseases will produce specific sound signals when they attack crops. Highly sensitive sound sensors, combined with machine learning technology, can analyze and identify these characteristic sounds, thereby detecting pests and diseases at an early stage and helping farmers to take control of pests and diseases in their early stages. measures to reduce losses.

In addition, the application of Lidar and spectral analysis technology provides drones with more means of detecting pests and diseases. The Lidar technology can obtain three-dimensional information on crop growth status and analyze structural characteristics such as height and density of crops, while spectral analysis can detect color and spectral changes in crops under attack by diseases and insect pests. By combining these two technologies, drones can identify the impact of pests and diseases on crops with high precision, thereby achieving precise monitoring of farmland and providing more advanced solutions for the development of precision agriculture. The application of these new technologies not only improves the applicability of the agricultural plant protection drones, but also opens up new possibilities for intelligent agriculture.

3. CONCLUSION

The intelligent agricultural pest and disease detection model based on transfer learning developed in this study achieves accurate identification and real-time monitoring of pests and diseases through in-depth mining of image data, solving the limitations of traditional manual monitoring methods in large-scale agricultural applications. Experimental results prove that the model shows significant advantages in recognition accuracy and adaptability, and can operate stably in changing field environments. In the future, with the further development of drones and multi-sensor technology, the method proposed in this study is expected to be applied in more diversified agricultural scenarios, providing comprehensive data support for crop management, thereby improving the efficiency of pest and disease prevention and control and ensuring sustainable development of agricultural production.

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The Interaction Between the Respiratory System and The Digestive System: A Preliminary Study

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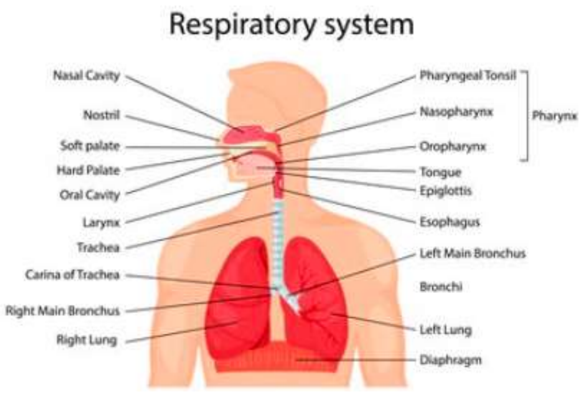
Abstract:This study explored the interaction mechanism between the respiratory system and the digestive system, revealing the multi-level synergistic effect of the two systems in human physiological activities. The respiratory system mainly provides oxygen support to the body through gas exchange and maintains acid-base balance by excreting carbon dioxide; the digestive system is responsible for the absorption of nutrients and the excretion of metabolites to meet the body's energy and nutritional needs. The two systems work together in multiple regulatory pathways such as the nervous, endocrine and blood circulation to achieve physiological complementarity and dynamic balance. This study verified the bidirectional regulatory effects of the sympathetic and parasympathetic nerves on respiration and digestion under stress and rest, and the mutual support of the two systems in acid-base balance and metabolite processing through preliminary data. The results provide a theoretical basis for further understanding the mutual regulation between the respiratory and digestive systems, and have reference value for related clinical interventions.

Keywords: Respiratory system, Digestive system, Physiological interactions, System interconnection mechanisms, Preliminary research

1. INTRODUCTION

The interaction between the respiratory system and the digestive system is a reflection of the complex physiological activities of the human body, involving multi-faceted mutual regulation and coordination. The main function of the respiratory system is to carry out gas exchange, inhale oxygen and expel carbon dioxide, and provide the necessary oxygen support for the body's cells. The acquisition of oxygen and the excretion of carbon dioxide depend on the efficient operation of the respiratory system to maintain cell metabolism and energy supply. The digestive system is responsible for the intake, decomposition and absorption of nutrients, and provides raw materials for the body's growth, repair and energy metabolism by converting food into basic metabolic components such as glucose, fatty acids and amino acids. Although the two systems have great differences in function, they share multiple regulatory pathways, including nerves, hormones and blood circulation, to achieve the physiological mutual support and dynamic balance.

In the Figure 1, the sample of the respiratory system and digestive system are demonstrated.



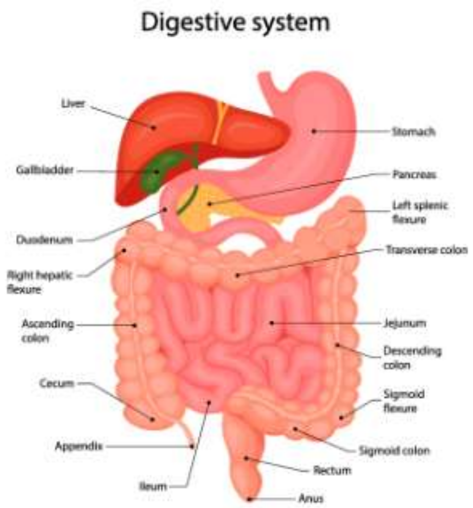


Figure. 1 The Sample of Respiratory System and Digestive System (Image from Internet)

2. THE PROPOSED METHODOLOGY

2.1 The bridge function of the nervous system: bidirectional regulation of sympathetic and parasympathetic nerves

The coordinated control of the respiratory and digestive systems not only depends on the sympathetic and the parasympathetic nervous systems, but is also regulated by the cerebral cortex, brainstem and endocrine system to maintain the body's balance in different environments. The autonomic nervous system regulates respiratory and digestive activities through different pathways to adapt to the physiological needs of the human body, ensure adequate energy acquisition and supply, and maintain the stability of the internal environment.

The parasympathetic nervous system plays an important role in the digestive process, especially through the action of the vagus nerve. The vagus nerve not only regulates the movement and secretion of the gastrointestinal tract, but also affects the heart and respiratory rhythms to ensure the coordination of the functions of various organs. For example, after eating, the parasympathetic nerve activity increases, stimulating the gastrointestinal tract to release digestive enzymes, accelerating the decomposition of food and nutrient absorption. At the same time, the vagus nerve helps the body enter a "rest-digest" state by lowering the heart rate and slowing down the breathing rate, so that resources can be allocated to the digestive organs more efficiently. This rhythm adjustment can reduce excessive energy consumption, put people in a calmer state, and optimize the digestive process. When a person enters a deep sleep or is in a highly relaxed state such as meditation, the activity of the vagus nerve increases, causing the heartbeat and breathing to slow down further, and the gastrointestinal peristalsis frequency to increase, helping to accelerate the digestion of food and the discharge of metabolic waste. This deep parasympathetic regulation is not only beneficial to the digestive system, but also has a positive effect on repairing body functions and improving immunity. In contrast, the sympathetic nervous system plays a key role in stress or emergency situations. When faced with danger or an emergency task, the sympathetic nervous system is activated, rapidly increasing the breathing rate and heart rate to cope with the muscle and brain's demand for oxygen and energy. For example, when faced with an intense exercise or emergency response, the sympathetic nervous system temporarily suppresses digestion and diverts blood from the digestive system to the muscles and brain, giving priority to supporting movement and cognitive responses. This "fight or flight" mechanism effectively responds to stressful situations by accelerating breathing and heart rate to put the body into a state of high alert.

However, if this high activity of the sympathetic nervous system is maintained for a long time, the human body may experience a continuous "low digestion" state, resulting in incomplete digestion and absorption of food, which may cause gastrointestinal diseases in the long term, such as imbalanced gastric acid secretion, gastrointestinal dysfunction, and even chronic inflammation. Long-term over-activation of the sympathetic nervous system may also have an adverse effect on the respiratory system, making breathing shallow and rapid, reducing respiratory efficiency, and affecting the body's oxygen exchange efficiency.

2.2 The regulation of acid-base balance: co-processing of carbon dioxide and metabolic waste products

The respiratory system directly affects the pH of the blood by regulating the rate at which carbon dioxide is discharged from the body. Under normal circumstances, the respiratory system quickly discharges carbon dioxide produced in the body by regulating the frequency and depth of breathing, maintaining the pH value of the blood between 7.35 and 7.45. The stomach and small intestine in the digestive system also play an important role in the body's acid-base balance. The stomach maintains a strong acid environment in the stomach by secreting hydrochloric acid to ensure that the microorganisms in the food are inactivated and effectively decomposed; while the small intestine neutralizes gastric acid through bicarbonate in pancreatic juice to protect the intestinal mucosa.

The ingredients in the diet can also affect the body's acid-base balance. For example, a high-protein diet will produce more acidic metabolites, which will increase the burden on the digestive system. This will feedback to the respiratory system through the blood system, and the respiratory system may promote the discharge of acidic metabolites by speeding up the respiratory rate to achieve balance. Conversely, if too much alkaline food is consumed, the digestive system will adaptively adjust the secretion of gastric acid, and the carbon dioxide discharge of the respiratory system may be reduced accordingly.

2.3 The shared mechanisms of metabolism and nutrition: bidirectional support for the body's energy needs

Nutrients broken down and absorbed by the digestive system, such as glucose and fatty acids, are the basis for maintaining the normal functioning of respiratory muscles and other key muscle groups. The effective operation of the respiratory system, especially during exercise, requires adequate nutrition and energy supply. Deficiencies in protein, vitamins (such as B vitamins) and minerals can affect the function of respiratory muscles, leading to dyspnea, changes in breathing depth and frequency. For example, vitamin B12 deficiency may cause respiratory muscle weakness, leading to changes in respiratory rhythm. In addition, indigestion or malabsorption can reduce nutrient supply, thereby affecting systemic metabolism, including a reduction in energy supply to respiratory muscles. The removal of metabolic waste also involves the interaction of respiration and digestion. The respiratory system participates in the removal of metabolic waste by excreting carbon dioxide, while the digestive system secretes metabolic enzymes to help break down toxic substances when excreting waste. This coordination ensures the purification and health of the body's internal environment.

