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Design Parameters Effects on a Quadrotor Mini-UAV Consumed Energy

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Abstract: This article focuses on the influence that a selection of design parameters has on the energy consumption of a quadcopter minidrone. The minidrone was modeled as a rigid body of the cylinder type with a 30 cm of radius, a 1,47 kg of weight and a 20 cm of height to assess the impacts of the piloting mode. To determine the mass and size effects, 250 g of loads were added, radius and height were increased 5 cm. A cubic minidrone and an oblate spheroid minidrone were studied to understand the influence of the shape choice. It was found that the oblate spheroid minidrone is the least energy-consuming, if we refer to the traveled distance and the maximum reached altitude with the same consumed energy. MATLAB-SIMULINK are used for the simulation.

Keywords: piloting mode, cubic minidrone, oblate spheroid minidrone, energy-consuming, shape choice

1. INTRODUCTION

UAV design is based on three notions: the desired performance, the required energy and the weight and size of the embedded equipment. Even if the list of equipment can be determined, the risk of energy consumption increasing, it's subsist. Obtaining optimal energy autonomy remains a challenge for designers [1]. Integrating parameters into the assessment of the minidrone energy consumption from the design stage is an option to consider. In this article, we will focus our analysis on the piloting mode, the mass and size and the shape and general appearance of a minidrone. To simulate the impacts of these parameters, some modifications are made to the model presented in reference [2].

2. PILOTING MODE

Two piloting mode are considered: hard piloting and soft piloting. These piloting modes will be identified from the motor speeds variations. Hard piloting corresponds to rapid changes motor speeds, which is the opposite of soft piloting.

2.1 Parameters and hypothesis

For the simulation, the quadrotor is modeled as a rigid body of the cylinder type with a 30 cm of radius, a 1,47 kg of weight and a 20 cm of height. We assumed that for soft piloting, 12 s is necessary to change to another speed, and for hard piloting, this duration is 2 s. Figure 1 shows the motor speeds evolution according to the piloting mode.

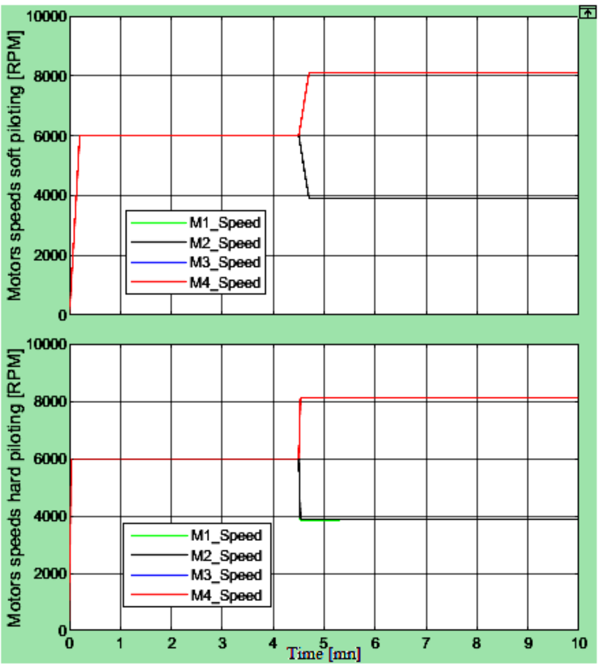

Figure. 1 Motor speeds evolution according to the piloting mode

For soft piloting, the starting time is 12 s to reach 6000 RPM. We kept this speed for all motors for 4 min 18 s. We change the speeds of the motors 4 min 30 s after starting and we use as new values : $\omega_1=\omega_2$ = 3900 RPM and $\omega_3=\omega_4$ = 8100 RPM. For hard piloting, we push the motors to reach 6000 RPM in 2s. We maintain this speed for 4 min 28 s. And 4 min 32 s after starting, we access the new values: $\omega_1=\omega_2$ = 3900 RPM and $\omega_3=\omega_4$ = 8100 RPM.

2.2 Consumed powers

These speed values correspond to a take-off and a forward movement simulation. Figure 2 shows the evolution of the consumed powers according to the piloting mode.

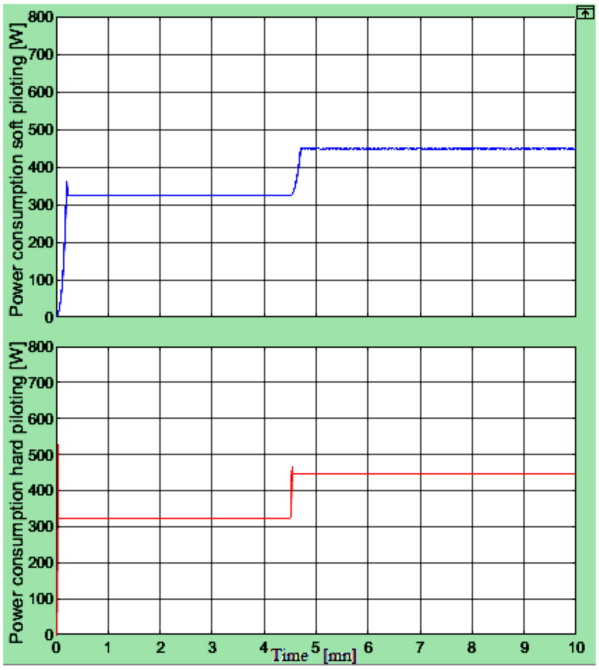

Figure. 2 Consumed powers evolution according to the piloting mode

The required power peak at start-up reaches 360 W for soft piloting, compared to 515 W for hard piloting. Still for the hard piloting mode, a second peak of 467,75 W corresponding to speed changes was observed. Apart from these peaks, the consumed powers remains the same for all piloting mode and varies from 323,5 W to 446,5 W.

2.3 Traveled distances

With soft piloting, the minidrone covered a distance of 10 m in 5 min 18 s without deviating from its trajectory. The maximum altitude of 111,25 m is reached in 7 min 42 s after starting the motors. For hard piloting, the minidrone covered a distance of 9,13 m with a slight deviation to the right in 5 min 28 s. The maximum altitude of 123.65 m is reached in 7 min 36 s after starting the engines. Figures 3 and 4 illustrate these movements.

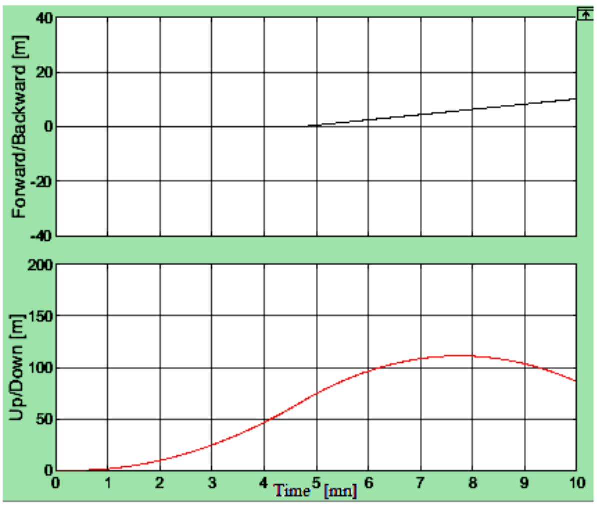

Figure. 3 Traveled distances for soft piloting mode

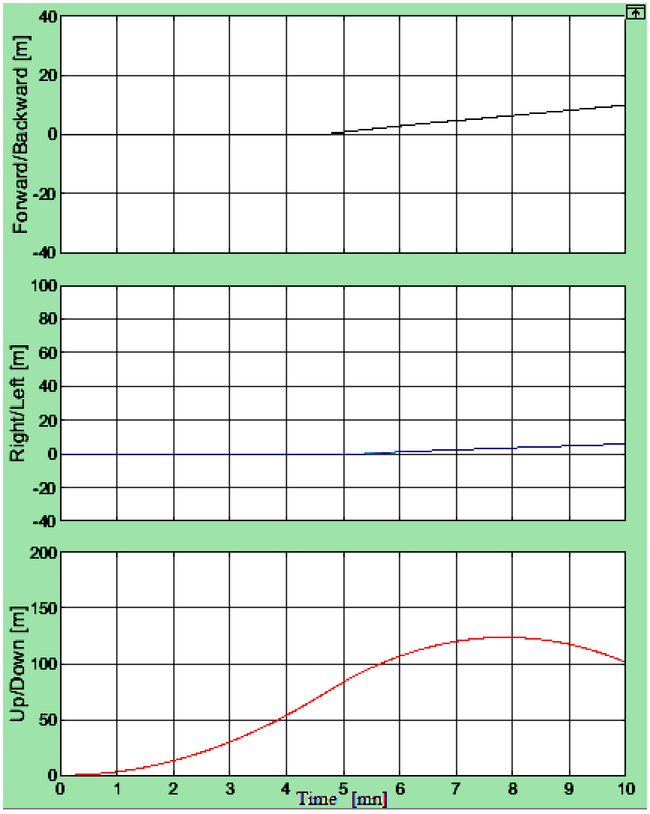

Figure. 4 Traveled distances for hard piloting mode

Assuming that the research results presented in reference [2] are obtained from a moderate piloting mode, Table 1 shows the comparison of some parameters according to the piloting mode.

Table 1. Comparison of all piloting mode

Parameters	Piloting mode		
	Soft	Moderate	Hard
Traveled distances [m]	10	9,4	9,13
Maximum altitude [m]	111,25	117,9	123,65
Take-off after starting motors [s]	34	18	4
Peak at start-up [W]	360	394,5	515

3. ADDING LOADS WITH UAV SIZE EXPANSION

The size and mass of the payloads and their power requirements are the main determinants of the layout, size and total mass of a minidrone [3]. To simulate adding payloads with UAV size expansion, we will modify the model in reference [2], adopting a radius of 35 cm, a height of 25 cm and a weight of 1,72 kg.

3.1 Consumed powers

For the simulation, we chose the moderate piloting mode. Figure 5 shows the evolution of the power consumed by the minidrone.

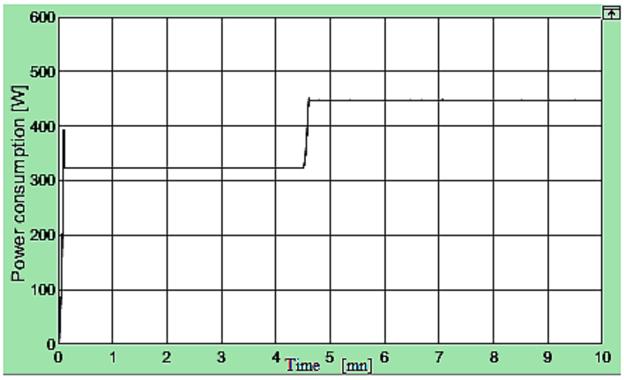

Figure. 5 Consumed powers evolution with additional loads

From the figure, we obtain the same result as the first simulation of the reference [2]. This shows that even if we add loads while expanding minidrone size, with the same values for the motor speeds, consumed powers remains unchanged.

3.2 Traveled distances

The minidrone continues to climb and begins to move forward 4 mn after takeoff. In 5 mn 12 s, the minidrone has traveled a distance of 9,59 m without deviating from its trajectory. The maximum altitude of 61,58 m is reached 7 mn 30 s after takeoff. Figure 6 illustrate these movement with additional loads and an expanded size.

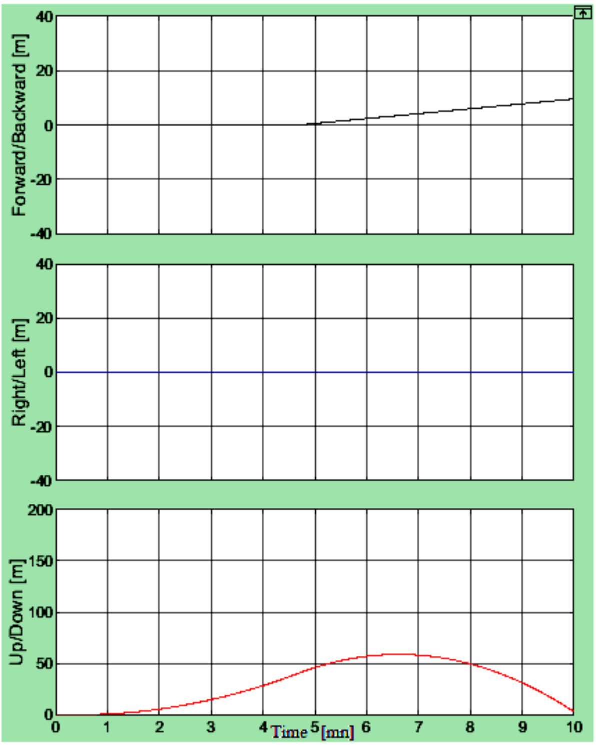

Figure. 6 Traveled distances with additional loads

4. SHAPE CHOICES

To have an improved energy autonomy, either we increase the number of on-board batteries or we implement another power embedded system. This approach would have an impact on the choice of the shape of the minidrone. The prototype in Fig. 7 could be considered for a minidrone that embeds a network of rectennas to reinforce the battery.

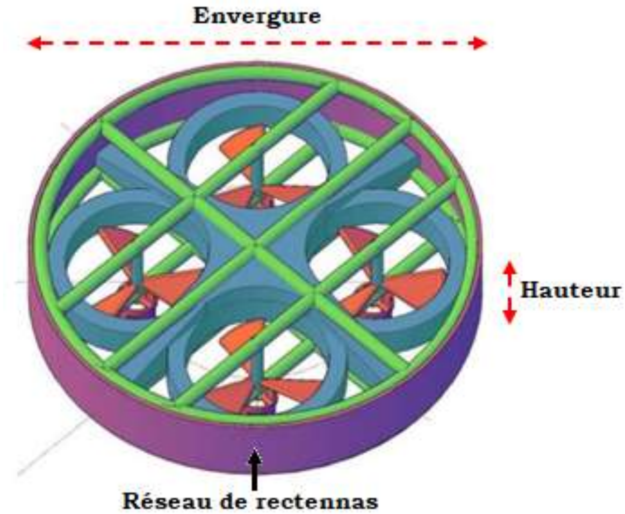

Figure. 6 Prototype with embedded rectennas networks [4]

Figure 8 illustrate the general appearance of a solar-powered quadcopter UAV from different views.

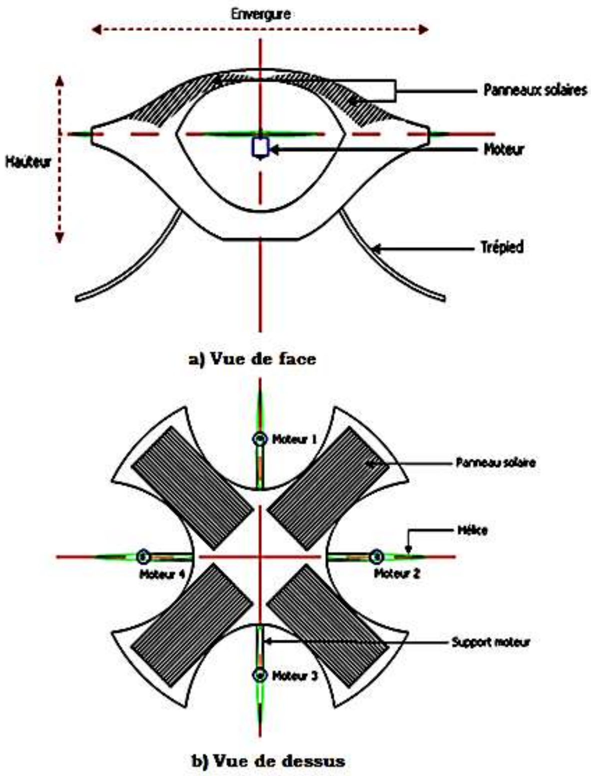

Figure. 6 Prototype of a solar-powered quadcopter UAV [5]

As the cylindrical shape is already mentioned in reference [2], we will focus our analysis on two other shapes: the cubic shape and the oblate spheroid shape.