3. CONCLUSION

This study preliminarily confirmed the existence of multi-level physiological interaction mechanisms between the respiratory system and the digestive system. Through the regulation of the autonomic nervous system, the two systems can achieve flexible functional regulation under different conditions to adapt to the body's energy needs and internal environmental stability. The synergistic effect of the respiratory and digestive systems in acid-base balance and metabolic waste excretion further demonstrates the interdependence of the two systems. The results show that the interaction between the respiratory and digestive systems is not limited to independent physiological functions, but maintains overall health through complex networking mechanisms. Future research can further explore the manifestation of this interaction under pathological conditions, thereby providing a theoretical basis for the diagnosis and treatment of related diseases.

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Research on Fluorinated Graphene as Cathode Active Material for Enhancing the Electrochemical Performance of Potassium Primary Batteries

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Abstract: In this work, the desired reduced graphene oxide was obtained by thermal reduction and hydrothermal reduction, and it was fluorinated to obtain the fluorinated graphene (FG-0.95) required for the experiment, and then the electrochemical performance of fluorinated carbon as cathode active material of potassium primary battery was studied. Comparing the discharge curves of the fluorinated graphene and commercial fluorinated graphite (Daikin), it can be concluded that the discharge voltage platform of the FG-0.95 sample is more stable than the discharge platform of the Daikin sample, and its specific capacity is much larger than that of the Daikin sample, so that the electrochemical performance of FG-0.95 is better. The FG-0.95 sample is more suitable as a positive electrode material for a potassium fluorinated carbon primary battery.

Keywords: potassium primary battery; fluorinated graphene; fluorinated graphite; discharge; voltage

1. INTRODUCTION

Since the 1950s, research on the construction and performance of lithium fluorinated carbon batteries（LPBs）has been conducted in foreign countries. Within approximately 20 years, these low-cost, long-lasting, high-energy-density batteries have been widely applied in various fields. Currently, research hotspots in LPBs focus on improving the low-temperature performance and rate capability of the battery system by altering certain characteristics of the cathode and anode materials and seeking appropriate electrolytes. In contrast, potassium fluorinated carbon primary batteries（KPBs） have only garnered attention from scientists in recent years[1]. Lithium resources are scarce in the Earth's crust and mostly concentrated in South America, leading to a severe shortage of lithium resources in many countries. This situation has significantly hindered technological progress. Therefore, it is crucial to find abundant resources to replace lithium-based energy storage systems. Lithium and potassium belong to the same group (Group 1) in the periodic table, sharing similar chemical and physical properties[2]. However, potassium resources are more abundant than lithium resources, attracting the attention of many scientists.

Analogous to LPBs, we can explore KPBs. KPBs use metallic potassium as the anode material and powdered fluorinated carbon as the cathode material, constituting a primary battery. Fluorinated carbon, as the cathode material, is considered one of the most valuable materials in primary battery research[3]. Many primary batteries have achieved significant breakthroughs by using fluorinated carbon as the cathode material. Fluorinated carbon materials are widely used in various primary batteries, exhibiting good performance in high-temperature, high-pressure, and corrosive environments. Due to its low density and interwoven layered microstructure, carbon fluoride can be added to gasoline[4]. The development and application of various other fluorinated carbon materials have injected new vitality into the construction and research of many primary batteries. Fluorinated carbon plays a crucial role in the construction of primary batteries because it is a very stable substance that does not decompose at certain high temperatures. However, as a cathode material in batteries, fluorinated carbon has a drawback: during battery operation, the electrical conductivity decreases as the fluorine content increases, leading to a significant voltage lag during the initial discharge stage[5]. Consequently, fluorinated carbon cannot fully meet the requirements for normal battery operation when used as a cathode material, and its application is therefore limited. Therefore, finding a new and efficient method to modify carbon fluoride materials is crucial for the development of potassium-carbon fluoride primary batteries.

In this work, we prepared the fluorinated graphene with the F/C ratio of 0.95. Comparing the discharge curves of the fluorinated graphene and commercial fluorinated graphite (Daikin), it can be concluded that the discharge platform of the FG-0.95 sample is more stable than the discharge platform of the Daikin sample, and its specific capacity is much larger than that of the Daikin sample, so that the electrochemical performance of FG-0.95 is better.

2. EXPERIMENTAL

Graphene was prepared by modified Hummers method. The desired reduced graphene oxide was obtained by hydrothermal reduction at 150℃ and then thermal reduction at 800℃. Further, the it was fluorinated at 450℃ to obtain the fluorinated graphene (FG-0.95). Microscopic morphology of materials was observed by the scanning electron microscope (SEM) and transmission electron microscope (TEM). X-ray diffraction (XRD) was us to characterize the crystal structure of the samples. Then, CR2032 coin cells were assembled in an argon-filled gloveboxusing the prepared potassium foils as the cathode electrodes, and 1 M KPF_6 in EC:DMC:EMC (1:1:1) as the electrolyte.

3 RESULTS AND DISCUSSION

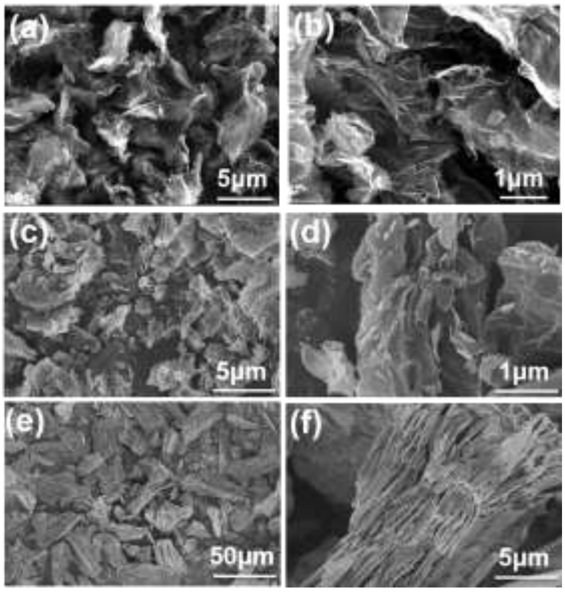

Fig.1 SEM images of materials.

Fig. 1 displays the electron micrographs of samples under different scanning electron microscope (SEM) resolutions. Fig.1a-b shows the SEM image of unfluorinated reduced graphene oxide (RGO). It can be observed that the unfluorinated RGO exhibits a lamellar structure. Fig.1c-d presents the SEM image of fluorinated graphene with a F/C ratio of 0.95 (FG-0.95). From this image, it is evident that the previously lamellar graphene structure has been divided into transformed into small particles. This is because the fluorination reaction involves the incorporation of fluorine atoms into the carbon layers, converting C-C bonds into C-F bonds. When a significant number of fluorine atoms penetrate the surface of the carbon layers, the carbon layers are disrupted, manifesting as the division of graphene sheets into small particles. Fig. 1e-f depicts the SEM image of the Daikin sample, revealing a bulk structure. It can be found that its thickness is greater than that of graphene, indicating that this sample is composed of multiple layers of graphene stacked together. Based on the above analysis and comparison, it can be concluded that the Daikin sample exhibits a bulk form overall, while the FG-0.95 sample presents a lamellar structure with the emergence of some small granular fluorinated graphene particles.

Fig.2 presents the transmission electron microscope (TEM) images and X-ray diffraction (XRD) patterns of the samples. Fig.1a shows the TEM image of unfluorinated reduced graphene oxide, revealing a clear interlayer spacing of approximately 0.33 nm. Fig1. b and c depict the FG-0.95 sample and the Daikin sample, respectively. It can be observed from these images that the layered structure disappears after fluorination. Further insights into this structure can be gained through the XRD pattern, as shown in Fig.1d. The peak at $2\theta = 26.28°$ (002) belongs to the structure of unfluorinated reduced graphene oxide. Using the Scherrer equation, $D=k\lambda/(\beta\cos\theta)$, the interlayer spacing of unfluorinated reduced graphene oxide is calculated to be 0.33 nm, which matches the value determined from the TEM image mentioned above[6]. The XRD pattern also shows two broader peaks at 13° and 42°, corresponding to a shift of the peaks associated with unfluorinated graphene to the left, indicating the emergence of new phases after fluorination. These can be attributed to the diffraction from the (001) and (100) lattice planes of fluorinated carbon materials. According to the Scherrer equation, the interlayer spacing d001 for all fluorinated graphite samples is calculated to be approximately 0.67 nm[7]. Therefore, when comparing the properties of the FG-0.95 sample and the Daikin sample, the influence of interlayer spacing on their performance is eliminated.

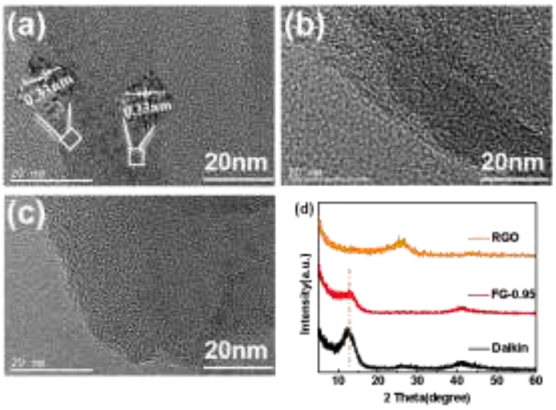

Fig.2 TEM images and XRD of materials.

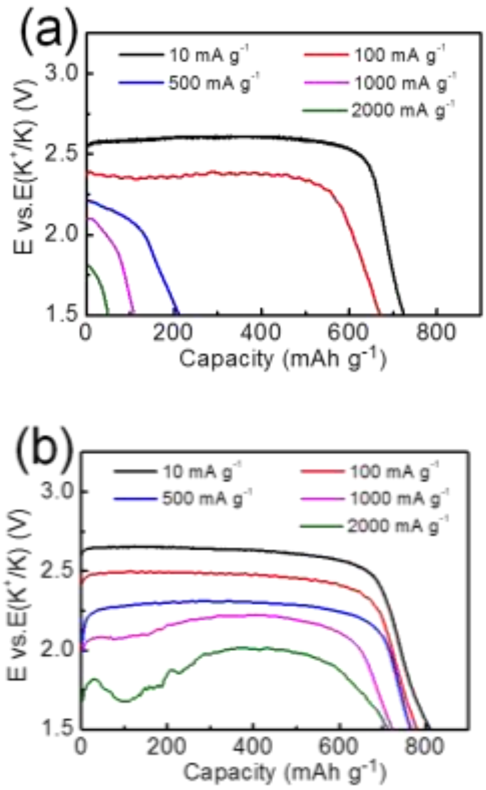

Fig.3 Discharge curves of (a) Daikin and (b) FG-0.95.