4.1 Inertia matrix

The inertia matrix of a cubic shape is given by the relation:

$$\begin{bmatrix} I_{xx} \\ I_{yy} \\ I_{zz} \end{bmatrix} = \frac{1}{6} . m . a^2 \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

where *m* is the weight and *a* is the edge of the cube.

For the ellipsoid shape of length 2a, width 2b and height 2c, the inertia matrix is given by the relation:

$$\begin{bmatrix} I_{xx} \\ I_{yy} \\ I_{zz} \end{bmatrix} = \frac{1}{5}.m \begin{bmatrix} (b^2+c^2) & 0 & 0 \\ 0 & (a^2+c^2) & 0 \\ 0 & 0 & (a^2+b^2) \end{bmatrix} \quad (2)$$

Also, to have an oblate spheroid shape, we adopted a = b < c, and the relation that defines the inertia matrix becomes:

$$\begin{bmatrix} I_{xx} \\ I_{yy} \\ I_{zz} \end{bmatrix} = \frac{1}{5}.m \begin{bmatrix} (a^2+c^2) & 0 & 0 \\ 0 & (a^2+c^2) & 0 \\ 0 & 0 & (2.a^2) \end{bmatrix} \quad (3)$$

Equations (1) and (3) are implemented in the "Inertial_system" block of the main model presented in reference [2], to identify the interaction between the chosen shape and the consumed energy. With the initial cylindrical shape, Table 2 resume the shape specifications of the studied minidrones.

Table 2. All shape specifications

Parameters \ Shapes	Cylindrical	Cubic	Oblate spheroid
Weight [kg]	1,72		
Radius / Edge [cm]	35	46	34
Height [cm]	25	-	20
Volume [m^3]	0,09		

4.2 Simulation results

The same parameters were used as those of the first simulation of the reference [2]. We therefore simulate a take-off and a forward movement for 10 mn. Table 3 recaps the results of our simulations for these shapes.

Table 3. Recapitulation of the simulation results

Results \ Shapes	Cylindrical	Cubic	Oblate spheroid
Traveled distances [m]	9,59	7	9,31
Maximum altitude [m]	61,58	63,31	64,32
Take-off starting motors [s]	36	36	30
Total thrust [N]	24,5 to 27,5		
Peak at start-up [W]	394,5		
Consumed powers [W]	323,5 to 447,5		

From this table, we can conclude that the oblate spheroid shape minidrone is the least energy-consuming, followed by the cylindrical shape. This conclusion is based only on the traveled distance and the maximum altitude reached by the minidrone, with the same power consumption.

5. CONCLUSION

Many parameters can affect the energy consumption in a quadcopter minidrone. In this article, we focused on the piloting mode, the addition of loads and the choice of shape. Simulations were performed with MATLAB-SIMULINK to identify the impacts of these parameters on the energy consumed. It was found that with the aggressive piloting mode, power peaks appear at each acceleration. With the additional loads, the mass, size and shape of the minidrone could be modified, as needed. It was concluded that the oblate spheroid shape minidrone is the least energy-consuming, if we refer to the traveled distances and the maximum altitude reached with the same consumed energy.

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Exploring the Limitations, Challenges, and Regulatory Strategies of AI-Based Content Filtering Systems

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Abstract: AI-based content filtering systems have become essential for moderating the vast and dynamic online space. Widely adopted by online platforms and governments, these systems promise efficiency in detecting and removing harmful content. However, their reliance on machine learning introduces critical limitations, including biases in training datasets, lack of contextual understanding, and challenges in real-time moderation. These issues undermine the effectiveness of content moderation and raise significant ethical and legal concerns, such as threats to free speech, privacy, and transparency. This paper explores the limitations and challenges inherent in AI-based content filtering systems and examines the regulatory strategies needed to address them. The study advocates for a balanced regulatory framework that ensures technological innovation while safeguarding fundamental human rights by emphasising ethical principles such as fairness, explainability, and accountability.

Keywords: AI-based content filtering, Content moderation, Ethical AI, Regulatory frameworks, Free speech, Online content regulation, Bias in machine learning

1. INTRODUCTION

Artificial Intelligence (AI) has revolutionized the digital landscape, becoming an indispensable tool for online content moderation. From social media platforms to government-led initiatives, AI-based content filtering systems are employed to tackle the challenges posed by harmful, illegal, or otherwise objectionable content (Hussain et al., 2018; Lee & Chen, 2012). These systems leverage advanced algorithms to detect, track, and remove such content, often far surpassing human capabilities in speed and efficiency. However, as reliance on these technologies grows, so do concerns about their limitations, ethical implications, and potential societal impact. According to Lee & Chen (2012), the internet, as a medium, thrives on its openness, offering unprecedented avenues for communication, information dissemination, and creative expression. Yet, this same openness allows for the spread of harmful material, including hate speech, misinformation, and graphic content. The sheer scale and volume of user-generated content make manual moderation nearly impossible, driving the adoption of automated solutions. AI-based content filtering systems, often powered by machine learning and natural language processing (NLP), are designed to handle these immense workloads, making them critical in maintaining the safety and integrity of online spaces (Kebriaei et al., 2024).

Vilas-Boas (2023) mentioned that despite their technological sophistication, these systems are far from flawless. Their effectiveness depends heavily on the quality and diversity of the datasets on which they are trained. Biases in these datasets can lead to discriminatory outcomes, disproportionately targeting certain groups or failing to account for cultural and linguistic nuances. Furthermore, the lack of contextual understanding inherent in AI models means they often struggle to distinguish between harmful content and legitimate expressions, such as satire or parody. This results in a phenomenon known as "overblocking," where legitimate content is unjustly removed, thereby infringing on users' rights to free expression and access to information (Alizadeh et al., 2023). Equally concerning are the implications for privacy and accountability. The datasets required to train AI models often include personal information, raising significant privacy issues. Moreover, the decision-making processes of AI systems are frequently opaque, leaving users with little recourse when content is incorrectly flagged or removed. This "black box" nature of AI not only undermines user trust but also complicates efforts to hold platforms accountable for their actions.

The regulatory landscape surrounding AI-based content filtering systems is similarly complex and fragmented. While some jurisdictions have enacted laws encouraging the adoption of automated content moderation tools, others have imposed stricter guidelines to prevent misuse and ensure accountability. For instance, the European Union's Digital Services Act seeks to balance innovation with user protection, emphasizing transparency and fairness in automated decision-making. In contrast, laws like the United States' Communications Decency Act grant broad immunity to platforms, fostering innovation but leaving significant gaps in accountability (Khan & Alkhalifah, 2018).

This paper seeks to address these pressing issues by exploring the limitations and challenges of AI-based content filtering systems and proposing regulatory strategies to mitigate their risks. By critically examining the technological, ethical, and legal dimensions of these systems, this study aims to contribute to a more nuanced understanding of their role in the digital ecosystem. It argues for a balanced approach that prioritizes ethical AI development, robust regulatory oversight, and the protection of fundamental human rights, ensuring that these systems serve as tools for good rather than instruments of harm.

2. HISTORICAL AND LEGAL CONTEXT

According to Fong et al., (2009), The regulation of online content has undergone significant transformations since the advent of the internet. Initially, online platforms operated in an environment of minimal oversight, emphasizing the free exchange of ideas and innovation. However, as the internet expanded, so did the prevalence of harmful, illegal, and controversial content, prompting legislative interventions to establish clearer rules and responsibilities for service providers. One of the earliest landmark legislative efforts was the Communications Decency Act (CDA) of 1996 in the United States. Its most notable provision, Section 230, granted immunity to service providers for content posted by third-party users. This legal framework enabled platforms to flourish without fear of liability, effectively encouraging the growth of user-generated content. However, this broad immunity also limited the incentive for platforms to take proactive steps to moderate harmful material, leaving gaps in addressing online safety.

In the realm of copyright, the Digital Millennium Copyright Act (DMCA) of 1998 introduced a new paradigm. It required platforms to implement "notice and takedown" mechanisms to address copyright infringements. This marked a shift from the broad immunity granted under the CDA to a more conditional model of liability, contingent on platforms' responsiveness to complaints (Hussain et al., 2018). While effective in curbing copyright violations, the DMCA also highlighted the challenges of content moderation, as automated takedown systems often removed legitimate content, such as fair use materials, stifling free expression. The European Union's E-Commerce Directive of 2000 similarly sought to balance innovation with accountability (Khan & Alkhalifah, 2018). Like the DMCA, it provided liability exemptions for service providers, contingent on their efforts to remove illegal content once notified. However, it explicitly prohibited the imposition of general monitoring obligations on platforms, reflecting concerns about overreach and the potential impact on user privacy and free speech (Elkin-Koren, 2020).

Recent years have seen a shift in regulatory focus toward greater accountability for online platforms. The Digital Services Act (DSA), enacted by the European Union, represents a significant evolution in content regulation. The DSA emphasizes transparency and due diligence, requiring platforms to disclose their content moderation policies and ensure fairness in automated decision-making processes. This framework aims to address the shortcomings of earlier laws by fostering trust and accountability while maintaining the benefits of automation (Khan & Alkhalifah, 2018; Basu & Sen, 2024).

Beyond copyright and intermediary liability, content moderation laws have expanded to address specific types of harmful content, such as hate speech and terrorism-related material. For example, the European Union's Regulation on Terrorist Content, enacted in 2021, obligates platforms to remove terrorist content within one hour of receiving a notification. Similarly, Australia's Criminal Code Amendment (Sharing of Abhorrent Violent Material) Act of 2019 imposes criminal liability on platforms that fail to remove violent content expeditiously (Kakati & Dandotiya, 2024). These laws underscore the increasing expectation that platforms adopt proactive measures, often using AI, to combat harmful content. Despite these advances, regulatory efforts remain fragmented globally (Kebriaei et al., 2024). The United States continues to rely on the immunity framework established by the CDA, fostering innovation but leaving significant gaps in accountability. In contrast, the European Union's evolving legal landscape reflects a more interventionist approach, emphasizing user protection and ethical governance. These differences highlight the challenges of creating a unified regulatory framework for content moderation in an interconnected digital ecosystem (Vahed et al., 2024).

3. TECHNOLOGICAL EVOLUTION OF CONTENT FILTERING

The journey of content filtering technology reflects the broader evolution of the internet and the growing complexity of online interactions. According to Guo (2024), content filtering systems were at initial time rudimentary, relying on simple, rule-based approaches to block or restrict undesirable content. Over time, these systems have evolved into sophisticated tools powered by Artificial Intelligence (AI) and machine learning, addressing the exponential growth of user-generated content and the need for real-time moderation.

Early Content Filtering Techniques

In the early stages of the internet, content filtering primarily relied on keyword-based systems. These systems worked by scanning text for specific words or phrases deemed inappropriate or harmful. While easy to implement, these methods were limited in scope and precision (Khan & Alkhalifah, 2018). They often blocked legitimate content containing flagged keywords, leading to significant overblocking. For example, a keyword-based system might block a scholarly article discussing violence because of specific terms, even though the content itself was not harmful. URL and IP-based filtering represented another foundational approach. These systems blacklisted specific web addresses or IP ranges to restrict access (Garg & Jain, 2023). While effective for certain applications, such as limiting access to known malicious sites, these methods were static and reactive, unable to adapt to rapidly changing online content. Furthermore, they were easily circumvented by users employing techniques such as URL shortening or IP spoofing.

Transition to AI and Machine Learning

Gongane et al., (2022) relates that ss the limitations of early methods became apparent, the need for more adaptive and nuanced filtering systems grew. This marked the transition to AI-driven approaches, which brought significant improvements in accuracy and scalability. Unlike static rules, AI-based systems could learn from data and improve over time, making them better suited to handle the dynamic nature of online content. Pedersen (2022) mentioned that the integration of natural language processing (NLP) enabled these systems to understand context, moving beyond simple keyword matching. For instance, NLP allows AI to differentiate between a sarcastic comment and genuine hate speech or to recognize slang and regional dialects that traditional systems might miss. Video and image recognition technologies further expanded the scope of content filtering, enabling platforms to identify harmful visual content, such as graphic violence or child exploitation materials, with greater precision.

Platforms like YouTube and Facebook have adopted advanced AI algorithms to detect and remove harmful content at scale. These systems can process millions of posts, comments, and uploads daily, significantly reducing the burden on human moderators. However, while AI has enhanced efficiency, it has also introduced new challenges, such as false positives (overblocking) and false negatives (underblocking) (Kakati & Dandotiya, 2024; Kebriaei et al., 2024).

Real-Time Content Filtering Challenges

The rise of live-streaming platforms and real-time communication channels has introduced additional complexities. Traditional content filtering methods struggle to keep pace with the immediacy of live broadcasts, where harmful material can spread rapidly. AI-based solutions have been developed to address these challenges, leveraging technologies like real-time object detection and audio analysis. However, the computational demands of real-time filtering often lead to trade-offs between speed and accuracy (Vahed et al., 2024).

Integration with User-Centric Features

Modern content filtering systems also integrate with user-centric features, allowing individuals to report or flag inappropriate content. This hybrid approach combines the efficiency of AI with the contextual understanding of human moderators (Andersson & Milam, 2023). For instance, flagged content can be escalated for human review when an AI system is uncertain about its classification. This collaboration helps mitigate the shortcomings of automated systems while maintaining scalability.

Emerging Trends in Content Filtering

The next frontier in content filtering lies in the development of more transparent and explainable AI systems. As concerns about bias and accountability grow, there is increasing demand for algorithms that can justify their decisions in clear and understandable terms. Additionally, the adoption of federated learning techniques—where AI models are trained across decentralized datasets—promises to enhance privacy while improving the diversity and representativeness of training data (Kakati & Dandotiya, 2024).

According to Vahed et al., (2024), Another emerging trend is the integration of content filtering with blockchain technology. By leveraging immutable ledgers, platforms can maintain transparent records of moderation decisions, fostering trust and accountability among users.

4. LIMITATIONS OF AI-BASED CONTENT FILTERING SYSTEMS

While AI-based content filtering systems have become essential tools for moderating vast amounts of online content, their limitations reveal critical gaps in their design, implementation, and impact. These shortcomings arise from technical, ethical, and operational constraints, often undermining their effectiveness and raising significant concerns about their broader societal implications.

1. Bias in Training Data

AI systems rely heavily on the datasets used to train them, and the quality of these datasets significantly impacts their performance. Training data often reflects existing biases in society, which the AI system may then replicate. For example, a content filtering system trained primarily on English-language content may disproportionately fail to detect harmful content in other languages or cultural contexts. This bias can result in unequal enforcement of content policies, where some groups face stricter moderation while others experience underblocking of harmful content (Vahed et al., 2024).

Moreover, datasets used for training are rarely exhaustive, leaving AI systems ill-equipped to handle emerging trends, new slang, or evolving online behaviors. This limitation exacerbates the risk of both overblocking legitimate content and failing to identify harmful material.