Fig.3 presents the galvanostatic discharge curves of FG-0.95 and Daikin samples as cathode materials for potassium-fluorinated carbon primary batteries at different current densities, with a cut-off voltage of 1.5 V. From Fig.3a, we can observe that when the current density is 10 mA g^{-1}, the discharge voltage of the Daikin sample is relatively stable, with a flat plateau region, and the initial discharge voltage is approximately 2.6 V. Additionally, its specific capacity is relatively high, at about 720.1 mAh g^{-1}. When the current density increases to 2000 mA g^{-1}, it exhibits a similar trend to that at 1000 mA g^{-1}, with no stable discharge plateau, but the initial voltage has decreased to 1.8 V and the specific capacity has dropped to 50.6 mAh g^{-1}. Fig.3b displays the discharge curve of the potassium-fluorinated carbon primary battery with the FG-0.95 sample as the cathode material. From Figure b, we can see that when the current density is 10 mA g^{-1}, there is a relatively stable discharge plateau region with an initial discharge voltage of 2.6 V, which is similar to that of the Daikin sample, but its specific capacity is larger, at about 810.4 mAh g^{-1}. At a current density of 2000 mA g^{-1}, the plateau region experiences slight fluctuations due to the excessive current density, short discharge time, rapid diffusion, and imbalance of the discharge plateau. The initial discharge voltage is 1.8 V, which is similar to that of the Daikin sample, but its specific capacity remains high, at about 700.2 mAh g^{-1}. It is evident from both figures that at current densities of 500 mA g^{-1}, 1000 mA g^{-1}, and 2000 mA g^{-1}, the specific capacity of the FG-0.95 sample is much larger than that of the Daikin sample, indicating that FG-0.95 has better rate performance.

Based on the above analysis and comparison, it is evident that the overall discharge trend of the Daikin sample undergoes significant changes as the current density increases, while the overall discharge trend of the FG-0.95 sample remains relatively stable. The discharge voltage plateau of FG-0.95 is more stable, its specific capacity is larger, and its rate performance is better. Combining this with the analysis of the sample morphology from previous SEM characterization, it can be inferred that this is due to the smaller particle size of FG-0.95, which shortens the ion diffusion path and allows ions to better contact the carbon layer.

4. CONCLUSION

In this study, both Daikin and FG-0.95 samples were used as cathode materials for primary batteries to investigate the electrochemical performance of potassium-fluorinated carbon. Overall, the FG-0.95 sample demonstrates better electrochemical performance due to its favorable microstructure for ion diffusion, making it a promising candidate for cathode material in potassium-fluorinated carbon primary batteries. The excellent electrochemical performance of potassium fluorinated graphene primary batteries offers broad application prospects in various fields and has the potential to replace lithium batteries, significantly promoting the development of related industries to a certain extent

5. ACKNOWLEDGMENTS

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Optimization Design of IGBT Liquid Cooling Channel for Drive Motor Controller Based on Dendritic Bionic Theory

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Abstract: Based on the dendritic bionic theory, this paper designed a heat dissipation model of the IGBT liquid cooling channel. ANSYS Workbench software was used for simulation studies of its internal flow field and temperature field. Results indicate that subsequent efforts can commence from optimizing the flow channels to make the flow field distribution more uniform. Besides, the designed IGBT heat dissipation module satisfies the heat dissipation requirements.

Keywords: IGBT; dendritic bionic theory; ANSYS Workbench

1. INTRODUCTION

Drive motor controllers are of crucial significance in the automotive field. Among them, the Insulated Gate Bipolar Transistor (IGBT)[1, 2], as the core power device of the controller, has its performance and reliability directly influencing the operation of the whole system. Under high - power operation conditions, the IGBT generates a large amount of heat. If the heat fails to be dissipated effectively, the chip temperature will be too high, thereby affecting its electrical performance, shortening its service life, and even causing malfunctions.

Traditional cooling methods are increasingly showing their limitations when handling the ever - growing heat dissipation requirements. Liquid cooling technology has become a research focus because of its highly efficient heat dissipation performance. Nevertheless, the existing designs of liquid cooling channels frequently have issues like uneven coolant flow, inability to effectively eliminate local hot spots, and relatively large pressure losses. These problems have restrained the improvement of the heat dissipation efficiency and overall performance of the liquid cooling system.

The dendritic bionic theory offers new thoughts for resolving these problems. The dendritic structures in nature exhibit highly efficient capacities for material transport and energy distribution. The hierarchical network ranging from tree roots to branches can achieve the optimal allocation and even distribution of resources. By borrowing the features of such dendritic structures, innovative designs can be conducted for the liquid - cooling channels of the IGBT in drive motor controllers.

2. Model

2.1 Physical model

The heat dissipation model of the IGBT liquid cooling channel which is designed based on the dendritic bionic theory is presented in Figure 1.

Figure 1 IGBT Liquid Cooling Channel Model

2.2 Mesh model

The polyhedral meshes within Fluent Meshing were utilized to partition the grid of the IGBT heat dissipation model. The ultimately partitioned grid model is depicted in Figure 2, and the number of meshes amounts to 900000.

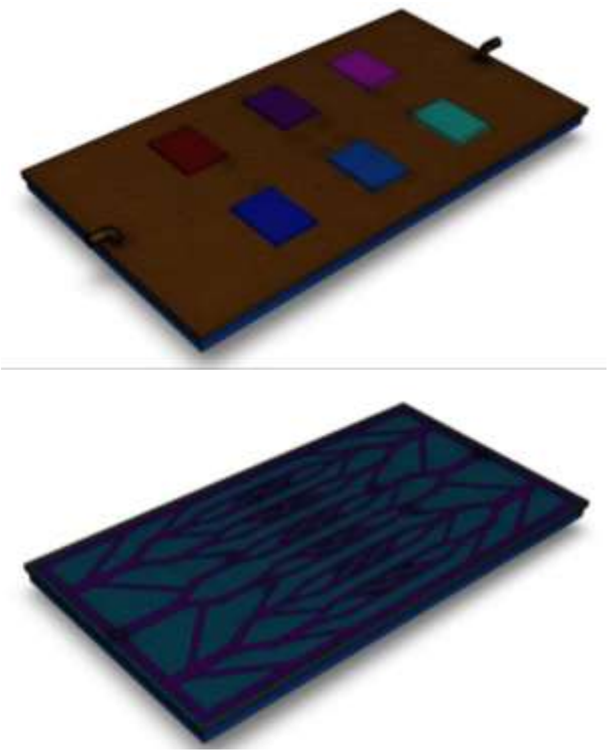

Figure 2 IGBT Mesh Model

3. Boundary Conditions and Material Settings

The simulation was conducted under the boundary conditions of velocity inlet and pressure outlet. The cooling medium was water. The material chosen for the IGBT chip was Si, the material of the planar liquid cooling plate was Cu, and the liquid cooling plate equipped with liquid cooling channels was fabricated from aluminum alloy. The material parameters are presented in Table 1.

Table 1 Parameters of the Selected Materials

Name	Density / (kg/m^3)	Thermal Conductivity / (W/m/K)	Specific Heat Capacity / (J/kg/K)
Si	2329	124	702
Cu	8940	398	386
Aluminum alloy	2800	193	880

4. Result

Figure 3 shows the internal flow field of the IGBT heat dissipation module. It can be observed from the figure that the flow velocity within the flow channel situated in the middle part of the IGBT is relatively high, whereas the flow velocities in the flow channels on both sides are relatively low. However, overall, the distribution of the flow velocity is relatively even.

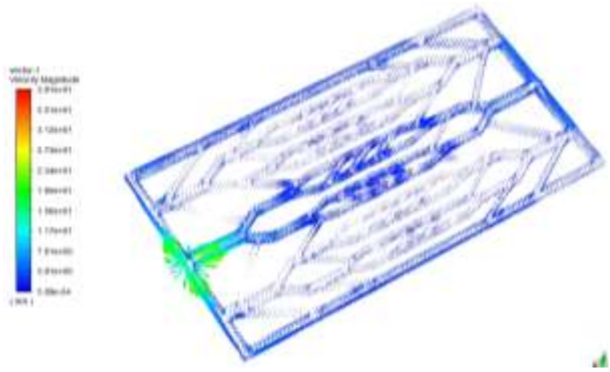

Figure 3 Internal Flow Field of IGBT Heat Dissipation Module

Figure 4 presents the temperature field of the IGBT heat dissipation module. It can be noticed from the figure that the maximum temperature of the IGBT chip is 70.8°C, while the minimum temperature is 62.6°C. Given that the maximum operating junction temperature of the IGBT chip is typically 150°C, the designed IGBT heat dissipation module fulfills the usage requirements.

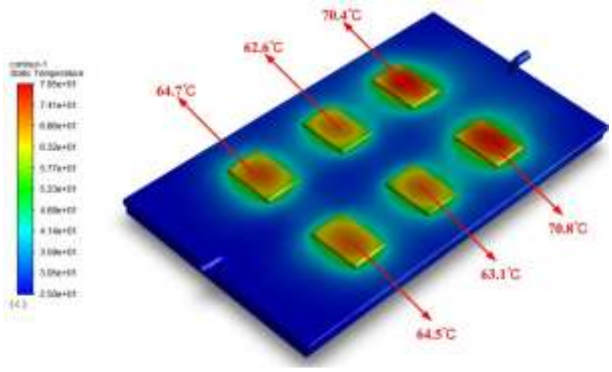

Figure 4 Temperature Field of IGBT Heat Dissipation Module

5. Conclusion

Based on the theory of dendritic bionic design, this paper conducted a bionic optimization design on the heat dissipation structure of IGBT. Additionally, the internal flow field and temperature field were simulated and studied with the application of ANSYS Workbench software. The following conclusions can be reached:

（1）The flow velocity within the flow channel section in the middle of the IGBT is relatively high, whereas that in the flow channels on both sides is relatively low. In the subsequent optimization and enhancement work, attempts can be made from this perspective to further optimize the flow channels and render the flow field distribution more even.