2. Lack of Contextual Understanding

Zheng & Nils-Hennes (2023) mentioned that one of the most significant limitations of AI-based content filtering systems is their inability to fully understand context. Unlike human moderators, who can interpret the nuances of language, tone, and cultural references, AI often relies on literal interpretations. This can lead to false positives, where legitimate content is flagged as harmful, and false negatives, where harmful content is allowed to remain online.

For instance, a satirical post criticizing hate speech may be flagged as hate speech itself, while cleverly disguised harmful content—such as coded language or euphemisms—may evade detection. This inability to grasp subtleties undermines the reliability of these systems, particularly in scenarios where context is critical, such as political commentary or artistic expression.

3. Overblocking and Underblocking

AI-based systems frequently struggle to strike a balance between overblocking (removing legitimate content) and underblocking (failing to remove harmful content). Overblocking occurs when the system errs on the side of caution, removing content that does not violate platform guidelines. This can suppress free speech and limit access to important information, particularly in sensitive areas like political discourse or health-related content (Zigmontienė & Vaida, 2023).

Underclocking, on the other hand, happens when the system fails to detect harmful content, allowing it to proliferate. For example, graphic violence or extremist propaganda may bypass filters if it is presented in a way that falls outside the system's predefined parameters. Both outcomes—overblocking and underblocking—can erode user trust in platforms and undermine their credibility.

4. Real-Time Moderation Challenges

The rise of live-streaming and instant communication platforms has added a layer of complexity to content moderation. Real-time filtering requires AI systems to process vast amounts of data almost instantaneously, leaving little room for error. This demand for speed often compromises accuracy, increasing the likelihood of both overblocking and underblocking.

Additionally, Khan & Alkhalifah (2018), pointed the dynamic nature of live content—where harmful material can appear fleetingly—poses significant challenges. AI systems may detect harmful content too late, allowing it to cause harm before being removed. This is particularly concerning in cases such as live-streamed violence or rapidly spreading misinformation.

5. Ethical and Privacy Concerns

AI-based content filtering systems often operate as "black boxes," with their decision-making processes opaque even to their developers. This lack of transparency makes it difficult for users to understand why certain content was flagged or removed, eroding trust in these systems. Furthermore, the datasets used to train these systems often include personal information, raising significant privacy concerns (Akanbi & Akinseye, 2023).

In some cases, the use of AI in content filtering can result in discriminatory outcomes, disproportionately targeting specific groups or perspectives. This has led to accusations of censorship and bias, particularly when the systems are deployed by governments or other entities with vested interests. Balancing the need for effective content moderation with the ethical imperative to protect user rights remains a significant challenge.

6. Dependence on Human Oversight

Despite their advanced capabilities, AI-based systems are not entirely autonomous and often require human oversight to address edge cases and resolve disputes. Human moderators are needed to review flagged content that AI systems cannot confidently classify, creating a bottleneck in the moderation process. Furthermore, the reliance on human oversight undermines the scalability of AI systems, particularly on platforms handling vast amounts of user-generated content (Gongane et al., 2022).

7. Cost and Accessibility

Implementing and maintaining AI-based content filtering systems is resource-intensive, making them inaccessible to smaller platforms and organizations. This disparity creates a gap in content moderation standards across the digital ecosystem, where only large companies can afford sophisticated AI tools, leaving smaller platforms more vulnerable to harmful content (Garg & Jain, 2023).

5. ETHICAL AND REGULATORY CHALLENGES

According to Pedersen (2022), The deployment of AI-based content filtering systems presents profound ethical dilemmas and regulatory hurdles that complicate their adoption and effectiveness. As these systems take on increasingly critical roles in moderating online content, their design and implementation often raise questions about fairness, accountability, transparency, and the preservation of fundamental human rights. Addressing these challenges requires balancing the technical potential of AI with the ethical and regulatory frameworks necessary to safeguard societal values.

1. Transparency and Accountability

One of the most significant ethical challenges of AI-based content filtering systems is their inherent opacity. These systems often function as "black boxes," where the decision-making processes behind content removal or retention are neither visible nor easily explainable to users or regulators.

This lack of transparency creates a trust deficit, as users cannot understand why certain content was flagged or removed (Akanbi & Akinseye 2023).

Kebriaei et al., (2024) mentioned that accountability further complicates the issue. When AI systems make erroneous decisions—such as removing legitimate content or failing to block harmful material—it is unclear who should be held responsible. Platform operators often deflect blame onto the AI, while users demand clearer explanations and recourse mechanisms. This lack of accountability undermines trust in platforms and raises questions about the ethical deployment of AI in public-facing roles.

2. Bias and Discrimination

Bias in AI-based content filtering systems remains a persistent ethical concern. These systems are only as good as the data on which they are trained, and if training datasets reflect societal biases, the AI will perpetuate these issues. For instance, studies have shown that AI systems often disproportionately target content from marginalized groups, particularly when the language, tone, or cultural context deviates from the norms embedded in the training data (Basu & Sen, 2024).

This bias can lead to discriminatory outcomes, suppressing the voices of underrepresented communities while allowing harmful content from dominant groups to remain online. Such outcomes not only exacerbate existing inequalities but also create ethical questions about whether AI systems can ever truly be neutral arbiters of online content (Delgado & Stefancic. 2023).

3. Privacy Concerns

The use of AI in content filtering relies heavily on vast amounts of user-generated data for both training and operation. This dependence on data raises significant privacy concerns, as sensitive user information may be exposed or misused during the training process. Additionally, real-time moderation systems often require constant monitoring of user activities, leading to fears of surveillance and overreach.

These privacy challenges are particularly pronounced in jurisdictions with strict data protection laws, such as the European Union under the General Data Protection Regulation (GDPR). Balancing the need for effective content moderation with the imperative to protect user privacy is a key regulatory challenge that has yet to be fully addressed (Andersson & Milam, 2023).

4. Freedom of Expression

AI-based content filtering systems often walk a fine line between moderating harmful material and suppressing legitimate expression. Overclocking, where lawful and appropriate content is incorrectly flagged as harmful, can have a chilling effect on free speech. This is especially concerning in politically sensitive contexts, where governments or platforms may use AI systems to suppress dissent under the guise of content moderation.

The ethical challenge lies in ensuring that AI systems respect the diversity of viewpoints and cultural contexts while effectively addressing harmful content. This balance is difficult to achieve, as what constitutes harmful material can vary widely depending on cultural, political, and social factors (Vahed et al., 2024).

5. Global Regulatory Fragmentation

The regulatory landscape for AI-based content filtering systems is highly fragmented, with different jurisdictions adopting varied approaches to content moderation. For instance, the European Union's Digital Services Act (DSA) emphasizes transparency and user rights, requiring platforms to disclose their content moderation practices and provide recourse mechanisms. In contrast, the United States' Communications Decency Act (CDA) offers broad immunity to platforms, fostering innovation but leaving significant gaps in accountability.

This disparity creates challenges for platforms operating across multiple jurisdictions, as they must navigate conflicting legal requirements and ethical expectations. For example, a platform adhering to the EU's stringent transparency standards may face fewer obligations in other regions, leading to inconsistent application of content moderation policies (Qiu & Dwyer 2023).

6. Balancing Innovation and Oversight

Guo et al., (2024) states that regulators face the difficult task of balancing the benefits of AI innovation with the need for oversight and user protection. Overregulation may stifle technological advancements, discouraging the development of more effective content moderation tools. Conversely, lax regulation risks enabling misuse, whether through biased filtering, privacy violations, or suppression of free expression.

Ethical AI frameworks, such as those proposed by organizations like the OECD and UNESCO, advocate for principles like fairness, transparency, and human-centric design. However, translating these principles into actionable regulatory policies remains a work in progress, particularly in the fast-moving digital landscape.

6. PROPOSED REGULATORY STRATEGIES

To address the limitations and ethical concerns associated with AI-based content filtering systems, regulatory strategies must evolve to balance the need for effective content moderation with the protection of fundamental human rights. These strategies should focus on fostering transparency, ensuring accountability, and promoting fairness while enabling innovation. Below are key recommendations for creating a robust and adaptive regulatory framework:

1. Mandating Transparency and Explainability

One of the fundamental issues with AI-based content filtering systems is their lack of transparency. To build trust and ensure accountability, regulators should require platforms to disclose the algorithms and datasets underlying their content moderation systems. Transparency measures could include:

- Publishing clear guidelines on how AI systems identify and categorize harmful content.
- Providing users with explanations for content removal decisions, along with options for appeals and reviews (Zigmontienė & Vaida, 2023).
- Developing standards for explainable AI (XAI) to make filtering processes understandable to non-technical stakeholders.

2. Ensuring Dataset Diversity and Quality

Bias in training datasets is a significant source of discriminatory outcomes in AI-based content filtering. Regulatory frameworks should enforce strict standards for dataset diversity, ensuring that training data reflects a wide range of languages, cultures, and contexts. Key strategies include:

- Requiring periodic audits of training datasets to identify and mitigate biases.
- Encouraging platforms to collaborate with diverse stakeholders, including linguists, sociologists, and human rights organizations, to improve data quality (Zheng & Nils, 2023).
- Promoting the use of federated learning techniques, which enable decentralized model training to protect user privacy while incorporating diverse datasets.

3. Establishing Accountability Mechanisms

Regulators must create clear accountability structures to ensure that platforms take responsibility for the outcomes of their AI systems. This includes:

- Introducing legal obligations for platforms to conduct impact assessments of their AI systems, evaluating potential risks to free expression, privacy, and fairness.
- Requiring platforms to document and report instances of overblocking and underblocking, along with steps taken to address these issues.
- Implementing liability frameworks that hold platforms accountable for harm caused by their content filtering systems, particularly in cases of systemic bias or privacy violations.

4. Promoting International Collaboration

The global nature of the internet necessitates harmonized regulatory approaches to AI-based content filtering. Disparate national regulations create challenges for platforms operating across multiple jurisdictions. To address this, international collaboration is essential:

- Developing global standards for ethical AI through organizations like the OECD or UNESCO (Marsoof et al., 2023).
- Facilitating cross-border dialogue among governments, tech companies, and civil society to align content moderation practices with universal human rights principles.
- Encouraging regional regulatory bodies, such as the European Union, to share best practices and frameworks with other jurisdictions.

5. Encouraging a Human-AI Hybrid Approach

While AI is essential for moderating vast amounts of online content, human oversight remains critical to address edge cases and ensure fairness. Regulators should encourage platforms to adopt a hybrid approach, combining AI's scalability with human judgment. This can be achieved by:

- Mandating the use of human reviewers for flagged content that AI systems cannot confidently classify(Marsoof et al., 2023).
- Requiring platforms to allocate resources for training and supporting moderation teams, emphasizing diversity and cultural sensitivity (Alizadeh et al., 2023).
- Encouraging the development of tools that assist human moderators by providing AI-driven insights without replacing their judgment.

6. Fostering Ethical AI Development

Regulatory strategies should incentivize platforms to adopt ethical AI principles in the design and deployment of content filtering systems. These principles include:

- Fairness: Ensuring that systems do not disproportionately target or exclude specific groups (Berretta et al., 2023).

- Accountability: Establishing mechanisms for users to challenge and appeal decisions (Vilas-Boas, 2023).
- Safety: Protecting users from harmful content while preserving their privacy and freedoms.

7. Building Adaptive Regulatory Models

Given the rapid pace of technological advancements, static regulations may quickly become obsolete. Instead, regulators should adopt adaptive models that evolve alongside emerging technologies. Key strategies include:

- Establishing regulatory sandboxes where platforms can test new AI tools under government supervision (Akanbi & Akinseye, 2023).
- Periodically reviewing and updating regulations to address new challenges and opportunities in AI-based content filtering.
- Encouraging continuous research and innovation in AI ethics, explainability, and bias mitigation (Bayer, 2022).

7. CONCLUSION AND FUTURE DIRECTIONS

AI-based content filtering systems have become indispensable tools in managing the vast and diverse landscape of online content. By leveraging advanced algorithms, these systems offer unprecedented efficiency and scale in detecting and moderating harmful material. However, their limitations—ranging from biases in training data and lack of contextual understanding to issues of transparency and accountability—highlight the critical challenges that must be addressed to ensure their responsible and ethical use.

The ethical and regulatory challenges surrounding these systems are particularly pressing. Biases embedded in AI can perpetuate discrimination, while overblocking and underblocking of content risk infringing on free speech and failing to protect users from harm. Moreover, the lack of transparency and explainability in these systems erodes user trust, leaving platforms vulnerable to criticism and legal challenges. The global regulatory landscape further complicates matters, as fragmented approaches across jurisdictions create inconsistencies in implementation and enforcement.

To overcome these challenges, a multi-faceted strategy is essential. Transparency and accountability must be prioritized, requiring platforms to disclose their algorithms and provide users with mechanisms to appeal moderation decisions. Dataset diversity and quality need to be enhanced to minimize biases, while ethical principles such as fairness, safety, and user-centricity must guide AI design and deployment. International collaboration is also crucial in developing harmonized standards that reflect universal human rights principles while accommodating regional differences.

Looking to the future, several key directions must be explored to maximize the benefits of AI-based content filtering systems while mitigating their risks:

1. Advancements in Explainable AI (XAI): Research and development in explainable AI will be critical to making content filtering systems more transparent and accountable. Improved explainability can help users understand why content is flagged and enable regulators to audit these systems effectively.
2. Hybrid Human-AI Models: The integration of human oversight into AI moderation processes will remain vital. By combining the scalability of AI with the contextual understanding of human moderators, platforms can achieve more balanced and fair content moderation outcomes.
3. Dynamic and Adaptive Regulatory Frameworks: Regulations must evolve to keep pace with technological advancements. Adaptive frameworks that incorporate regulatory sandboxes, periodic reviews, and collaborative policymaking will ensure that laws remain relevant and effective in addressing emerging challenges.
4. Ethical AI Development: The adoption of ethical AI principles—such as fairness, inclusivity, and safety—must guide the creation and deployment of content filtering systems. Stakeholders should focus on aligning technological innovation with societal values.
5. Global Cooperation and Standardization: The harmonization of regulatory approaches across jurisdictions will be essential to creating consistent and fair content moderation practices. Platforms, governments, and international organizations must work together to establish universal standards while respecting regional and cultural differences.

According to Kakati & Dandotiya (2024), AI-based content filtering systems have immense potential to make the internet safer and more inclusive. However, realizing this potential requires a concerted effort to address their limitations and ethical challenges. We can build a digital ecosystem that balances safety, fairness, and freedom of expression by fostering collaboration among stakeholders, investing in ethical and technological advancements, and implementing adaptive regulatory frameworks. As these systems continue to evolve, their responsible deployment will play a pivotal role in shaping the future of online communication and governance.

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DOCTOR'S COMPANION: A Support Vector Machine Image Classifier to Enhance Decision Making

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Abstract: An ailing child depends on the parents to detect that the child is not feeling well through observations and a doctor (pediatrician) to know exactly what the problem is and administer medication for such child to get well in the shortest possible time. It has been observed, that the number of doctors in hospitals are not enough to manage the number of patients that need medical attention. These doctors can at some point be overwhelmed by the number of cases they handle on daily basis and therefore require some assistance. The assistance would reduce the work load on the doctor and help the doctor to make accurate diagnosis as the wrong diagnosis could be very disastrous. This work used support vector machine, a machine learning technique to classify X-ray images to enable the doctor make better decisions in administering medications to the patient as wrong diagnosis leads to wrong medications which might lead to death eventually. This work employed object oriented and analysis design methodology in order to model software objects after real world objects. The dataset used for model training was chest X-ray dataset from Kaggle. 70% of the data was used for training while 30% of the data was used for testing. RESNET 50 was used for feature extraction while tensorflow were used as framework for model learning development and computer vision library respectively. The performance metrics used for this work are accuracy, precision, recall and F1. The result is a doctor's companion that that has a high accuracy of 97% which will help doctor to make better decisions in image analysis.