（2）The maximum temperature of the IGBT chip reaches 70.8°C, which is beneath the maximum operating junction temperature of the IGBT chip. Consequently, the designed IGBT heat dissipation module satisfies the usage requirements.

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Application and Challenges of Intelligent Nursing Technology in an Aging Society

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Abstract:With the aging of the global population and the increase in the burden of chronic diseases, the traditional nursing model faces unprecedented challenges, especially in the context of growing nursing needs and shortage of human resources. Intelligent nursing technology has emerged, aiming to improve the efficiency and quality of nursing services and meet the diverse nursing needs in an aging society through the integration of modern information technology. The intelligent nursing system integrates cloud computing, the Internet of Things, big data, artificial intelligence and other technologies, and realizes personalized, continuous and intelligent nursing services by collecting, analyzing and processing patient health data in real time. The system can predict potential health risks through data analysis and remotely monitor the health status of patients, thereby reducing dependence on human resources and improving the speed of nursing response. In addition, the intelligent nursing system has self-learning and error correction functions, and can continuously optimize nursing plans based on real-time data to provide patients with efficient and comprehensive nursing services. However, although my country's "Internet + nursing service" has made certain progress, it still faces many challenges in terms of imperfect security management system, inconsistent charging standards, and differences in service quality between regions and institutions. This article will explore the current status and challenges of intelligent nursing in an aging society, and propose corresponding countermeasures in order to promote the further development of intelligent nursing technology.

Keywords: Intelligent Nursing Technology, Aging Society, Elderly Care, Healthcare Innovation, Challenges and Solutions

1. INTRODUCTION

Globally, the aging population and the increasing burden of chronic diseases have indeed brought unprecedented challenges to the medical and health service systems of various countries. The traditional nursing model is difficult to cope with the growing nursing needs and human resource shortages. The rise of smart nursing is to solve these problems and provide effective solutions for an aging society. Smart nursing is a comprehensive nursing model that integrates modern information technology. It aims to improve the quality and efficiency of nursing through advanced technical means and meet the diverse needs of nursing objects. Smart nursing is centered on information technology, artificial intelligence and communication technology, including cloud computing, the Internet of Things, the Internet, big data and blockchain, and uses these technologies to collect, integrate, analyze and present a large amount of information (data) generated in nursing services. In the nursing process, the smart nursing system can not only obtain and process the physical health status of the nursing object in real time, but also predict potential health risks through data analysis. With the help of IoT devices and sensors, nursing staff can remotely monitor the health indicators of the nursing object, reduce dependence on human resources, and improve response speed. In addition, the smart nursing system has the ability to learn and correct errors autonomously, and can continuously update and optimize nursing plans to improve the intelligence level of services, providing nursing objects with more efficient, comprehensive, continuous, intelligent and personalized nursing services. For example, AI algorithms can automatically adjust care plans based on patients' health data and implement personalized interventions to meet the unique needs of each care recipient.

This intelligent model not only improves the quality of care, but also provides a feasible path to alleviate global medical resource shortages and improve public health levels. Although my country's "Internet +" continuing care services have achieved certain results, especially in improving the efficiency of medical resource utilization and alleviating the shortage of medical manpower, they have shown great potential. However, compared with international advanced standards, they are still in the exploration and trial stage, and there are still many aspects that need to be improved. Domestic scholars pointed out that in the process of promoting "Internet + nursing services", my country faces a series of practical challenges, such as imperfect security management system, lack of the unified regulations on charging standards, and differences in service quality between regions and institutions.

1. Imperfect security management system is a key issue that cannot be ignored in the development of "Internet + nursing services". Since Internet nursing involves a large amount of personal health information and data of patients, how to ensure the privacy and security of data is crucial. At present, the risk of data leakage and information abuse still exists, and it is urgent to establish more perfect privacy protection measures and network security protection mechanisms to ensure the safe flow of information in the Internet environment, so as to protect patients' personal information from being illegally obtained or misused.

2. The problem of inconsistent charging standards has affected the popularization and standardization of "Internet + nursing services". At present, there are obvious differences in the charging standards for Internet nursing services in different regions and medical institutions in China, and there is a lack of unified normative guidance, which not only causes trouble for patients, but also brings pricing confusion to service providers. Reasonable and unified charging standards will help promote the sustainable development of services, make patients more receptive to Internet nursing services, and provide a clear basis for charging for service agencies in various places.

3. Uneven service quality is another important factor affecting the effect of "Internet + nursing services". There are large differences in the allocation of nursing resources, technical

levels, and the capabilities of practitioners in different regions, resulting in different service quality between regions. Especially in remote areas, medical resources are relatively scarce, professional nursing staff are insufficient, and the quality and coverage of Internet nursing services are often low. To solve this problem, it is necessary to strengthen the training of nursing staff nationwide, improve the Internet technology application capabilities of the grassroots medical institutions, narrow the service gap between regions, and ensure that all patients can enjoy high-quality Internet nursing services.

In the Figure 1, intelligent nursing framework is referred. This is the basis of the whole study.

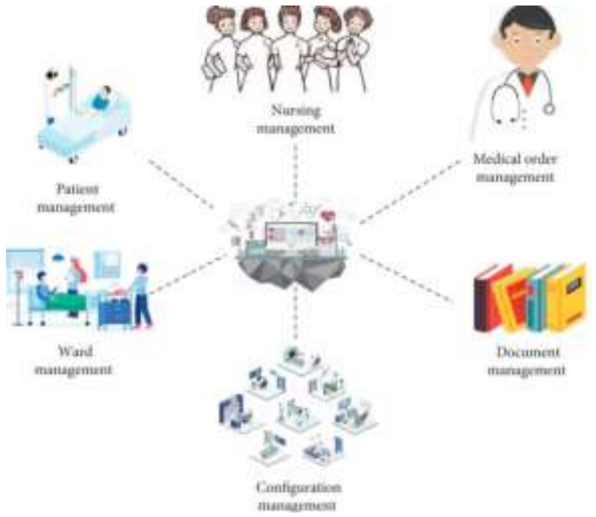

Figure. 1 The Intelligent Nursing (Image Source: https://www.researchgate.net/figure/Main-functions-of-the-intelligent-nursing-system_fig3_362903251)

2. THE PROPOSED METHODOLOGY

2.1 The Concept of Smart Nursing

Smart nursing is a comprehensive nursing system that integrates a variety of information technologies. It is patient-centered and is committed to providing efficient, convenient, and personalized nursing services to meet the people's growing health needs. This nursing system not only improves the quality and efficiency of nursing services, but also optimizes resource allocation through data-driven and intelligent analysis, making nursing services more precise and humane. Therefore, smart nursing has become an important part of the construction of smart hospitals and runs through all aspects of modern hospital nursing work. The core of smart nursing lies in combining modern nursing with advanced information technologies such as the Internet of Things, cloud computing, big data, and artificial intelligence, and through these technologies, it can be seamlessly applied in core business scenarios such as clinical nursing, nursing management, smart wards, continuing care, and nursing management. For example, in clinical nursing, the smart nursing system can monitor the patient's health indicators in real time, provide early warning information in a timely manner, and enable nursing staff to respond to the patient's health status at the first time. At the same time, smart nursing can also achieve standardized management of the nursing process to ensure that the quality of all nursing links reaches consistent high standards. In smart wards, smart nursing uses IoT devices to achieve interconnection between bedside nursing equipment and monitoring equipment, helping nursing staff to understand the patient's status in real time and provide nursing intervention in a timely manner, reducing the workload of nursing staff. In terms of continuing care, smart care can provide continuous care services to patients after discharge through remote monitoring and data tracking, helping patients obtain necessary health guidance and risk prevention during recovery, thereby reducing the rate of readmission. In addition, the smart care system also has significant advantages in nursing management. Through information technology, the work content and performance of nurses can be scientifically managed to ensure the quality and consistency of nursing services. Smart care can also analyze the workload and scheduling of nurses through artificial intelligence algorithms, provide decision support for managers, and reasonably allocate human resources.

2.2 The Problems and Challenges in Development of Smart Nursing in China

The promotion and application of smart nursing does face many technical bottlenecks, which limits its comprehensive popularity in the medical field. Although our country has made significant progress in the field of information technology, especially in cloud computing, big data, Internet of Things, etc., which has gradually approached the international level, the widespread application of these technologies in medical care still faces a series of challenges. For example, data interconnection is the key to the development of smart nursing. However, in actual operations, information systems between different medical institutions often have compatibility issues, making it difficult to effectively integrate data and limiting the full realization of smart nursing. In addition, the security of medical information also needs to be strengthened. Smart care involves a large amount of sensitive patient data. If data protection measures are not in place, there will be risks of information leakage and privacy infringement, which will affect patients' trust in smart care. Therefore, building a sound information security system and improving the level of data protection are important parts of the promotion of smart nursing.

The popularity of smart nursing also needs to be further improved. At present, due to the uneven economic development level and medical resource allocation in various regions of my country, the development of smart nursing in different regions shows obvious differences. In first-tier cities and economically developed areas, the infrastructure of smart nursing is relatively complete, equipment updates are rapid, technology investment is sufficient, smart nursing application scenarios are more extensive, and patient experience is relatively good; while in remote or economically underdeveloped areas, affected areas Limited by factors such as insufficient investment in technology funds and low acceptance of information technology by medical staff, the development of smart nursing is relatively lagging behind. For example, medical institutions in rural areas are limited by backward infrastructure, lack of smart equipment, and lack of professional and technical personnel, making it difficult to realize the full application of smart care, leading to a further widening gap between urban and rural patients in nursing experience and service quality. In addition, the promotion of smart nursing also needs to overcome the dual shortage of technology and human resources. Smart nursing not only requires high-level information system support, but also requires professional nursing staff with information technology capabilities. At present, some medical staff are relatively unfamiliar with the technical operation of smart nursing, and the training system is not yet fully mature. Nursing staff need time to adapt when faced with new equipment and systems, and there are even differences in acceptance of new technologies. Therefore, strengthening the information technology training of nursing staff so that they can master the operation and application of smart nursing systems becomes the basic guarantee for the popularization of smart nursing.

2.3 An Example Technology: Smart Infusion System

The smart infusion system is an innovative nursing tool based on information automation technology, which can realize the automated management of a series of infusion processes from infusion verification, infusion replacement to disinfection. As an important part of smart nursing in clinical applications, smart infusion systems not only effectively reduce the workload of nursing staff, but also significantly improve the efficiency of nursing work, freeing nursing staff from repetitive and time-consuming mechanical labor. , allowing them to devote more energy to comprehensive patient care. The smart infusion system uses high-precision sensors, intelligent controllers, data analysis platforms and other technical means to achieve real-time monitoring and precise management of the infusion process. In actual operation, the smart infusion system can automatically identify the infusion bag and infusion time, automatically check the type and dosage of infusion drugs, prevent medication errors caused by human factors, and further improve the safety of infusion. For example, when the infusion is nearing the end or an infusion blockage occurs, the system can automatically send out an alarm to remind the nursing staff to promptly replace the medicinal solution or handle abnormal situations to ensure the continuity and safety of the infusion process. In addition, the intelligent infusion system can customize the infusion speed according to the patient's needs and adapt to personalized medical needs, thereby optimizing the treatment effect.

The smart infusion system also realizes automatic collection and analysis of infusion data through a big data platform, providing strong support for clinical management and nursing decision-making. The system can automatically record the patient's infusion data in the electronic medical record, making it easier for nursing staff to query the patient's infusion history and drug usage at any time, and helping doctors and nursing staff make more accurate judgments during the diagnosis and treatment process.

2.4 The Suggestions for Intelligent Nursing Technology in an Aging Society

Here are some suggestions:

1. Develop personalized intelligent monitoring systems. Aiming at various health problems of the elderly, such as cardiovascular, diabetes, joint diseases, etc., the intelligent care system should meet the needs of different patients through personalized monitoring.

2.Develop smart walking aids and smart home care equipment. For elderly people with limited mobility, smart walking aids, smart wheelchairs and home care equipment can greatly improve their quality of life. For example, smart wheelchairs using sensors and artificial intelligence technology can help the elderly move autonomously according to their needs, with functions such as obstacle avoidance and path planning.

3.Strengthen data security and privacy protection. With the large-scale application of smart nursing devices, the health data involving the privacy of the elderly is increasing. How to ensure the security of data has become an important issue in the promotion of smart nursing technology. Therefore, a strict data security and privacy protection mechanism should be established in the development and implementation of smart nursing systems, including data encryption, identity authentication, and permission management, to ensure that the personal information of the elderly is not leaked or abused.

3. CONCLUSION

As an important solution to cope with the aging society and the burden of chronic diseases, intelligent nursing technology has shown broad application prospects. By integrating advanced technologies such as cloud computing, big data, the Internet of Things, and artificial intelligence, smart nursing can provide personalized and precise nursing services, greatly improving the quality and efficiency of nursing services. However, although smart nursing technology has made significant progress in some areas of my country, its popularization and application still face a series of challenges such as technology, safety, talent and regional differences. First of all, data security and privacy protection issues need to be resolved urgently, and a complete security management mechanism needs to be established to ensure the safe flow of patient health information. Secondly, differences in charging standards and uneven service quality in different regions have affected the sustainable development of smart nursing services. Therefore, the government and relevant institutions should strengthen policy formulation, promote the standardization of smart care across the country, and narrow regional gaps. At the same time, strengthening the technical training of nursing staff and improving their acceptance and operational capabilities of intelligent nursing systems are also key factors in promoting the popularization of the intelligent nursing.

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Human Stress Level Prediction using Decision-based SVM

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Abstract: Stress is the root causes of every internal problem. There are numerous ways to describe the stress situation, which has been show to have a negative impact on the human body. Hence, stress has a server impact on the life of a working professional due to advanced prospects of the operation, time, it promotes depression and anxiety traps. We use a brain signal for dissection of stress. We introduced a noisy data with smoothing wind empirical function to overcome the threat of over fitting in prognosticate target variables. SVM methods were independently trained, tested, and redounded into certain accuracy.

Keywords: EEG Signal, Data cleaning, Django server, Backend development and SVM.

1. INTRODUCTION

Stress detection insights, driven by data science and machine learning, aims to forecast stress level in individuals**.** By analyzing a variety of data sources, such as physiological measurements, behavioral data, and environmental factors, predictive models can identify patterns and risk factors associated with stress.

2. OBJECTIVES

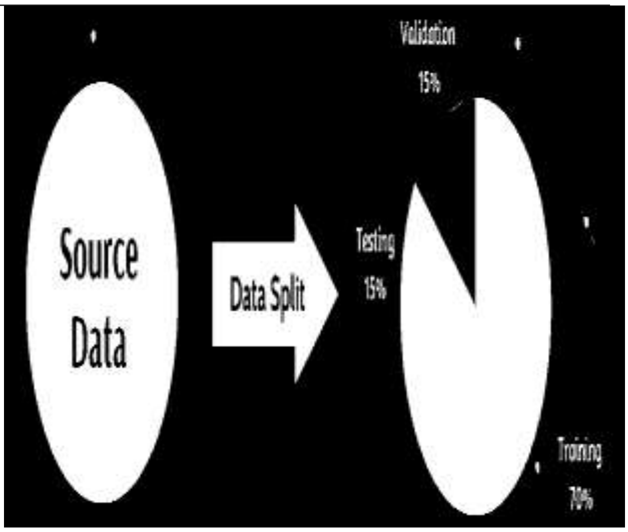
1.The stress is a supporter of depression and anxiety risks, left ignored for a long span of time. The physiological parameters help to identify the stress related issues.

2.Machine learning is one of the fast-growing areas of interest in artificial intelligence adopted by professional in every sphere of **life** that uses algorithms with data to systematically learn patterns and improve from experience.

3.METHODOLOGY

3.1 DATA PREPROCESSING

Standardize the data to ensure that each features contributes equally to SVM . Choose features that are most indictive of stress .If the stress level is categorial encode them numerically for the model.



3.2.SPLITTING DATA

Split the dataset into multiple subsets for training testing and evaluating machine learning models .It provides fair evolution of the model performance on unseen datasets.

3.3.DATA CLEANING

The process of fixing or removing incorrect, corrupted, incorrectly formatted, duplicated, or incomplete data within a dataset. The combination multiple data source, there are many opportunity for data to be duplicated .

3.4.DATA COLLECTION

The process of collecting and evaluating information or data from multiple sources to find answers to research problems, answer questions, evaluate outcomes, and forecast trends and probabilities.

4.EVALUATION AND OPTIMIZATION

Human stress is a physiological and psychological response to external pressures, demands, or threats. It can have a significant impact on an individual's well-being, productivity, and overall health. Evaluating and optimizing stress management involves understanding how stress is experienced, measured, and mitigated in various settings (e.g., workplaces, educational environments, daily life).

5. PSYCHOLOGICAL ASSIGNMENT

5.1. SELF-REPORT QUESTIONNAIRES

1.Perceived stress scale is commonly used scale to measure the perceived level of stress. At the same time state trait anxiety inventory as both temporary(state) and chronic(trait) anxiety levels.

5.2.HEART RATE VARIABILITY(HRV)

HRV measures the variation in time between heartbeats. Low HRV is associated with chronic stress and poor stress resilience.5.3BLOOD PRESSURE AND CORTISOL LEVELS

1.Elevated blood pressure can be an indicator of acute or chronic stress.
2.Cortisol, a stress hormone, can be measured through blood, saliva, or hair samples to assess the body's stress response over time.

5.4. ELECTROENCEPHALOGRAPHY

The EEG modality has some advantages such as high temporal resolution, low cost, and ease of use. Hence, it is the most used technique to analyze mental states including stress.

5.5. TIME MANAGEMENT AND PRIORITIZATION

Training in time management helps individuals handle work pressures and deadlines more effectively. Strategies like breaking tasks into smaller parts, setting achievable goals, and learning to delegate can alleviate stress.

6. SECTIONS

Stress management is a multi-faceted approach that involves various strategies to reduce and cope with stress, improve resilience, and promote well-being.

Figure. 1 Example for the selection process

7.DATA SOURCES FOR STRESS PREDICTION

7.1.PHYSIOLOGICAL DATA

This includes heart rate variability (HRV), blood pressure, skin conductivity, respiratory rate, and even facial muscle activity. These physiological signals are often captured using wearable devices like smartwatches, fitness trackers, and sensors embedded in clothing.

7.2. BEHAVIORAL DATA

Stress levels are often influenced by cognitive and emotional states. Data from questionnaires, interviews, or real-time self-reports (e.g., the Perceived Stress Scale) can provide insights into an individual's mental.

7.3. ENVIRONMENTAL FACCTORS

stress can also be triggered by external factors, such as noise levels, environmental temperature, or even situational stressors like deadlines and workload. Data from environmental sensors or apps that track external conditions can be used to refine prediction.

8. CONCLUSION

This stress level prediction model effectively used physiological, behavioural, and environmental data to assess stress. Leveraging machine learning, it holds potential for applications in healthcare, workspace wellness, and personal well-being. The model can be improved with more diverse datasets and refined algorithms. Future work will focus on enhancing accuracy and exploring personalized stress management solutions. This research contributes to a deeper understanding of stress and supports the development of better mental health tools. Ultimately, it aims to help individuals manage stress more effectively.