Keywords: ailing, SVM, RESNET50, companion

1. INTRODUCTION

In Africa, child bearing is seen as an important part of the society and a blessing to young couples. When these children are born, they are nurtured to adulthood by their parents. This nurturing consists of selective feeding and adequate medical care. Medically caring for a child is very difficult as kids are unable to explain how they are feeling. It takes rapt attention of parents to know when a kid is not feeling well by taking note of the child's behavioral pattern. Once parents notice that the child is not as active as usual, they check the child's temperature, give first aid and then take the child to hospital to see a pediatrics doctor. A pediatrician is a doctor that treats infants and those yet to enter adulthood. A pediatrician does the following;

a. Conducts physical examination on the patient
b. Prescribe medications and give vaccines
c. Listens to parents' concerns and educate them in the process
d. Refer families to specialists when needed.

The workload of doctors cannot be over-emphasized. This could lead to a doctor being fatigued. Fatigue impacts heavily in the decision making of a doctor. Every action taken **by** a doctor requires spot-on decisions. Any wrong decision could lead to the death of the child.

In its unrelenting efforts to offer quality services to ailing individuals, the healthcare industry embraced artificial intelligence (AI) technology in order to aid doctors make accurate decisions while diagnosing their patients. AI technology has had a very big impact in the world by increasing throughput in its areas of application as shown in the increase in the rate of its patronage (Safavi and Kalis, 2019). AI based applications have also done excellently in image processing and classification. The use of convolutional neural network (CNN) and support vector machine (SVM) have been tremendous in that aspect.

Kalaiselvi and Deepika (2020) posited that ML has excelled in medical imaging diagnostics, personalized treatment, crowd-sourced data gathering, smart health records, ML based behavioural modification, clinical trials and research. ML has also improved forecasting. Bak et al (2021) noted that the first ML system developed could forecast critical toxicities for patients undergoing radiation therapy for head and neck cancers.

A diagnostic tool known as reverse transcription-polymerase chain reaction (RT-PCT) is used to diagnose breath related ailments. This tool is however very expensive and may not be able to provide accurate results especially for diseases with similar symptoms. Identifying this shortcoming, chest X-rays can be accurately classified the use of machine learning tools.

This work focuses on the use of machine learning technique to improve decision making by helping the doctor to accurately classify X-ray images. If a doctor makes a wrong analysis/classification of images, a different prescription would be recommended that would likely lead to complications and eventually death of the patient being treated. This work uses SVM to classify chest X-ray images accurately to enable the doctor make the right prescriptions for the patient.

2. LITERATURE REVIEW

Qilong and Xiaohong (2018) posited that extracting image feature points and classification method are important to content based image classification. They extracted image points using scale invariant feature transform (SIFT) algorithm and then clustered the features with K-means clustering algorithm and bag of work (BOW) of each image constructed. They finally used SVM classifier and got an accuracy of 90%.

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Bak et al (2021) noted that the first ML system has been developed to forecast critical toxicities for patients undergoing radiation therapy for head and neck cancers.

Deep learning in healthcare finds complicated patterns automatically in radiology and assists radiologists in making decisions while analyzing images from PET, MRI, CT Scans, radiology reports and conventional radiography (Sarker, 2021).

Qi et al (2023) reviewed comprehensively the use of machine learning in healthcare industry. They looked at classification, restrictions, opportunities and challenges of using machine learning. They reviewed several machine learning algorithms in healthcare applications. They concluded that with the far reaching capabilities of these techniques, the choice on which one to use lies on the specific task, data availability and resources. They believe that as healthcare data grows, machine learning would be essential in improving patient’s outcomes and advancing medical research. They however identified data privacy, ethical issues and that the requirements for validation and regulations are very rigorous.

Narin, Kaya and Pamuk (2021), developed a system capable of detecting COVID-19 using chest X-rays. They employed convolutional neural network for the classification of images (from dataset). They segmented the images into COVID-19, Pneumonia and normal during the training phase. They used 100 images to test and got an accuracy of 93.5%.

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3. METHODOLOGY

The methodology used for this work is object oriented analysis and design methodology. This is to model software objects used after real world objects. Chest X-ray dataset was selected from Kaggle for model training

4. DESIGN AND IMPLEMENTATION

The dataset used is chestX-Det-Dataset for pediatrics from Kaggle. Figures 1.1 through 1.5 show the first forty images from each of the ailment modeled.

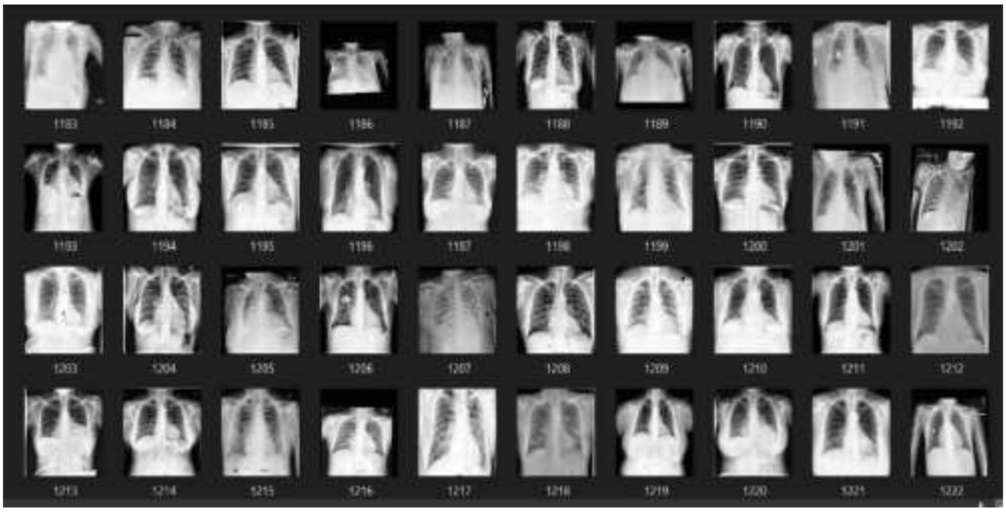

Fig.1.1: First 40 X-ray images of cardiomegaly dataset

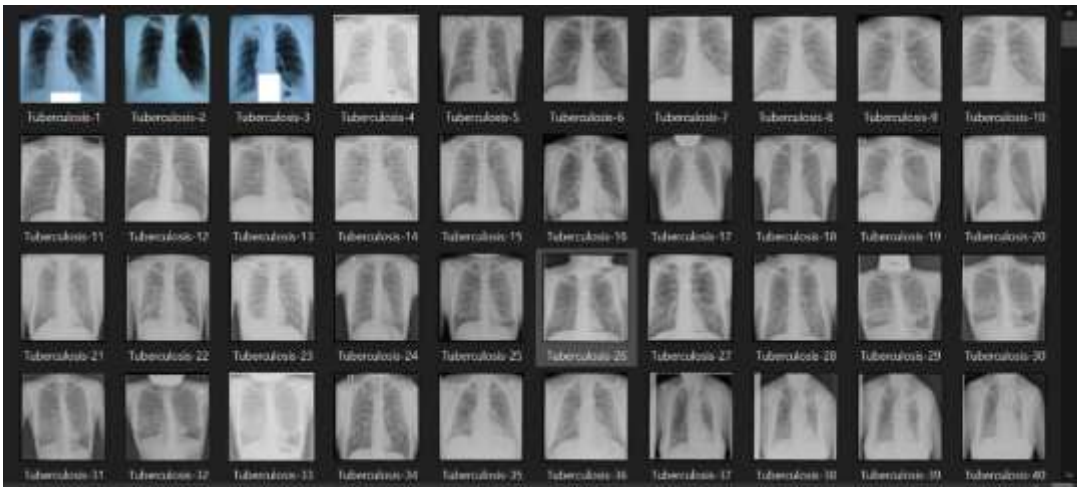

Figure1.2: First 40 X-ray images of tuberculosis dataset

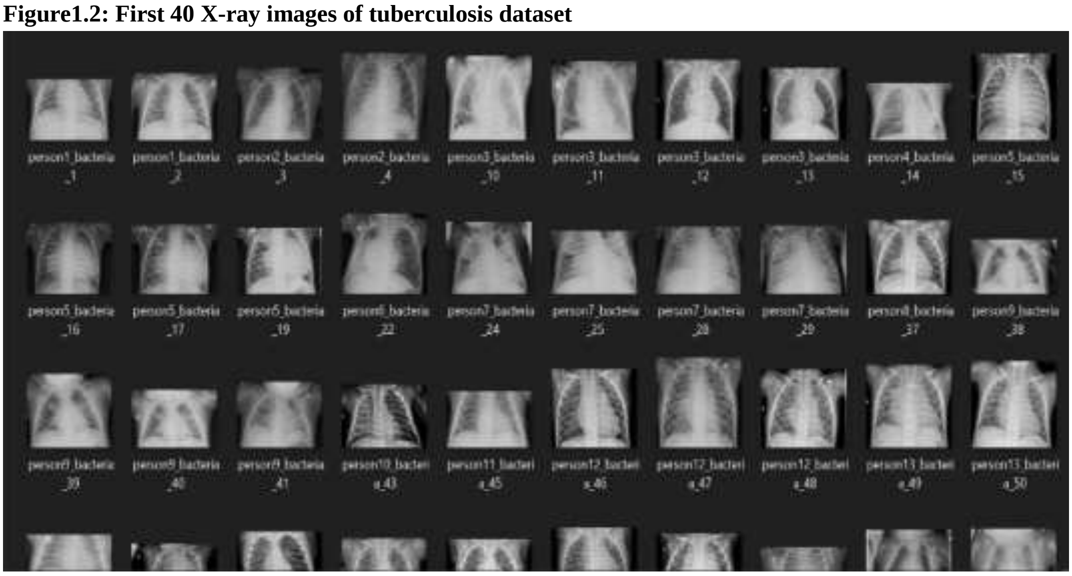

Figure 1.3: First 40 X-ray images of pneumonia dataset

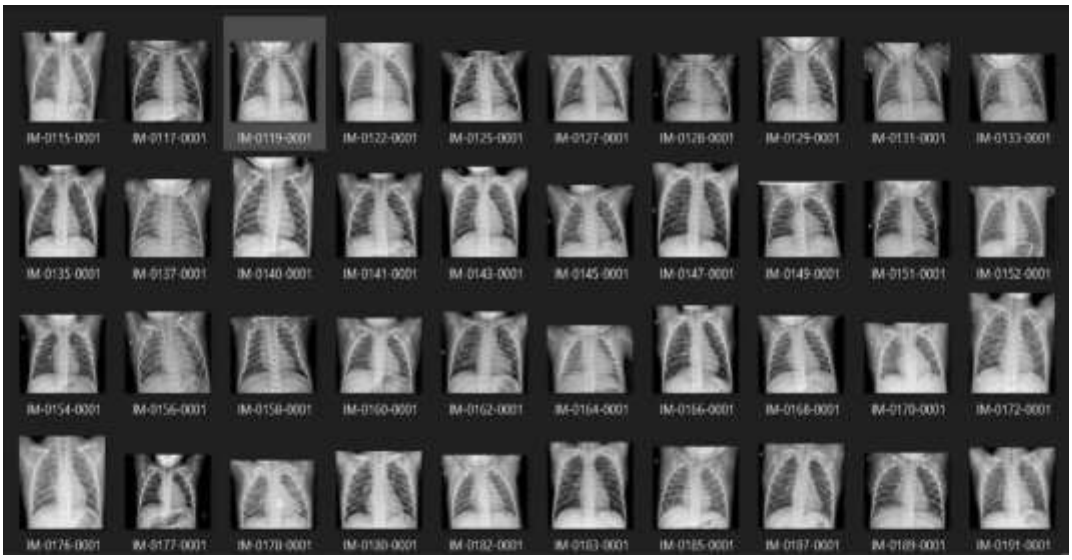

Figure1.4: First 40 X-ray images of normal dataset

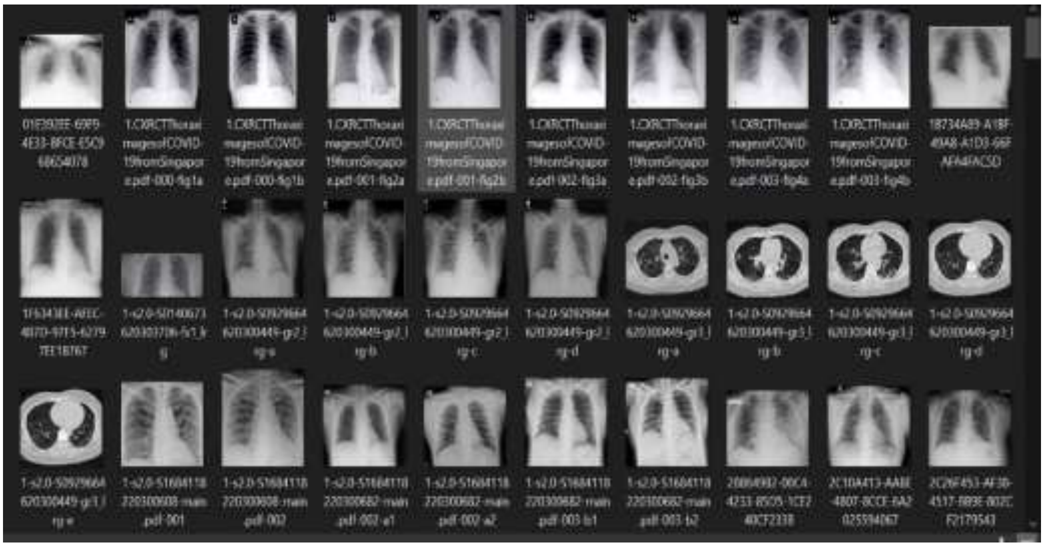

Figure 1.5: first 30 X-ray images of COVID dataset

After data collection, the model is trained with the preprocessed data. Pre-processing is done to ensure that the data used is unbiased. Chest X-ray images usually have pixel value range of 0 to 255. The required value for model training is 0 to 1. Therefore, the data is transformed into the required range. The size of the image was also resized to 224*224 pixel for best results.

The dataset is now split into two; the training set (70%) and the testing set (30%). Feature extraction takes place here. Then, the ML classifier classifies the image. Figure 1.6 shows the architecture of the model developed.