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Solar-Enhanced Waste Stabilization Ponds: A Comparative Analysis of Reflector Shapes for Optimizing Urban Wastewater Treatment

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Abstract: The extensive land requirement is a primary barrier to the adoption of waste stabilization ponds (WSPs) in urban areas. Solar-Enhanced Waste Stabilization Ponds (SEWSPs) address this limitation by incorporating reflectors to intensify solar radiation, thereby enhancing pollutant removal efficiency and reducing land usage. This study assessed the performance of plane and parabolic reflectors in SEWSPs, hypothesizing that the parabolic reflector, due to its unique optical and geometric properties, would concentrate solar radiation more effectively than the plane reflector. Samples from the influent and effluent valves of a pilot-scale facultative SEWSP were analyzed for 5-day biochemical oxygen demand (BOD_5) and fecal coliform (FC), demonstrating that pollutant removal efficiency varied with temperature, which was influenced by reflector shape. Suitability of standard ANOVA for mean comparisons was assessed, and robust alternatives were considered. At a 5% significance level, the Games-Howell Q-test indicated that the parabolic reflector significantly improved BOD ($p = 0.024$) and FC ($p = 0.002$) removal over the control, while the plane reflector showed no significant enhancement. These findings suggest that concentrating solar radiation in WSPs could enhance treatment efficiency and reduce land demands, positioning SEWSPs as a viable wastewater treatment option for urban environments.

Keywords: BOD, faecal coliform, reflector, solar radiation, temperature, ANOVA

1. INTRODUCTION

Waste stabilization ponds (WSPs) are shallow, large basins surrounded by natural embankments where organic material in wastewater is broken down through natural biological processes [1], [2]. While WSPs use relatively simple technology, they support a complex ecological network, including algae, viruses, protozoa, rotifers, insects, crustaceans, and fungi, all of which contribute to organic waste stabilization and reduction of pathogen levels in the effluent [3]. This engineered system leverages the natural synergy between algae and bacteria to process wastewater efficiently. When optimally designed, WSPs produce high-quality effluent, rich in nutrients and suitable for irrigation without requiring costly chemical disinfection [4]–[6]. These systems are widely adopted by both municipal and industrial sectors. However, the requirement for large tracts of land limits the feasibility of WSPs in densely populated urban areas [7].

Extensive research has focused on enhancing the operational efficiency of waste stabilization ponds (WSPs) while minimizing their spatial footprint. Strategies to optimize WSPs include several innovative techniques, such as implementing recirculating stabilization ponds in series [8], step-feed approaches [9], hybridizing with attached growth systems [10], and using natural zeolite to enhance the irrigation potential of WSP effluent [11]. Improvements also encompass precise calculation of design parameters for optimal performance [12]–[16]. Additional studies examine the impact of deeper pond configurations and modified surface areas on treatment efficacy [17]–[20], including tapered pond surfaces [17]. Among these land-saving innovations, Solar Enhanced Waste Stabilization Ponds (SEWSPs) have garnered notable interest. SEWSP technology integrates a tilted reflector to concentrate sunlight onto the wastewater surface, producing a "solar image" that amplifies the energy available for treatment processes, thereby increasing the efficiency of stabilization [21]–[26].

The efficiency of stabilization in waste ponds hinges largely on microbial processes within the system, with bacteria and algae playing key roles [27], [28]. Three main environmental factors influence these microbial communities: temperature, sunlight, and mixing. Temperature has an exponential effect on bacterial activity [29], [30]; light intensity directly impacts algal concentration [34]; and mixing aids in the distribution of oxygen and non-motile algae throughout the pond's depth [32]. Mixing in WSPs occurs through two mechanisms: wind and thermal mixing. Without wind, thermal stratification issues can be mitigated by introducing additional heat, thereby enhancing the pond's capacity [33]. The reflectors in Solar Enhanced WSPs (SEWSPs) serve dual functions to support this natural microbial symbiosis: they directly increase water temperature, enhancing bacterial action and promoting thermal mixing, and indirectly boost algal photosynthesis, which raises pond pH and dissolved oxygen levels due to rapid photosynthetic activity [31].

Solar-Enhanced Waste Stabilization Ponds (SEWSPs) have shown high effectiveness in wastewater treatment, offering both operational and economic advantages. Studies highlight that integrating solar reflectors into SEWSPs significantly reduces land usage—by up to 75%—and cuts costs of conventional WSPs by approximately 50% [21], [22]. However, the plane reflector commonly used in SEWSPs has been criticized for its limited optical efficiency, as it simply reflects parallel rays without focusing them, which results in a lower-intensity solar image that shifts with the sun's movement throughout the day [25], [35], [36]. Additionally, the fragility and maintenance costs of glass mirrors used as reflectors pose further challenges, suggesting a need for alternative shapes and materials to enhance SEWSP performance, especially in urban areas. Previous studies found that parabolic reflectors outperform plane reflectors and control setups in pollutant removal [26], yet some analyses in these studies relied on standard ANOVA without verifying its assumptions, which can yield inaccurate results when normality and homoscedasticity are violated [37]. To address these limitations, this study re-evaluated reflector shapes using robust analysis of variance methods, specifically to more accurately assess the treatment performance of plane versus parabolic reflectors in SEWSPs.

2. MATERIAL AND METHODS

2.1 Pond Design and Dimensions

This study utilized a pilot scaled 1:20 model of a conceptual prototype facultative waste stabilization pond (WSP), designed based on Froude number similarity principles. Table 1 outlines the necessary scaling ratios between the model and the prototype, along with associated flow characteristics. The pilot ponds were constructed from 2 mm metal sheets, which were precisely cut into rectangular sections and welded to achieve the desired pond volume. Each pond was equipped with an adjustable frame to mount the reflectors at specified angles.

Table 1. Model-prototype relationships based on Froude similarity law

Parameter	Unit	Dimension	Equation	Relationship	Prototype	Model
Length, L	m	L	L_r	$1/20$	20	1
Width, W	m	L	L_r	$1/20$	6	0.3
Depth, D	m	L	L_r	$1/20$	4	0.2
Surface Area, A	m^2	L^2	${L_r}^2$	$(1/20)^2$	120	0.3
Volume, V	m^3	L^3	${L_r}^3$	$(1/20)^3$	480	0.06
Ideal retention time, (V/Q)	hrs	T	${L_r}^{0.5}$	$(1/20)^{0.5}$	322	72
Influent rate, Q	m^3/d	L^3T^{-1}	${L_r}^{2.5}$	$(1/20)^{2.5}$	36	0.02
Avg. theoretical velocity (QD/V)	m/d	LT^{-1}	${L_r}^{0.5}$	$(1/20)^{0.5}$	2.98×10^{-1}	6.67×10^{-1}
Avg. Froude No. $F_r = \frac{v}{\sqrt{gR_h}}$	$-$	$-$	${L_r}^0$	1	8.42×10^{-7}	8.42×10^{-7}

2.2 Reflector Assembly and Design

The plane reflectors were created by cutting rectangular sections from 12 mm plywood, then covering the surface with reflective aluminum foil. For the parabolic reflector, an off-axis parabolic satellite dish was repurposed, lining its concave surface with reflective material. This "off-axis" or "offset" design places the dish's focal point below its aperture, away from the center, enabling focused convergence of reflected sunlight at a specific point below the dish. This unique feature makes it particularly suitable for use in SEWSP systems.

Technically, an off-axis parabolic dish represents a type of quadric surface known as an elliptic paraboloid. Standard off-axis dishes are nearly circular but are slightly taller than they are wide, with their outer edges aligned on a flat plane. The height and width are straightforward to measure, while the maximum depth can be determined by referencing the dish's top and bottom straight edges. For "shaped" off-axis dishes, these measurements can be obtained by placing the dish on a level surface and filling it with water to gauge depth. The solar reflection cast by an off-axis parabolic reflector onto the wastewater surface forms an elliptical pattern, which shifts in size as the sun's position changes throughout the day.

Throughout the day, the reflected solar image gradually shifts away from the ponds. This image reaches its largest size twice daily, with a minimum size occurring between these peaks—typically around 4:00 pm when the reflector tilt angle is set to 68°, equivalent to (90 - θ), where θ is the dish's offset angle. The reflectors' dimensions, positioning, and tilt angle were optimized to align with the maximum size and movement path of the solar image across the wastewater surface. Table 2 provides the geometric and optical specifications of the reflectors.

The second phase of the experiment involved three ponds (1 m ×0.3 m ×0.2 m) designated as Pond A (parabolic reflector), Pond B (plane reflector), and Pond C (control). Each reflector, with an equal surface area, was installed at a 68° tilt. Table 4 includes detailed specifications for each pond and reflector, while schematic and photographic representations of the setup are illustrated in Figures 2 and 3.

Table 2. Reflector geometry and optical characteristics

Properties	Off-axis parabolic reflector	Plane reflectors
Surface area	0.622 m^2	0.622 m^2
Aperture area	0.566 m^2	0.622 m^2
Focal length	0.46 m	Infinity
Offset angle	24°	-
Location of the focus measured from the aperture edges	0.83 m (from top edge) 0.46 m (from the bottom edge)	-

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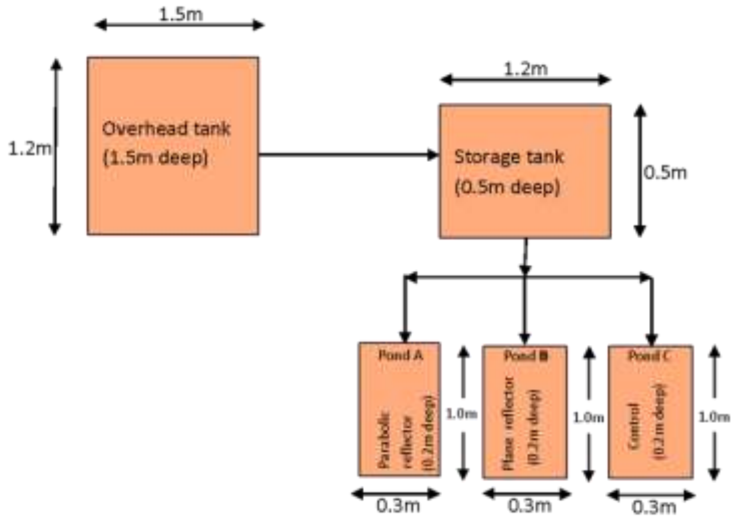

Figure 2. Illustration of experimental setup

Figure 3. Photographic diagram of experimental setup

Table 4. Functional details of ponds and reflectors

Experimental ponds	Size of pond (m)	Characteristics	Dimensions of reflector	Purpose
A	1 × 0.3 × 0.2	Off-axis parabolic reflector	Height (a)=0.89 m Width (b)=0.81 m depth (h)=0.08 m	Measure the effect of solar reflector
B	1 × 0.3 × 0.2	Plane rectangular reflector	Length = 0.40 m Width = 1.55 m	Measure the effect of solar reflector
C	1 × 0.3 × 0.2	No reflector	-	Control

2.3 Laboratory Analysis of Samples

Samples were taken from the effluent outlet valves and the common inlet valve of each pond, then labeled accordingly. Subsequent laboratory analyses were conducted to measure the concentrations of biochemical oxygen demand (BOD) and faecal coliform (FC). Additionally, the temperature, pH, and dissolved oxygen (DO) levels of the pond water were monitored. DO and temperature were recorded in situ at the sampling locations using a HI 9142 multi-parameter water testing meter. BOD measurements were also obtained in the laboratory using the same meter. All other tests were performed in the Sanitary Engineering Laboratory, Department of Civil Engineering, University of Nigeria, Nsukka, in accordance with Standard Methods [38].