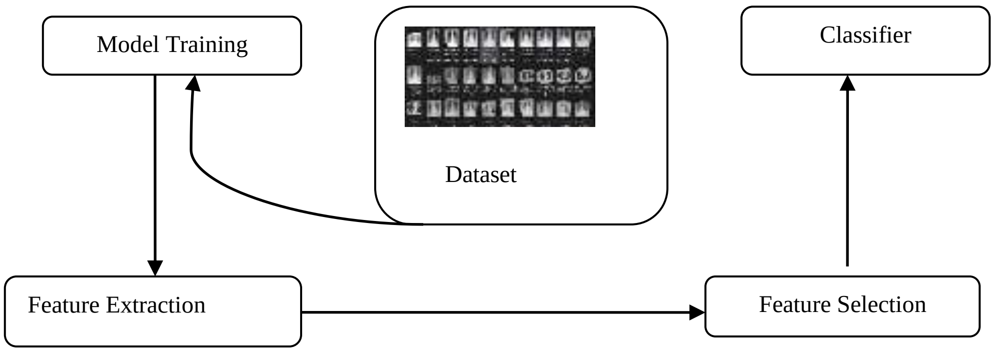

Figure 1.6: Architecture of the model

5. Results and Discussion

```
SVM Classification Report:
               precision    recall  f1-score   support

Cardiomegaly       1.00      0.97      0.98       255
       Covid       0.94      0.90      0.92        67
      Normal       0.96      0.97      0.96       220
   Pneumonia       0.97      0.99      0.98       244
Tuberculosis       0.98      1.00      0.99       148

    accuracy                           0.97       934
   macro avg       0.97      0.96      0.97       934
weighted avg       0.97      0.97      0.97       934

Accuracy: 0.97
SVM Precision Score: 0.9734124993225587
SVM Recall Score: 0.9732334047109208
SVM F1 Score: 0.9731677665510096
PS C:\Users\USER\Desktop\hybrid>
```

Figure 1.7: SVM Classification Report

Figure 1.7 shows the classifier report. This report shows that with the use of SVM, an accuracy of 97% was achieved. This is a significant improvement on the work of Narin, Kaya and Pamuk (2021) who used convolutional neural network for classification and got an accuracy of 93.5%. It is also an improvement of the work of Qilong and Xiaohong (2018) who got an accuracy of 90% using SVM for classification.

6. CONCLUSION

There are few doctors compared to the volume of job they have on daily basis. A doctor who consults with many patients on daily basis needs a “companion” to enhance the doctor’s decision making in classifying X-ray images. A wrong decision could be disastrous and may lead to death. Hence, the use of SVM for X-ray classification is recommended to doctors as companions.

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Statistical Analysis of Key Factors Influencing Leptospirosis Disease in Sri Lanka

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Abstract: In Sri Lanka, Leptospirosis is among the leading public health concerns due to its high morbidity and wide spectrum of clinical manifestations. This study uses data from hospitals all over Sri Lanka, from 2016 to 2019, to investigate the main determinants influencing the outcome of Leptospirosis. Statistical methods, such as logistic regression and chi-squared tests, have been used in order to examine the relationship between disease outcome and various clinical and demographic variables. The findings show a remarkable association between certain symptoms, diagnostic variables, and outcomes. Neck stiffness, leukocyte count, and diagnostic methods were the critical predictors established through logistic regression analysis. Although the predictive model has moderate accuracy 43.6% and an AUC of 0.546, it promises individually targeted interventions and better disease management in endemic areas. The present study underscores the importance of evidence-based approaches for the reduction of the leptospirosis burden in Sri Lanka.

Keywords: Leptospirosis, Chi-squared test, Logistic regression, Clinical variables, Statistical methods, Predictive model

1. INTRODUCTION

Leptospirosis frequently referred to as "rat fever," is a zoonotic bacterial infection caused by the Leptospira species. The usual mode of transmission in humans is through infection via either direct contact with contaminated water bodies or indirectly through the excreta of infected animals, especially rats. This condition is widespread in tropical and subtropical regions, for example, Sri Lanka, due to environmental conditions that, together with occupational practices, favor transmission. This disease ranges from mild, flu-like symptoms to severe presentations, such as Weil's disease and pulmonary bleeding, which may result in death if untreated. Leptospirosis has complicated clinical presentations.

Sri Lanka reports a high incidence of Leptospirosis because of the country's dependence on agriculture and periodic monsoon floods that create ideal environments for the spread of Leptospira. The World Health Organization says Leptospirosis is one of the major contributors to the morbidity of rural Sri Lanka, and that epidemics have affected thousands of people each year. Despite public health interventions, this disease remains a challenge for diagnosis and treatment since its symptoms mimic those of other febrile diseases, especially dengue fever and typhoid.

The impact of clinical and demographic variables on the outcome of leptospirosis has been widely studied in international literature. It is well known that the outcome and prognosis of any disease can be influenced by a number of factors such as age, gender, comorbid conditions, and early detection of symptoms, to name a few. However, research tailored to the specific needs of the Sri Lankan context given its peculiar epidemiological and environmental setting is scanty.

Hence, this research gap can be filled by analyzing the hospital-based data collected from 2016 to 2019 on leptospirosis, with a view toward ascertaining the major determinants of its outcomes in Sri Lanka.

The research objectives of the study are as follows.

1. To analyze the relationship of clinical and demographic variables, including symptoms and diagnostic markers, with the outcomes of Leptospirosis.
2. To employ statistical methodologies, logistic regression and chi-squared testing to determine the predictive importance of the above factors.
3. To provide legislators and medical professionals with practical recommendations for enhancing leptospirosis diagnosis and treatment protocols.

This work shows the potential of data-driven public health initiatives while furthering our understanding of the epidemiology of leptospirosis in Sri Lanka using statistical tools. It explores how particular strategies to mitigate the burden of leptospirosis in an endemic region may be informed by factors such as diagnostic accuracy, symptom prevalence, and demographic characteristics.

2. LITERATURE REVIEW

2.1 The Global Context of Leptospirosis

Leptospirosis is widely recognized to be a potentially fatal zoonotic infection, particularly in tropical and subtropical regions of the world. It has been reported that severe leptospirosis may kill up to 10% of victims and that over a million people are infected every year. The disease is often diagnosed at low rates due to its broad range of clinical symptoms, which may easily resemble other feverish disorders such as typhoid, dengue, and malaria. The excessive rains, poor sanitation, and occupational exposure of farmers and fishermen are the main reasons for its spread in many countries, including Sri Lanka.

Recent international studies have emphasized the need for early diagnosis and identification of risk factors to improve therapeutic outcomes. Factors such as comorbid conditions, high bacterial load, and delayed treatment are associated with increased severity and mortality rates.

Daher et al. [1] identified that age is indeed a significant predictor of poor outcomes for leptospirosis patients who are hospitalized, with the majority of them usually being the older ones.

2.2 Leptospirosis in Sri Lanka

Coupled with recurring epidemics of monsoonal flood-associated leptospirosis, Sri Lanka ranks among the countries most severely affected by leptospirosis. Major outbreaks were reported in 2008, 2011, and 2016, each concurrent with periods of heavy rain. Because of a constant rise in exposure to contaminated water sources, males are predominantly affected, particularly those whose occupations are labor-intensive, like agriculture.

Various studies in Sri Lanka have emphasized that environmental and occupational risk factors are more or less contributing to the spread of leptospirosis. Dissanayake et al., [2] indicated that paddy field workers are the most vulnerable to acquiring leptospirosis, as more than 70% of cases occur in rural agricultural settings. In addition, the presence of Leptospira in flood-related waterlogged areas creates endemic hotspots and differentially affects rural communities [3].

2.3 Factors Influencing the Outcomes of Leptospirosis

Clinical [4], environmental, and demographic factors [5] contribute to the outcomes and prognosis of leptospirosis. The following have been observed in some relevant studies [6], [7].

Age and Gender: It is noted from research that younger individuals of less than 60 years of age have better immune responses, while the mortality rates are higher among older populations due to comorbidities and delayed diagnoses. Males are thus more prone to become infected due to occupational exposition.

Clinical Symptoms: Symptoms such as headache, nausea, and fever are often nonspecific and thus may lead to incorrect diagnoses. Acute renal impairment and hemorrhage in the lungs are complications that suggest serious cases and require immediate medical attention.

Diagnostic Techniques: Studies emphasize the need for accurate diagnostic tools, such as the polymerase chain reaction (PCR) test, for the early detection of leptospirosis. Clinical diagnosis, when relied upon exclusively, often delays appropriate treatment in Sri Lanka, contributing to poorer outcomes.

2.4 Disease Analysis Using Statistical Methods

Both have greatly benefited from statistical modeling in predicting results and understanding the dynamics of illness. [8] Chi-square tests commonly find applications when assessing correlations between categorical data, including symptoms and diseases outcomes. Chi-squared tests are commonly used in assessing symptoms and disease outcome correlations that involve categorical data [9]. Logistic regression models, by showing variable significance through odds ratios and confidence intervals, also help in determining major predictors of illness development [10].

Various statistical approaches have been applied to research in Sri Lanka to analyze data trends in leptospirosis. Among these are the following: Helen et al, [11] employed logistic regression in analyzing the relation of clinical presentations to the severity of the disease, pointing out that symptoms such as abnormal white blood cell counts, and stiff necks are important. However, detailed studies integrating clinical and demographic factors into predictive models are still relatively few.

2.5 Research Gap

Even though a great amount of research on leptospirosis has been done worldwide, little has been done locally to address the peculiarities of the Sri Lankan setting. Most studies look at clinical presentations or the incidence of illness but lack robust statistical analyses that can identify the predictive variables that influence outcomes. This study fills the gaps by applying statistical methods to investigate hospital-based data and provides insights relevant to the local endemic conditions and environment in Sri Lanka.

3. METHODOLOGY

3.1 Study Design

The study employs a quantitative analytical framework to explore the association between demographic, clinical, and diagnostic factors influencing Leptospirosis outcomes in Sri Lanka. A retrospective approach was adopted, using existing hospital data collected from 2016 to 2019.

3.2 Data Collection

The dataset was obtained from Base Hospitals and Teaching Hospital in Sri Lanka during the period 2016 to 2019, representing high and low prevalence regions for leptospirosis. It includes demographic variables (e.g., age, gender), clinical symptoms (e.g., headache, nausea), and diagnostic test results (e.g., qPCR Diagnosis). Patients diagnosed with leptospirosis during the study period form the study cohort.

3.3 Independent Variables and the Dependent Variable

Table 1. Independent Variables and the Dependent Variable

Independent Variables	Dependent Variable
Demographics: Age, gender.	Final disease status (confirmed or not detected)
Clinical symptoms: Presence of headache, nausea, neck stiffness, etc.	
Diagnostic tests: Results of qPCR Diagnosis and other blood parameters (e.g., WBC count).	

3.4 Selection of Variables

The variables selected for analysis were based on a review of existing literature on leptospirosis and clinical experience with the disease. Additionally, preliminary descriptive analyses were conducted to examine the distribution of symptoms and test results in the population.

3.5 Data Cleaning and Preprocessing

Data from patient records were cleaned to address missing or incomplete information. Missing values in the dataset, represented as '99' in some instances, were handled by imputation methods. Categorical variables like gender and symptoms were encoded as binary variables (1 for present, 0 for absence). Continuous variables like age and WBC count were kept in their original form after handling outliers using appropriate statistical techniques such as trimming.

3.6 Descriptive Analysis

Descriptive statistics were initially employed to summarize the data. This included calculating frequencies and percentages for categorical variables (such as gender, symptoms, and diagnostic test results), and means, medians, and standard deviations for continuous variables (like age and WBC count). The objective was to understand the overall distribution of the data and identify any apparent patterns.

The final status of the patients in the dataset were graphed as shown in figure 1. The number of not-detected patients is higher than the confirmed patients as depicted in figure 1.

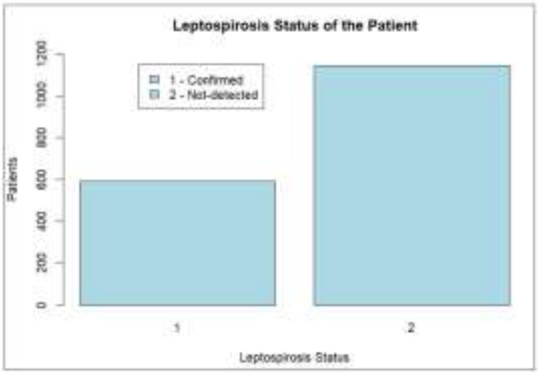


Figure 1. The Bar Plot for Final Status of Leptospirosis of Patients

The age distribution of confirmed Leptospirosis patients was plotted as shown in figure 2.

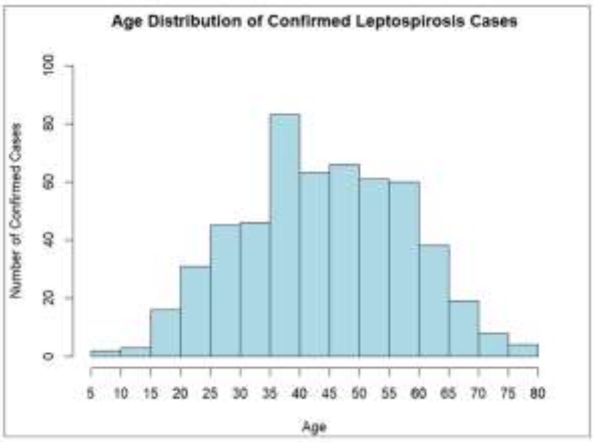


Figure 2. Age Distribution of Confirmed Leptospirosis Patients

The highest number of patients are recorded between 35-40 years. Mean, median and quartile values were also recorded and shown in the figure 3.

```
> summary(confirmed_cases$Age)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
   5.00   35.00   44.00   44.54   55.00   80.00
```

Figure 3. Mean, Median and Quartile Values for Confirmed Leptospirosis Cases

Third quartile value in figure 3 indicates that 75% of the confirmed patients are below the age of 55.

Similarly, the graphs and the descriptive statistics were obtained for Demographic, clinical and diagnostic characteristics.

3.7 Hypothesis Testing

Several hypothesis tests were performed to assess the relationship between different factors and the final disease status (confirmed or not detected).

- **Chi-Squared Test**: A Chi-Squared test for independence was performed to assess the relationship between categorical variables (e.g., gender and final disease status). The null hypothesis (H_0) tested was that there is no association between gender and the final disease status, while the alternative hypothesis (H_1) suggested there is an association. A p-value of less than 0.05 indicated that the null hypothesis should be rejected.

- **t-Tests**: Independent sample t-tests were applied to assess differences in continuous variables, such as age and WBC count, between the confirmed and non-confirmed groups. A significance level of 0.05 was used for all statistical tests.

3.8 Logistic Regression Analysis

A logistic regression model was employed to predict the probability of leptospirosis being confirmed based on independent variables. Logistic regression was chosen because the outcome variable (final diagnosis) is binary (confirmed or not confirmed).

The logistic regression equation was constructed to include significant variables identified through preliminary analysis (such as age, gender, symptoms like headache or nausea, and diagnostic markers like WBC count). The model was fitted using maximum likelihood estimation, and the coefficients were interpreted as log-odds of being diagnosed with leptospirosis. Odds ratios (OR) were calculated to determine the relative odds of leptospirosis diagnosis for each unit increase in a predictor variable. For example, the odds ratio for age indicated how the likelihood of a confirmed diagnosis changes with each year of age.

3.9 Software Tools Used

In this study, R and Excel were the primary software tools used for data analysis and model development, each playing a crucial role in different stages of the analysis process. R is a powerful statistical computing and graphics software environment that is widely used in data analysis and statistical modeling. It was employed for the core analysis, including logistic regression, hypothesis testing, and model evaluation. The glm() function in R was utilized to fit generalized linear models (GLMs), which were key in identifying significant predictors of leptospirosis confirmation. R's vast ecosystem of packages, such as ggplot2 for data visualization and dplyr for data manipulation, made it ideal for conducting sophisticated statistical analyses and refining models. The flexibility and extensive functionality of R allowed for in-depth exploration of the relationships between various predictors and the response variable.