The removal efficiency of BOD is typically expressed as a percentage that quantifies the reduction in BOD from influent to effluent in a treatment process. The formula is given as:

$$\text{BOD (\%)} = \frac{BOD_{influent} - BOD_{effluent}}{BOD_{influent}} \times 100 \quad (1)$$

Where $BOD_{influent}$ is the initial BOD concentration (usually in mg/L) before treatment and $BOD_{effluent}$ is the BOD concentration after treatment.

The efficiency of FC removal was evaluated as log. reduction value (LRV). LRV quantifies the reduction in concentration on a logarithmic scale and is commonly used in water treatment to assess performance at removing pathogens. The formula for LRV is given as:

$$\text{LRV of FC} = \log_{10}\left(\frac{FC\ concentraion\ in\ influent}{FC\ concentraion\ in\ influent}\right) \quad (2)$$

In this context, a higher LRV indicates a greater reduction in the FC concentration, meaning the treatment process is more effective. For example, an LRV of 1 corresponds to a 90% reduction, an LRV of 2 corresponds to a 99% reduction, and an LRV of 3 corresponds to a 99.9% reduction. LRV is especially useful when contaminant concentrations vary widely or when very high removal efficiency needs to be quantified.

2.4 Statistical Methods for Comparing Means

Levene’s test [39] is used to assess the homogeneity of variances (equal variances) across groups, which is an assumption in many statistical tests like ANOVA. Homogeneity of variances is important because it affects the robustness of these tests. Levene's test specifically tests if the variance among groups is similar, helping determine whether a test like standard ANOVA is appropriate or if a more robust method, like Welch’s ANOVA, should be used. Furthermore, Levene’s test doesn’t assume that the data are normally distributed, making it suitable for many types of data. However, it’s sensitive to outliers, which can sometimes affect results.

Modified Z-score test is a robust alternative to the standard Z-score, useful for detecting outliers in data that may be non-normal or have extreme skew. It is used to test suitability for data with potential outliers that may affect the mean. No strict distributional assumptions are required, making it robust. It uses the median and median absolute deviation (MAD) values with a modified Z-score outside ±3.0 are flagged as outliers.

Welch’s test [40] was used to check for any statistically significant difference in the performances of the ponds in removing BOD and faecal coliform. Welch’s ANOVA (or Welch’s test) is a variation of the standard ANOVA designed to compare the means of three or more independent groups, particularly when assumptions of equal variances across groups are violated. It’s a more robust approach than traditional ANOVA for handling datasets with heterogeneous variances, providing reliable results without requiring transformations or adjustments.

If Welch’s test indicates a significant difference, post hoc tests can determine where the differences lie. Games-Howell test [41] is a common post hoc test used with Welch’s ANOVA, as it also doesn’t assume equal variances and is well-suited for unequal sample sizes. The study of Sauder and DeMars [42] found slightly higher power for the Games-Howell test when compared with other pairwise comparison procedures.

All comparison tests, including assumption tests, were computed with Real Statistics Using Excel (version: Rel 8.9.1, released on October 2, 2023).

3. RESULTS AND DISCUSSION

3.1 Laboratory Analysis of Samples

The influent wastewater characteristics were assessed weekly over the 5-month experimental period. Characteristics of wastewater used in the experiments are presented in Table 1. Parameters evaluated included BOD_5, fecal coliforms, suspended solids, total nitrogen, total ammonia, free ammonia, sulfide, pH, and dissolved oxygen. Notably, only pH conforms with the World Health Organization’s (WHO) in effluent standard for discharged into inland surface waters. While BOD, fecal coliforms, and sulfide may necessitate additional treatment, such as a maturation pond, to meet discharge standards, the remaining requirements are not likely to cause difficulty to anaerobic and facultative ponds in series.

Hydrogen sulfide, primarily generated by the anaerobic reduction of sulfate by sulfate-reducing bacteria like Desulfovibrio, serves as the main potential source of odor. However, trace levels of sulfide can be beneficial, as it binds with heavy metals to form insoluble metal sulfides that precipitate out of the water column. Additionally, small concentrations of sulfide (10–12 mg/L) are advantageous, as they are highly toxic to Vibrio cholerae, the causative agent of cholera [43].

Wastewater pH is also known to play a significant role in odor inhibition. In well-designed anaerobic ponds, with typical pH values around 7.5, most sulfide exists in the form of the odorless bisulfide ion. Odor arises only from the release of hydrogen sulfide gas, which diffuses to achieve a partial pressure in the air above the pond, in equilibrium with its concentration in the water (according to Henry’s law). For further details on the impact of pH on the equilibrium between hydrogen sulfide, bisulfide, and sulfide, refer to Sawyer et al. [44].

3.2 Suitability of BOD Data to ANOVA Test

Table 2 presents descriptive statistics and the Shapiro-Wilk test of normality for the BOD values recorded across the three pond types. Normality and equal variance are part of the assumptions implicit in many statistical tests like ANOVA. Figure 4 shows the dot plot, box plot, and Q-Q plot for the control, plane reflector, and parabolic reflector ponds. Notably, the Q-Q plots exhibit S-shaped curves, with most points deviating from the 45-degree reference line, indicating a lack of fit to a normal distribution. The S-shaped pattern in the Q-Q plots suggests that the distributions are skewed or have heavier tails than a normal distribution. This visual assessment is further corroborated by the Shapiro-Wilk test results, which confirm that BOD values across all ponds are not normally distributed ($p<0.05$)—an important consideration for selecting appropriate statistical tests for comparing the pond’s BOD removal efficiencies. Even though Levene’s test is not significant at 95% level, it is significant at 90% level ($p=0.091$), raising questions about the suitability of ANOVA for comparing the group means of the pond’s efficiencies.

The dot plot reveals that the parabolic reflector pond has the widest spread and variability, followed by the plane reflector pond, and then the control pond. No outliers are visible in the dot plot, which is consistent with the box plot findings, where no points fall outside the whiskers, indicating an absence of outliers. The absence of outliers in all three datasets is further confirmed by the modified z-scores, which show no significant outliers across the datasets.

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Table 1. Characteristics of wastewater used in experiment

Parameter	Influent values	Discharge standard
BOD (mg/l)	288	30
Faecal Coliform (per 100 ml)	3×10^6	$<1\times10^3$
Suspended solids (mg/l)	256	100
Total Nitrogen (mg/l)	31	100
Total Ammonia (mg N/l)	35	50
Free Ammonia (mg N/l)	6.1	5
Sulphide (mg/l)	9.0	2
pH	8.8	5.5 – 9.0

Table 2. (a) Descriptive statistics and (b) Shapiro-Wilk test

(a) Descriptive statistics

	Control	Plane	Parabolic
Mean	26.388	36.714	40.872
Standard Error	3.161	3.949	4.324
Median	32.033	43.301	46.62
Standard Deviation	17.600	21.989	24.077
Sample Variance	309.775	483.525	579.694
Kurtosis	-1.495	-1.582	-1.324
Skewness	-0.039	-0.162	-0.317
Range	55.177	66.725	75.163
Maximum	55.286	68.307	76.763
Minimum	0.110	1.583	1.600
Sum	818.024	1138.123	1267.033
Count	31	31	31

(b) Shapiro-Wilk test

	Control	Plane	Parabolic
W-stat	0.912	0.898	0.913
p-value	0.015	0.007	0.016
alpha	0.05	0.05	0.05
normal	No	No	No

Table 3. (a) Descriptive statistics, (b) Shapiro-Wilk test, and (c) Levene's test for FC efficiency

(a) Descriptive statistics

	Control	Plane	Parabolic
Mean	1.382	1.654	2.289
Standard Error	0.151	0.199	0.207
Median	1.321	1.897	2.406
Standard Deviation	0.841	1.105	1.154
Sample Variance	0.707	1.222	1.333
Kurtosis	-0.929	-1.396	-0.982
Skewness	0.272	0.110	-0.395
Range	2.879	3.358	3.720
Maximum	2.974	3.469	3.869
Minimum	0.094	0.112	0.149
Sum	42.842	51.268	70.957
Count	31	31	31

(b) Shapiro-Wilk Test

	Control	Plane	Parabolic
W-stat	0.955	0.92	0.936
p-value	0.216	0.024	0.065
alpha	0.050	0.05	0.050
normal	Yes	No	Yes

3.3 Laboratory Analysis of Samples Suitability of Log. Reduction Values of Faecal Coliform Data to ANOVA Test

Table 3 presents descriptive statistics and the Shapiro-Wilk test of normality for the log. reduction values (LRV) of faecal coliform recorded across the three pond types. Figure 5 shows the dot plot, box plot, and Q-Q plot for the control, plane reflector, and parabolic reflector ponds. Notably, the Q-Q plots exhibit S-shaped curves, suggesting lack of normality, although that of the control pond is not very profound. However, the Shapiro-Wilk test results show that the hypothesis of normal distribution could not be rejected for control (p=0.251) and parabolic reflector (p=0.154) at 95% level of significance. Whether ANOVA or other robust methods for comparing group means is employed depends on normality and homogeneity of variance. Even though Levene's p-value was not significant (p=0.053), it was close, raising concern about the suitability of standard ANOVA for comparing the group means the LRV of FC.