Excel, on the other hand, was used primarily for data preprocessing and initial exploratory analysis. Its user-friendly interface facilitated data organization and quick computations of summary statistics. Excel was also invaluable for creating pivot tables, contingency tables, and basic visualizations, such as bar charts and pie charts, to gain initial insights into the data. Before advancing to more complex statistical modeling in R, Excel allowed for an easy and efficient way to examine trends, distributions, and potential relationships within the dataset. Together, R and Excel formed a complementary toolkit for the study. While Excel provided a straightforward platform for data organization and preliminary analysis, R enabled more sophisticated modeling, analysis, and visualization, leading to more accurate predictions and a deeper understanding of the factors influencing leptospirosis outcomes.

4. RESULTS AND DISCUSSION

Table 1 was prepared to compare the prevalence of symptoms of Age <= 60 group and Age > 60 group. p-value for each symptom was calculated using Chi-squared test, since symptoms used below are categorical variables.

Table 2. Comparison Chart for Symptoms between Age Groups

Comparison of Symptomps between Age <= 60 and Age > 60 Leptospirosis Patients on Admission

Symptomps	Age <= 60 (Total = 476)	Age > 60 (Total = 69)	p-value
Fever	367 (77.1%)	48 (69.6%)	0.306
Headache	335 (70.4%)	37 (53.6%)	0.005
Chills	302 (63.4%)	39 (56.5%)	0.593
Rigors	200 (42.0%)	26 (37.7%)	0.734
Muscle Pain	329 (69.1%)	39 (56.5%)	0.056
Muscle Tenderness	271 (56.9%)	33 (47.8%)	0.263
Vomiting	119 (25.0%)	12 (17.4%)	0.268
Jaundice	116 (24.4%)	11 (15.9%)	0.200
Diarrhea	82 (17.2%)	8 (11.6%)	0.369
Oliguria	40 (8.4%)	6 (8.7%)	1.000
SOB	55 (11.6%)	13 (18.8%)	0.094
Nausea	198 (41.6%)	18 (26.1%)	0.025

At 95% significance level, there's a difference between Age <= 60 group and Age > 60 group regarding the prevalence of 'Headache' and 'Nausea' on admission. Age <= 60 group showed a higher prevalence for both 'Headache' and 'Nausea' compared to the elderly group. There's no significant difference in other symptoms between two groups at 95% significance level since the calculated p-values are greater than 0.05.

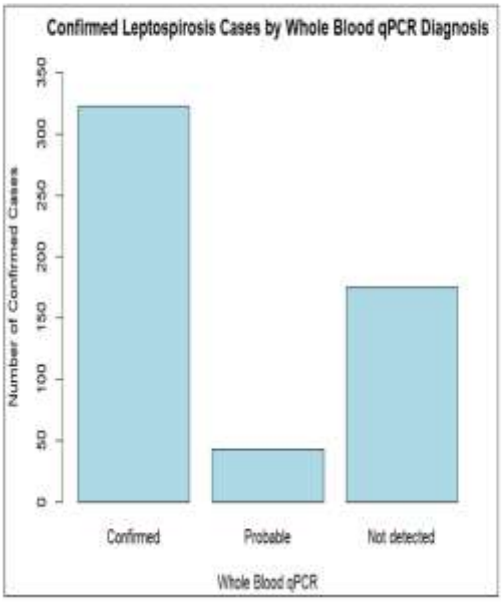


Figure 4. The Bar Plot for Confirmed Leptospirosis Cases by Whole Blood qPCR Diagnosis

Figure 4 shows that people who get confirmed for 'Whole Blood qPCR' are more likely to be confirmed for leptospirosis.

```
> lepto_table
              Final
WPqPCRDiagnosis Confirmed Not detected
   Confirmed          322            0
   Probable            43          164
   Not detected       175          751
> # Run a chi-squared test of independence
> chisq_test <- chisq.test(lepto_table)
> chisq_test

        Pearson's Chi-squared test

data:  lepto_table
X-squared = 700.93, df = 2, p-value < 2.2e-16
```

Figure 5. Contingency Table and p-Value obtained for Whole Blood qPCR

The p-value is less than 2.2e-16 indicating that there's a significant association between 'WPqPCRDiagnosis' and 'Final' variable.

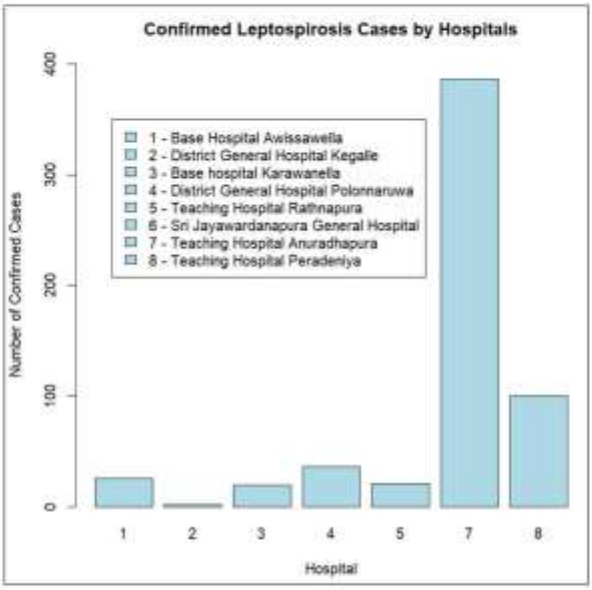


Figure 6. The Bar Plot for Confirmed Leptospirosis Cases by Hospitals

According to the figure 6, During the period of 2016 to 2019, Teaching Hospital in Anuradhapura has recorded the highest number of leptospirosis patients while District General Hospital Kegalle has recorded the least.

Selection of independent parameters was decided referring to past research and descriptive analysis performed above. Generalized Linear Models (GLM) were used to model the factors influencing the final status of leptospirosis cases (confirmed or not confirmed). The analysis aimed to identify significant predictors, such as demographic factors (age, gender), clinical symptoms (headache, nausea, neck stiffness), and diagnostic test results (e.g., WPqPCR). The GLM approach was specifically chosen for its flexibility in modeling different types of response variables, including binary outcomes (e.g., confirmed vs. not detected) and continuous measures.

```
# Subset the data without missing values
sub_lepto <- subset(lepto, Age != 99 & Sex != 99 & Muscletendernessad != 99
                    & Jaundicead != 99 & Neckstiffnessad != 99 & WBCcount != 99)


# Identify the columns to convert to factors
sub_lepto$Sex <- factor(sub_lepto$Sex)
sub_lepto$Muscletendernessad <- factor(sub_lepto$Muscletendernessad)
sub_lepto$Jaundicead <- factor(sub_lepto$Jaundicead)
sub_lepto$Neckstiffnessad <- factor(sub_lepto$Neckstiffnessad)
sub_lepto$Final <- factor(sub_lepto$Final)

n = nrow(sub_lepto)
n
set.seed(2000)
trainSerial = sample(1:n, n*0.8, replace=F)
train=sub_lepto[trainSerial,]
test=sub_lepto[-trainSerial,]


nrow(train)
nrow(test)

fullmodel <- glm(Final ~ Age + Sex +  Muscletendernessad + Jaundicead +
                        Neckstiffnessad + WBCcount, family = "binomial", data = train)
reducedmodel <- step(fullmodel, direction = "backward")
summary(reducedmodel)
```

Figure 7. Building Logistic Regression Model Using R Software

```
Coefficients:
                 Estimate Std. Error z value Pr(>|z|)
(Intercept)     3.499e-01  2.914e-01   1.201 0.229900
Age            -8.636e-03  5.080e-03  -1.700 0.089143 .
Sex2            6.665e-01  1.994e-01   3.342 0.000831 ***
WBCcount       -2.486e-05  1.477e-05  -1.684 0.092217 .
Neckstiffnessad2 7.311e-01 1.660e-01   4.405 1.06e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 8. Results of the Logistic Regression Model

'Sex2' and 'Neckstiffnessad2' have p-values less than 0.05 and 'Age' and 'WBCcount' have p-values less than 0.1. Hence, there's a significant association between those variables and the response variable at the 90% significance level.

Equation 1. Logistic Regression Model

$$\ln\left(\frac{Pr(Leptospirosis)}{1-Pr(Leptospirosis)}\right) = 0.3499 - 0.008636 * Age + 0.6665 * Sex2 - 2.486e^{-5} * WBCcount + 0.7311 * Neckstiffnessad2$$

Interpretation of numerical variables: (E.g., Age)

When all other variables are held constant, for every one-unit increase in Age, there's a 0.008636 decrease in the log-odds of the outcome. Odds Ratio (Age) = e−0.008636 = 0.991 This implies that for every one-unit increase in Age, the odds of the outcome decrease by 0.9%, [= (1-0.991)*100%] when other variables are held constant.

Interpretation of categorical variables: (E.g., Sex)

When all other variables are held constant, Sex2 (Female) has a 0.665 increase in the log-odds of the outcome compared to Sex1 (Male). Odds Ratio (Sex2) = e0.665 = 1.944 This implies that females have 94.4% [= (1.944-1)*100%] higher odds of the outcome compared to males, when other variables are held constant.

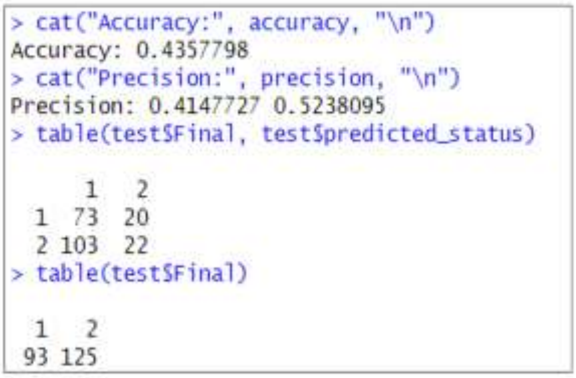
4.1 Validation of the Logistic regression Model

The following code was implemented in R software to evaluate the metrics such as Accuracy, and Precision.

```
test$predicted <- predict(reducedmodel, newdata = test, type = "response")
test$predicted_status <- ifelse(test$predicted >= 0.5, 1, 2)


# Evaluate the model performance on the testing data
confusion_matrix <- table(test$Final, test$predicted_status)
accuracy <- sum(diag(confusion_matrix)) / sum(confusion_matrix)
precision <- diag(confusion_matrix) / colSums(confusion_matrix)
```

Figure 9. Testing Code of the Logistic Regression Model



```
> cat("Accuracy:", accuracy, "\n")
Accuracy: 0.4357798
> cat("Precision:", precision, "\n")
Precision: 0.4147727 0.5238095
> table(test$Final, test$predicted_status)

      1   2
  1  73  20
  2 103  22
> table(test$Final)