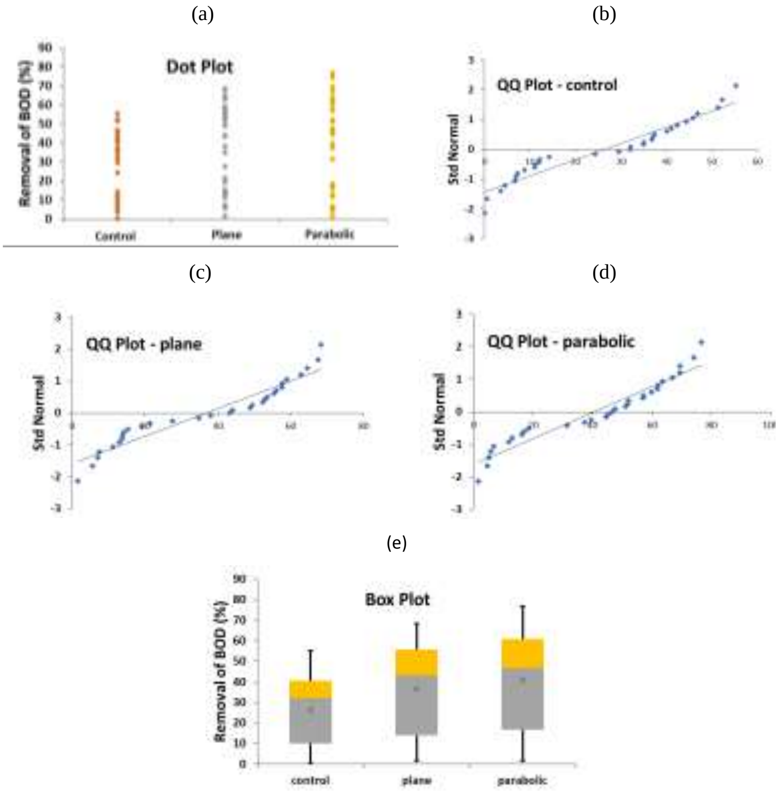

Figure 4. Analysis of BOD data: (a) Dot plot, (b) QQ plot for control, (c) QQ plot for plane reflector pond, (d) QQ plot for parabolic reflector pond, (e) Box plot

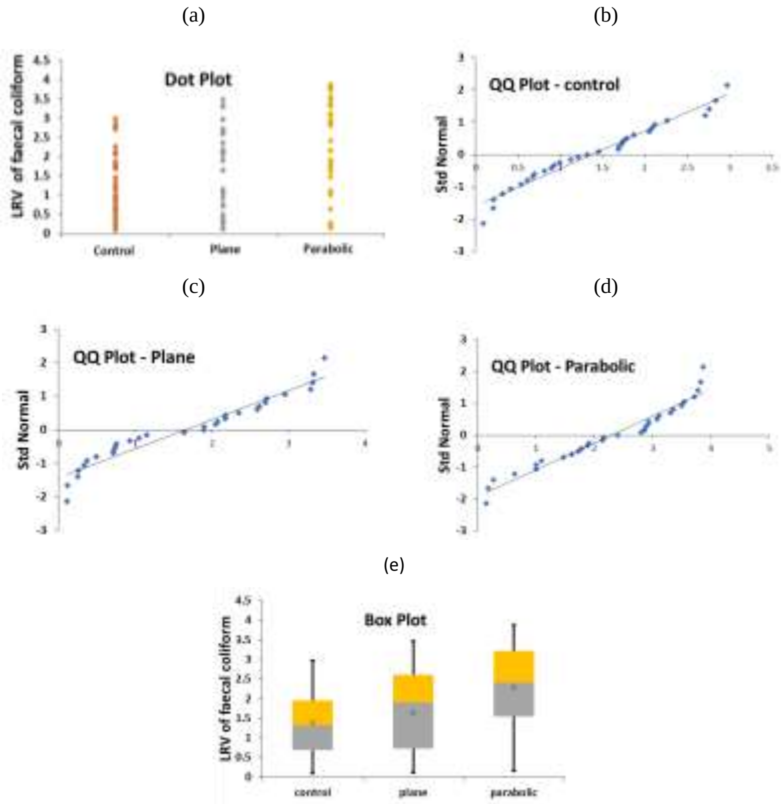

Figure 5. Analysis of LRV of faecal data: (a) Dot plot, (b) QQ plot for control, (c) QQ plot for plane reflector pond, (d) QQ plot for parabolic reflector pond, (e) Box plot

The dot plot reveals that the parabolic reflector pond has the widest spread and variability, followed by the plane reflector pond, and then the control pond. No outliers are visible in the dot plot, which is consistent with the box plot findings, where no points fall outside the whiskers, indicating an absence of outliers. The absence of outliers in all three datasets is further confirmed by the modified z-scores, which show no significant outliers across the datasets.

3.4 Effect of reflector on BOD removal efficiency

The pond performances at removing BOD varied depending on the reflector used. The parabolic reflector pond recorded the highest BOD removal efficiencies, followed by the plane reflector pond, then the control. The results of the Welch test shows that there is a significant difference among the BOD efficiencies recorded from the ponds (p=0.019). Games-Howell post hoc test presented in Table 4 was used to identify precisely which ponds' BOD efficiencies differ significantly. It can be seen that it was the means of the control and parabolic reflector pond that differ significantly (p=0.024). No significant difference exists between the means of control and plane reflector pond (p=0.112) as well as between the plane and the parabolic reflector ponds (p=0.759).

The primary mechanisms behind BOD removal are sedimentation and oxidation of organic compounds into settleable new cells. These processes are enhanced at elevated temperature. It is worthy of note that the performance of the ponds depended on their ability to focus radiation from the sun, which raises pond water temperature. The parabolic reflector pond, plane reflector pond, and the control recorded an average temperature of 32.9 oC, 29.4 oC, and 28.6 oC, respectively. The higher average temperature recorded in pond A (parabolic reflector) is the most critical effect parabolic reflector had over the plane reflector. This is because virtually all wastewater treatment processes are temperature dependent [33]. WSPs perform according to their water temperatures. Their water temperatures, in turn, depended on the amount of solar radiation energy received by the ponds. Ponds total radiation energy includes the portion received from the sun and the portion provided by the reflectors. Pond A (parabolic reflector) kept its reflected solar image on the wastewater longer than pond B (Plane reflector), resulting in higher water temperature in pond A. On the average, pond A's water temperature is 3.5 oC higher than that of pond B. For this reason, pond A recorded better BOD removal efficiencies. However, temperature affected pH and DO negatively.

Table 4. Games-Howell Q-test on BOD removal efficiency

Group 1	Group 2	Mean	Std err	Q-stat	df	Q-crit	p-value
Control	**Plane**	10.326	3.577	2.887	57.254	3.403	0.112
Control	**Parabola**	14.484	3.788	3.824	54.941	3.407	0.024
Plane	**Parabola**	4.158	4.141	1.004	59.513	3.400	0.759

Table 5. Games-Howell Q-test on LRV of faecal coliform

Group 1	Group 2	Mean	Std err	Q-stat	df	Q-crit	p-value
Control	**Plane**	0.272	0.176	1.541	56.003	3.405	0.524
Control	**Parabola**	0.907	0.181	5.001	54.836	3.407	0.002
Plane	**Parabola**	0.635	0.203	3.129	59.888	3.399	0.077

3.5 Effect of reflector on BOD removal efficiency

The pond performances at removing faecal coliform (FC) varied depending on the reflector used. The parabolic reflector pond recorded the highest FC removal efficiencies, followed by the plane reflector pond, then the control. The results of the Welch test shows that there is a significant difference among the LRVs recorded from the ponds (p=0.004). Games-Howell post hoc test presented in Table 5 was used to identify precisely the ponds whose LRVs differ significantly. It can be seen that it was only the means of the control and parabolic reflector pond that differ significantly (p=0.024). The superior performance of the parabolic pond could as well be explained by higher UV dose and temperature. No significant difference exists between the means of control and plane reflector pond (p=0.524). Also, the difference between plane and parabolic ponds was not statistically significant (p = 0.077), even though there was a trend toward significance. This suggests that while the observed effect may be noteworthy, it does not meet the conventional threshold for statistical significance. Further investigation with larger sample sizes may be warranted to explore this trend.

Faecal coliform is the most important consideration if effluents are to be reused for irrigation pond A (parabolic reflector) performed outstandingly well. Its removal efficiency is mediated by pH-temperature-DO relationship. The average pH recorded in pond A, B, C are 8.92, 8.99, and 8.74 respectively; those of DO are 5.9mg/l, 6.8 mg/l, and 6.0 mg/l respectively. While reduced DO in pond A could be explained by increased temperature and increased bacteria action, the pH-temperature dynamics of the ponds could not be explained by the existing theories within the context of the tested parameters. High pH occurs when algae use up CO_2 for photosynthesis. Sunlight is the primary driver of photosynthesis, and higher radiation as provided by parabolic reflector should mean more algal activities, using more CO_2. If CO_2 is taken up faster than bacterial respiration can supply, the concentration of CO_2 drops, causing a dissociation of the bicarbonate ion to form CO_2 and alkaline hydroxyl [2]. These processes raise pH levels in facultative ponds. Nevertheless, increased solar radiation in pond A, which is known to increase photosynthesis action and algae concentration, did not necessarily translate to higher pH. One plausible explanation is that lethal combination of high UV, temperature and other adverse climatic conditions affected algae growth hence pH negatively.

4. CONCLUSIONS

Experimental results across various wastewater treatment parameters indicated that the parabolic reflector provides superior pollutant removal at a comparatively low cost. The parabolic reflector's design, which focuses and transfers heat directly into the pond, proved to be highly effective at elevating water temperatures. Findings revealed that this reflector setup can raise pond temperatures by an average of

3.5°C more than a plane reflector. The addition of solar heat significantly enhances pond performance by increasing thermal mixing and raising overall temperatures, which allows for more efficient use of the pond's full volume. Although further assessment is needed to determine the technical and economic feasibility of implementing parabolic reflectors in full-scale ponds, it is clear that this design holds promising potential for SEWSP applications.

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