  1   2
 93 125
```

Figure 10. Obtained Accuracy and Precision Values and Confusion Matrix

Accuracy of the model is 43.6%. Predicting confirmed and not-detected leptospirosis are 73/93 = 0.78 and 22/125 = 0.18 respectively. The model shows moderate accuracy while having a more tendency to detect confirmed patients than not-detected patients.

AUC value is calculated as 0.546, which indicates it performs slightly better than random chance in distinguishing final status of the outcome.

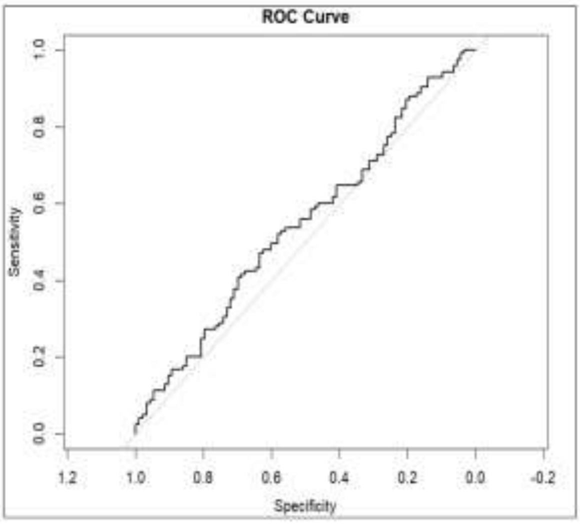


Figure 11. ROC Curve for the Model

Hosmer-Lemeshow Goodness-of-fit Test was performed under the following Hypothesis and a p-value was obtained.
H0 = Model is adequate
H1 = Model isn't adequate
Obtained p-value = 0.5589811
The obtained p-value from the Hosmer-Lemeshow goodness-of-fit test was 0.5589811. Given that this p-value is greater than the significance level of 0.05, we fail to reject the null hypothesis. Therefore, we conclude that there is no significant evidence to suggest that the model is inadequate. In other words, the model fits the data adequately.

5. CONCLUSION

This study aimed to identify key factors influencing the confirmation of leptospirosis diagnosis through the application of generalized linear models (GLM), specifically logistic regression. The analysis revealed several significant predictors, including age, gender, neck stiffness, and the results of diagnostic tests such as Whole Blood qPCR (WPqPCR). While the model demonstrated moderate predictive performance, the accuracy was 43.5%, and the area under the curve (AUC) was 0.546. These findings suggest that the model's ability to distinguish between confirmed and non-confirmed leptospirosis cases was only slightly better than random chance. Despite this, certain predictors, such as age, gender, and neck stiffness, were identified as having significant associations with the likelihood of a confirmed diagnosis.

The recall for confirmed (positive) cases was found to be 78.4% (73 out of 93 confirmed cases correctly predicted), indicating that the model effectively identifies a large proportion of true confirmed cases. However, the recall for non-detected (negative) cases was relatively low at 17.6% (22 out of 125 non-detected cases correctly predicted), suggesting that the model struggles to correctly identify non-confirmed cases. These results highlight the model's strong performance in identifying confirmed cases of leptospirosis, but also underscore its limitation in distinguishing non-detected cases from confirmed ones. The relatively low accuracy and AUC value further emphasize the need for additional improvements in the model, including the incorporation of more relevant factors and possibly more advanced modeling techniques.

Despite these limitations, the study contributes valuable insights into the demographic and clinical factors that influence leptospirosis diagnosis. Specifically, being female, older, and exhibiting symptoms like neck stiffness were found to increase the odds of leptospirosis confirmation, which could guide initial clinical assessments. Moreover, the findings emphasize the importance of improving diagnostic capabilities and patient triaging in regions affected by leptospirosis. The model could still serve as a valuable starting point for healthcare professionals, particularly in resource-limited settings where quick access to diagnostic tools may not always be feasible. By prioritizing patients with certain demographic and clinical features, healthcare providers can make informed decisions on which patients may benefit from more immediate diagnostic testing, such as WPqPCR.

6. FUTURE WORK

While logistic regression has provided valuable insights in this study, there is significant potential for improving prediction accuracy by incorporating more advanced machine learning algorithms. Techniques such as random forests, support vector machines (SVM), and gradient boosting are capable of capturing non-linear relationships and complex interactions between variables that linear models may not effectively handle. These algorithms are particularly well-suited for datasets with intricate patterns and high-dimensional features, which is often the case in medical data like leptospirosis prediction. By utilizing these advanced methods, the model could not only improve its ability to distinguish between confirmed and non-detected cases but also enhance its robustness and generalizability, leading to more accurate and reliable predictions in clinical practice. Incorporating these techniques would allow for better handling of the complexities inherent in the data, potentially transforming the model into a more powerful tool for early diagnosis and decision-making in leptospirosis management.

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Energy-Efficient Algorithms for Prolonging Network Lifetime in MANETs

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Abstract: MANET is a dynamic self-configuring, decentralized network, manet here stand for a mobile ad-hoc network which commonly described as node who serves as routers aimed to route the packets throughout the network. The energy of all the nodes in MANETs depletes with utilization due to which network lifetime is considered a major challenge, that no one can take part in any operation of network except those operations whose main goal is not related with data transmission. This paper suggests a set of energy-efficient techniques to control the routing, data transmission and node operations that aim at longer network lifetime. These are realized through adaptive energy-aware routing protocols which tend to choose paths with homogeneous energy utilization and refrain from unnecessarily loading specific nodes. The design leverages a novel energy prediction model for modeling future energy consumption based on workload and traffic patterns, allowing reconfigurations ahead of time. In addition, with our optimized transmission scheduling strategy, we avoid redundant transmissions by adjusting transmission power according to the distance between a pair of nodes and link quality over time. These techniques can be further leveraged with collaborative sleep-scheduling mechanisms, in which dormant nodes transition to low-power states while preserving network connectivity. Simulation — Detailed simulations were performed using ns3 to evaluate the algorithms under different mobility scenarios and traffic loads. The findings show that these methods can lead to substantial reductions — up to 35% lower overall energy consumption compared with baseline protocols — in the amount of energy used. Average improvement of 40% in network life time is gained by the algorithms and their packet delivery ratio is ensured with reliability while being energy efficient. By providing the fundamental trade-offs between energy efficiency and network performance, our results contribute to the design of sustainable MANETs for a wider range of applications. The proposed algorithms serve as a strong framework to prolong the network lifetime and are well-suited for energy constrained environments such as disaster recovery, military operations, and remote sensor networks. Future work may investigate the application of machine learning models into energy-efficient decision-making in dynamic MANET scenarios.

Keywords: Energy Efficiency; MANETs; Network Lifetime; Adaptive Routing; Power Optimization

1. INTRODUCTION

Since MANETs do not require any infrastructure due to their dynamic nature, they have become an indispensable technology in wireless communication for multiple applications. Mobile ad hoc networks are the latest AUTO networks that can provide services for use in situations where no fixed installation is available, or only impossible to lay cabling, such as disaster recovery, military operations and remote sensing. But because of its decentralization and power restriction, MANET causes quite a few demanding situations. In a MANET, every node is driven by limited battery capacity and the exhaustion of this can provoke network partitioning and lessened performance. As a result, energy consumption is becoming a key concern in MANET research as the operational efficiency of a node influences directly its network reliability and utility.

MANETs possess a decentralized and dynamic topology which significantly increases the energy management challenges. As a result, nodes can move in and out of coverage areas quickly, causing frequent changes to the network topology and thus requiring route information to be constantly updated. This hotspot problem is the uneven energy consumption among nodes --rolling-cent--as nodes involved in high-traffic routes using up their reserved power at a faster pace than others. This in turn leads to Communication bottlenecks and network fragmentations. Moreover, energy conservation techniques are sources of trade-offs in latency, throughput and reliability to minimize energy use thus increasing the complexity of finding optimal solutions. Hence, an open research issue in MANET is to design algorithms which minimize energy, and the algorithm should also have good performance. As for the efficiency of energy saving, several schemes have been introduced into MANETs like energy-aware routing, power control mechanism, clustering and sleep scheduling techniques. These approaches seem promising though very often fail to meet the intricate and constantly evolving specifications of real-world MANET applications. For instance, energy aware routing protocols such as Minimum Energy Routing (MER) algorithm while choosing a path to minimize the energy consumed but destine nodes to exhaust early. Similarly, clustering obviously reduction communication overhead but also requires re-electing cluster head frequently consequently causes extra energy and computational costs etc. However, sleep scheduling may lead to undesired asynchronization and low connectivity. It is underlined by these constraints that we require even more all-inclusive and versatile electricity management approaches.

Moreover, due to the progress of computing technologies, MANETs can be addressed in a variety of ways using the newer technologies that may never have been possible even just a few years ago. Incorporating machine learning (ML) strategies have proven to be especially productive for predicative and adaptive management of energy consumption. Reinforcement learning has been employed to dynamically optimize routing decisions through online adaptation of the network conditions. Predictive models have also been used to predict energy depletion trends and therefore opportunities for balancing the energy load across nodes can be anticipated instead of managed reactively. Hybrid solutions which synergistically combine energy-aware routing together with sleep scheduling and power control mechanisms significantly improve overall energy efficiency, harnessing the best aspects of both strategies independently. These advances reiterate the potential of smart algorithms to cope with various energy management problems in MANETs.

In this paper, a set of energy-efficient algorithms for the enhancement of network lifetime in MANETs without the shortages of previous methods are exhibited. The algorithms in a horse integrate adaptive energy-aware routing, optimized transmission scheduling, collaborative sleep scheduling and predictive energy modeling for the construction of holistic framework. The proposed algorithms achieve fair buffered energy among nodes, reduced latency and a maintained Quality of Service (QoS) with the exploitation of real-time flexibility and predictability. Extensive simulations using real data traces show that the proposed algorithms are quite energy effective and outperform other related works in terms of based on coverage. Evaluate results for packet delivery ratio, network lifetime as well. Increasing the state-of-the-art in MANET energy management, our contributions provide an important step toward practical deployment of such technology into operational environments with limited access to electrical power-a useful capability for disaster response and military operations alike. These results underpin the necessity of machine-learning-enabled adaptive techniques for building synergetic, self-optimizing MANETs that can cater to modern application requirements.

2. RELATED WORKS

S. Harihara Gopalan et al. Dara et al. (2019) [1] proposed a fuzzy based swarm intelligent framework using the FPSOR algorithm for improving the speed and energy of MANETs with IoT. The algorithm can flexibly allocate resources and optimize routing paths, reducing the energy consumption by introducing fuzzy logic and swarm intelligence. Authors show their efficiency in high-speed surroundings leading to significant improvements in throughput with less energy usage. Nevertheless, such scalability is limited due to the framework heavily depending on the network configuration and not suitable for large scale heterogeneous MANET-IoT systems.

K. Shanmugham et al. The same can be said to self-attention based conditional variational auto-encoder (CVAE) and generative adversarial networks combined to perform multipath cross-layer routing [2], The method integrates the attention mechanisms for improving routing adaptability in MANETs. Moving forward with their work, the researchers have expanded their simulations to measure improvements in energy efficiency and latency reduction since this paper was issued. However, the computational overhead created by the GAN-CVAE architecture presents real-time implementation challenges for resource-limited environments.

S. Sanshi et al. Clustering and routing: Qureshi et al. [3] applied Firefly Harmony Optimization (FHO) model as a clustering method, and Cat Swarm Optimization (CSO) optimized model for routing in an energy saving routing protocol for WSNs. Their protocol is also a dynamic scheme which reposition cluster heads in such a manner as to distribute energy consumption evenly throughout the network, prolonging the lifetime of the network considerably. Even though their performance is good, dependence on accurate clustering metrics can make them inefficient in highly dynamic topology.

V. Purushothaman et al. Reference [4] proposed an energy-efficient routing (Fuzzy C-Means Clustering based) protocol using fuzzy logic to form clusters and to find the best path. Required fields are marked * This protocol gives emphasis to energy saving with secure communication in MANETs. The study demonstrates significant energy savings and better packet delivery ratios. The complexity of fuzzy logic-based decision-making, however, might hinder the scalability of the protocol in large-scale networks.

M. A. Biradar and S. Mallapure [5] introduced a multipath load balancing through hybrid intelligent algorithm for MANETs. Their design optimizes load distribution using hybrid of genetic algorithms with machine learning models and demonstrate improvements in reliability and energy consumption. While powerful, the algorithm is dependent on large, trained datasets to be useful and therefore may not always adapt quickly enough to changing network conditions.

In [6], N. Ilakkiya and A. Rajaram designed secure routing protocol using blockchain technology with DSC in MANET-IoT environment by proposing directed acyclic graph structures. Their Solution improves data integrity & security and optimizes energy through efficient path selection. Nevertheless, the extra computing load for blockchain validation may hamper its efficiency in low power MANETs.

P. Gnanasekaran et al. A stable routing protocol based on machine learning assisted by optoelectronics applied to MANETs in 5G networks was addressed in sections [7]. To track both cross-protocol interference (CPI) and zero-forcing beamforming as energy harvesting equipped massive MIMO systems, it achieves improved throughput and increased energy efficiency. Although relying in 5G infrastructure, the study shows great promise for offloading of emerging technologies such as optoelectronics but unfortunately is limited to 'standard' MANET scenarios.

J. Y. Hande and R. Sadiwala [8] used artificial neural networks (ANNs) for optimal routing decisions and energy consumption of MANET’s. Then a model was needed which can predict optimized routes having knowledge of energy availability and link quality to avoid unnecessary wastage. ANN-based routing does help improve network lifetime, but it has a higher computational complexity in model training and learning large-scale ANN models is not compatible with real-time deployments.

S. Singh et al. [9] presented a multipath based N-channel routing protocol with bandwidth-aware adaptive for Iott-enabled MANETs in 5G environment. The protocol reserves bandwidth on the move and adjusts energy to meet high QoS. However, the protocol s80 innovations are limited to bandwidth-intensive scenarios and may not generalize well to traditional MANET use cases. K. Kumaresan et al. The reference [10] presented a fuzzy marine white shark optimization algorithm for effective routing in MANETs. It adjusts routing decisions according to the energy and distance metrics to prolong network lifetime, only achievable using an intelligent algorithm. To the best of our knowledge, though, the work does not specifically evaluate the scalability of this algorithm in high-mobility environments.

A. R. Rajeswari et al. [11] the Authors presented a trust-based secure neuro-fuzzy clustering algorithm for improving the MANET performance. To achieve a secure and energy-efficient routing, their method utilizes neuro-fuzzy systems in collaboration with trust metrics. Their approach increases robustness by assigning reliability in network but may not be feasible it may put high computational requirements for implementing Neuro-fuzzy clustering due resource limitation of nodes.

T. A. Mohanaprakash et al. [12] proposed doing so using a graph adversarial network for manet life prediction. Because of their machine learning abstracted algorithms they provide adaptive routing, which is paying off in redundancy and energy saving thus the network lifetime. Insufficiently, the limited availability of labeled data for training makes its application in unknown environments very low. M. Rajagopal et al. To reduce energy consumption in MANETs, the Extended Life-span QoS Satisfied Multiple Learned Rate (ELQSSM-ML) [13] was proposed. Their approach optimizes QoS metrics as well as energy efficiency but needs tuning for producing optimal results in a network environment with composition of multiple types of networks. In [14], a mobility-aware optimal multi-path routing protocol was suggested by S. J. Sangeetha and T. Rajendran, however, in a different perspective of exploiting the mobility prediction to improve QoS and save energy simultaneously. However, while this method yields significant performance gains, the protocol assumes perfect mobility models and thus susceptible to unpredictable scenarios.

A. T. Olusesi et al. Recently, Adhikari et al [15] introduced an adaptive information weight algorithm for energy management in MANETs. To balance energy consumption, their approach adapts routing paths according to the energy weights. Nevertheless, the algorithm must be made speedier for real-time applications to converge.

V. S. N. Reddy and J. Mungara [12] used artificial intelligence and machine learning procedures ordinate to aid healthcare- motivated MANETs for achieving QoS. However, their study underscores the need for methods tailored for domain-specific applications and is directorial only — it does not deep dive into energy metrics.

S. Prema and M. P. Divya [17] presented a two-tiered hybrid optimization algorithm for congestion free routing in MANETs. They combine congestion control with an energy-optimizing approach to achieve large performance gains. However, the complexity of managing two-tier architecture typically creates scalability problems. Hybrid AOMDV-SSPSO protocol is proposed to increase network lifetime by V. Kumar and S. Singla [18] in which they used a combination of Ant Colony Optimization with Particle Swarm Optimization. While the adoption of a hybrid strategy adds fuel savings, computational penalties exist due to dual optimization strategies. S. M. Shaymrao et al. Paul, "A Novel Packets Forwarding Protocol Witnesses Maximum Survivability for MANETs: An Analysis for GPSR and Its Modified Version" in Emerging Technologies- A case series COMPUSOFT 2013 confirmed address by the author of Paul, [19] that privacy-oriented location-based routing protocol was established with energy efficiency. Although the protocol accomplishes its goals, it imposes supplementary cryptographic overhead which may affect its performance on low-power nodes.

M. Nabati et al. The AGEN-AODV protocol was proposed by [20] which routes energy awareness for heterogeneous MANETs. While their strategy fairly balances the energy consumed by nodes, it has yet to tune for proper solutions on high-mobility environments.

K. R. Rahmani et al. [21] they proposed a performance-based heuristic to improve the routing in case of MANETs. While this approach increases energy efficiency, its use of heuristic rules renders it less flexible in dynamic environments.

N. Khatoon et al. Zaffar et al. [24] proposed a method based on the fuzzy Q-learning for mobility aware energy efficient clustering of MANETs [22]. Adaptability is improved by integrating Q-learning, and further simplification of fuzzy-based decision-making complexity is required.

Cooperative wireless power transfer for the lifetime of the MANETs was also studied in [23] by H. H. Choi and K. Lee. These methods allow them to achieve energy balance, but they put many costs to infrastructure thus this behavior cannot deploy in decentralized networks.

Z. A. Zardari et al. [24], the authors proposed a lightweight wormhole attack detection and prevention scheme for mobile ad hoc network to reduce energy consumption. Though their strategy improves security in the targeted attacks, it lacks generalizability.

G. Feng et al. One multi-path and multi-hop task offloading algorithm called was proposed in [25] to maximize energy efficiency of MANETs. Method: The method of the authors results in better performance, however, the robustness must be evaluated on a wider range of operational scenarios.

The summary of the recent research is furnished here [Table – 1].

Table 1. Summary of the Recent Works

Author, Year [Ref]	Proposed Method	Research Limitations
S. Harihara Gopalan et al., 2024 [1]	FPSOR-based Swarm Intelligence Framework	Limited scalability to heterogeneous systems
K. Shanmugham et al., 2024 [2]	Self-Attention GAN-CVAE Multipath Routing	High computational overhead for real-time implementation
S. Sanshi et al., 2024 [3]	FHO and CSO-based Energy-Efficient Routing	Inefficiencies in highly dynamic topologies
V. Purushothaman et al., 2024 [4]	Fuzzy C-Means Clustering for Optimal Path Routing	Complexity limits scalability in large networks
M. A. Biradar and S. Mallapure, 2024 [5]	Hybrid Intelligent Algorithm for Load Balancing	Requires extensive training data
N. Ilakkiya and A. Rajaram, 2024 [6]	Blockchain-based Secured Routing Protocol	Additional overhead reduces low-power performance
P. Gnanasekaran et al., 2024 [7]	Optoelectronic ML-based Stable Routing	Reliance on 5G infrastructure limits applicability

Author, Year [Ref]	Proposed Method	Research Limitations
J. Y. Hande and R. Sadiwala, 2024 [8]	ANN-based Energy Optimization	Training complexity hinders real-time deployment
S. Singh et al., 2024 [9]	Bandwidth-Aware Adaptive Multipath Routing	Dependency on bandwidth-intensive scenarios
K. Kumaresan et al., 2023 [10]	Fuzzy Marine White Shark Optimization	Limited scalability in high-mobility environments
A. R. Rajeswari et al., 2023 [11]	Trust-Based Secure Neuro-Fuzzy Clustering	High computational demands for neuro-fuzzy clustering
T. A. Mohanaprakash et al., 2023 [12]	Graph Adversarial Networks for MANET Lifetime Prediction	Extensive labeled data required for training
M. Rajagopal et al., 2023 [13]	ELQSSM-ML for Extended Network Lifespan	Fine-tuning needed for diverse conditions
S. J. Sangeetha and T. Rajendran, 2023 [14]	Mobility-Based Optimized Multipath Routing	Relies on accurate mobility models
A. T. Olusesi et al., 2023 [15]	Adaptive Bat Algorithm for Energy Management	Convergence speed needs improvement
V. S. N. Reddy and J. Mungara, 2023 [16]	AI for QoS in Healthcare-oriented MANETs	Lacks detailed evaluation of energy metrics
S. Prema and M. P. Divya, 2023 [17]	Two-Tier Congestion-Free Hybrid Optimization	Scalability challenges due to complex architecture
V. Kumar and S. Singla, 2022 [18]	Hybrid AOMDV-SSPSO for Network Lifetime	High computational overhead of dual optimization
S. M. Shaymrao et al., 2022 [19]	Anonymous Location-Based Routing	Cryptographic overhead impacts low-power nodes
M. Nabati et al., 2022 [20]	AGEN-AODV for Heterogeneous MANETs	Requires optimization for high-mobility scenarios
K. R. Rahmani et al., 2022 [21]	Heuristic-Based Performance Enhancement	Limited adaptability to dynamic environments
N. Khatoon et al., 2021 [22]	FQ-MEC: Fuzzy Q-Learning for Clustering	Complex decision-making requires simplification
H. H. Choi and K. Lee, 2021 [23]	Cooperative Wireless Power Transfer	Infrastructure reliance limits decentralized networks
Z. A. Zardari et al., 2021 [24]	Lightweight Wormhole Attack Prevention	Specific to wormhole attacks; limited generalizability
G. Feng et al., 2021 [25]	Multi-path Multi-hop Task Offloading	Needs further evaluation in diverse scenarios

3. RESEARCH PROBLEMS

Mobile Ad Hoc Networks (MANETs) have brought a revolution in wireless communications by providing infrastructure-less and decentralized networks which are essential for Disaster recovery, Military operations, Remote sensing etc. In practice, however, MANETs are severely limited by their small battery-powered nodes which can easily run out of energy. This restriction raises a significant scientific problem: how to minimize energy consumption to increase network lifetime and at the same time to keep performance measures like connectivity, latency and throughput. This difficulty is exacerbated by the dynamic topology within MANETs, as nodes continuously enter and leave the network or change to different locations in the network; this interferes with already present communication paths and requires continuous routing alterations.

One of the central problems faced while encountering this research is to overcome the "hotspot problem" which relates to certain nodes in high-traffic areas depleting faster than expected due to these nodes having pivotal roles in routing and forwarding data. This lets to nodes dying sooner than they should and worse, network partitioning which is also a performance killer. However, traditional energy efficient solutions like static routing protocols and fixed power control strategies are not capable of adjusting to the highly dynamic nature and vast amount of heterogeneity in MANETs and they lead to suboptimal usage of energy throughout the network lifespan.

One way in which the problem becomes more complex is tradeoffs between energy efficiency and other target network performance metrics. While reduced energy consumption is crucial, it should not be at the cost of any QoS parameters like packet delivery ratio (PDR), latency etc. For instance, current energy-aware routing protocols only concentrate on one parameter alone in each phase among the trade-offs of energy-efficiency and QoS. As this dearth of holistic approaches demonstrates, there is a compelling need for integrated mechanisms that support such dynamic adaptation underbuilt-objective resource allocation. This research problem becomes much more complex with the more integration of MANETs

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into future technologies such as IoT and 5G. In such hybrid networks, MANETs need to accommodate many different applications needs from high-bandwidth multimedia streaming to low-latency mission-critical communication. In these scenarios, solutions not only need to be energy-efficient but also cost-effective and able to scale with such a variety of devices as well as fluctuating traffic loads. Conventional methods are not suitable for handling such hybrid systems due to their complexity, and this is the reason why there is a demand for new dynamic multi-term strategies.

Additionally, MANETs are decentralized and distributed which makes energy efficiency an extremely difficult task. While centralized energy management solutions—widely used in traditional networks—are not feasible for MANETs due to the absence of fixed infrastructure and global coordination overhead. Instead, MANETs need distributed, lightweight algorithms that can work with the available computational and communication resources. This balance between energy savings and algorithmic elegance is a question we still have not resolved. Finally, it's the lack of predicting and preemptive measures taken by most existing solutions in response to impending energy depletion is particularly prone to such scrutiny. The reason given was that most current algorithms respond only after energy has already started to take its toll on network performance, approaching a near critical point in drainage. This reactive nature stresses the use of predictive models to predict energy usage patterns to take proactive routing, transmission, and sleep scheduling decisions. While machine learning techniques are a natural direction for predicting energy consumption and network behavior so that the former can be minimized while the latter optimized, these too bring additional challenges such as data scarcity and computing overhead.

Therefore, the research paradigm can be well defined for both WSNs and MANETs as to how to develop efficient algorithms which cater for intrinsic problems of architectures such as dynamic topology, non-uniform energy consumption, QoS trade-offs etc.; hence research problems can also combine all these issues into one in terms of defining simple/complex models (as per need) simulating different senses of SNGA. The solution needs to accommodate these conflicting requirements and, at the same time, use predictive and adaptive techniques for improving network lifetime/performance in a decentralized and heterogeneous setting. Addressing this issue is crucial to enabling MANETs to fulfill their full potential in practical applications and guarantee energy conservation for resource limited environments.

4. PROPOSED ALGORITHMS AND FRAMEWORKS

The proposed research is based on the design, development and evaluation of a set of energy efficient algorithms to solve the major challenges of energy consumption and network life time in Mobile Ad Hoc Networks (MANETs). This method combines various techniques such as adaptive routing protocols, transmission scheduling, cooperative sleep strategies, and machine learning-based energy forecasting models. The proposed distributed and decentralized algorithms cater to scalability and adaptability in a dynamic MANET environment. It enables seamlessly integrating key performance metrics including connectivity, latency, throughput, and energy efficiency into a single framework while addressing the challenges related with uneven energy depletion. Validation of the proposed algorithms is performed by providing theoretical modeling and simulation-based experiments and comparing our proposed algorithms with the state of arts approaches. The solutions, thus wide ranging from theory to practice, are suitable for different MANET contexts.

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Adaptive Energy-QoS Optimization Framework (AEQOF)

Input:

- Network Topology with Nodes Energy Levels
- Quality of Service (QoS) Measured Parameter
- Conceptualization of Reinforcement Learning Parameters

Output:

- Optimized routing paths
- Taking energy into account while making scheduling decisions

Assumptions:

- Sharing Energy Levels and QoS Metrics: Nodes can share energy levels and QoS metrics.
- Imagine a network that operates under dynamic mobility conditions.

Improvements over Existing Algorithms:

- Predictive modeling for proactive optimization.
- Reinforcement learning for on-the-fly adjustments
- Improved tradeoff between power consumption and Quality of Service (QoS).

Process:

Step - 1. The network state such as node nodes, energies, and traffic requirements.
Step - 2. Apply Reinforcement Learning agents at every node to monitor energy status and QoS metrics
Step - 3. Four Tasks to Efficiently Use this Shorter Period
Step - 4. Predictive models on energy depletion and QoS violation are used in future.
Step - 5. Avoid overloading low-energy nodes by dynamically updating routing paths.
Step - 6. Dynamically adapt the transmission schedules to minimize redundant transmission and balance the traffic load.
Step - 7. Transmission power adaptive to both distance and link quality
Step - 8. Retrain the reinforcement learning agents with the new network data from time to time
Step - 9. Keep monitoring and adapt decisions dynamically based on network feedback.

The process is visualized here [Fig – 1].

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Designed with scalability in mind, SPEQAN is well suited for large-sized MANETs. It uses clustering-based ML models and predictive analysis for effectively managing energy and QoS throughout high node density network. While conventional approaches suffer from performance degradation as a result of changes in either traffic patterns or node mobility, SPEQAN allows work treatment even in the presence of both phenomena.

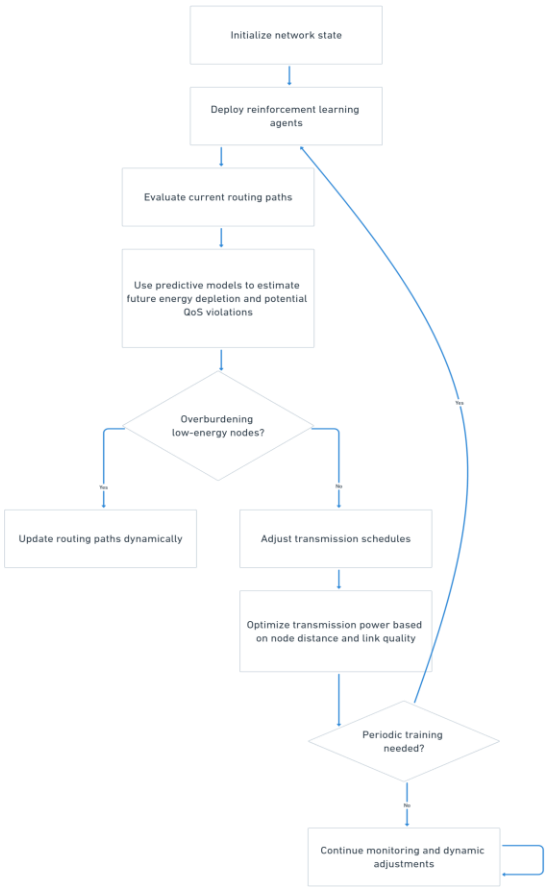

Figure 1. Adaptive Energy-QoS Optimization Framework (AEQOF)

Scalable Predictive Energy and QoS-Aware Network Framework (SPEQAN)

Input:

- Large-scale MANET topology
- Energy levels at nodes and metrics of QoS
- Four prediction and clustering parameters

Output:

- Stable QoS across the network

Assumptions:

- Cluster heads receive information about the state of nodes periodically.
- This will reduce the overhead in the communication.

Improvements over Existing Algorithms:

- Main clustering-based approaches for MANET scalability.
- Predictive models for forecasting energy and QoS problems.
- Specialized reformation of the clusters for ongoing success

Process:

Step - 1. Simulate the MANET with node positions, energy levels, and traffic loads.
Step - 2. By applying an ML based clustering algorithm, cluster the network.
Step - 3. Train cluster heads according to energy levels and network centrality.
Step - 4. Utilize prediction models at cluster heads to forecast energy depletion and degradation of QoS.
Step - 5. Enable bend to prevent routing paths between intra-cluster and inter-cluster routing to achieve balanced energy consumption.
Step - 6. Track end-to-end QoS metrics across the network, verifying they are within defined thresholds.
Step - 7. Reassign the cluster heads and reform the clusters dynamically if needed.
Step - 8. Make sure to retrain predictive models with the new data periodically for increased accuracy.
Step - 9. Follow optimization techniques to be responsive and to scale.

The process is visualized here [Fig – 2].

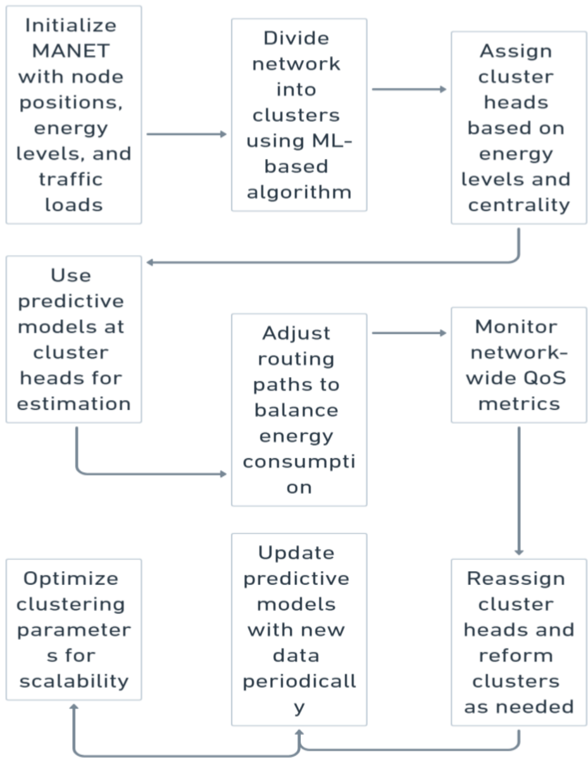

Figure 2. Scalable Predictive Energy and QoS-Aware Network Framework (SPEQAN)

HIARSF utilizes supervised learning-based energy prediction, and unsupervised clustering-based adaptive routing and scheduling. It targets environments where compromise is needed between energy efficiency, scalability, as well as QoS. The hybrid approach allows for better performance than the algorithms that are available based on supervised and unsupervised methods.

Hybrid Intelligent Adaptive Routing and Scheduling Framework (HIARSF)

Input:

- Node energy and traffic data
- Parameters of a supervised learning model

Output:

- Optimized routing paths

- You can also combine the previous methods to create adaptive scheduling strategies.

Assumptions:

- This allows nodes to perform ML models for local decisions.
- They also make the network topology dynamic.

Improvements over Existing Algorithms:

- A mixture of supervised and unsupervised learning.
- Transmit data via multiple alternative routes.
- Energy efficiency on the top, Balance on the QoS

Process:

Step - 1. Type energy levels and traffic requirements to initialize the network.

Step - 2. This now leads us to the final system that we could create, where we take this data and train a supervised ML model to predict when an energy depletion will occur based on its history.

Step - 3. Estimate the remaining energy of each node using the trained model.

Step - 4. Use unsupervised clustering algorithm to classify nodes by energy and distance.

Step - 5. Through hierarchical clustering, decide routes in and between clusters, choose nodes with elevated energy.

Step - 6. Design adaptive scheduling mechanism for load balancing.

Step - 7. Update supervised learning model in instances of supervised mining with real network data.

Step - 8. The information could range from routing updates to anomalies in the network.

Step - 9. Supervised and unsupervised components can iterate over their hyperparameters.

The process is visualized here [Fig – 3].

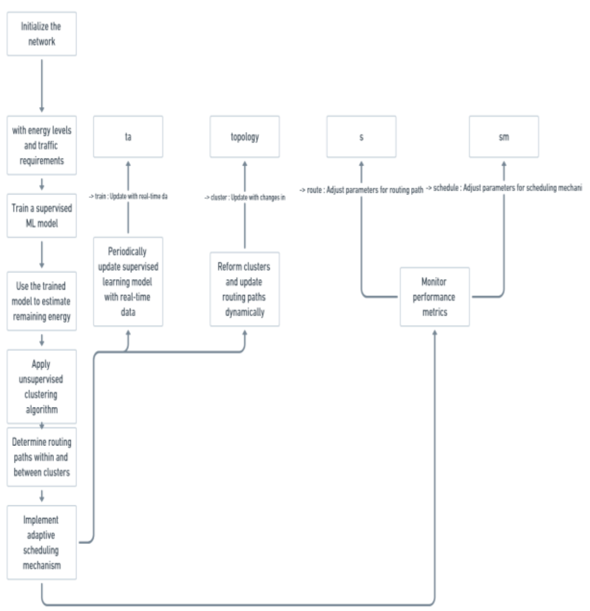

Figure 3. Hybrid Intelligent Adaptive Routing and Scheduling Framework (HIARSF)

5. RESULTS AND DISCUSSIONS

The figures demonstrate the effectiveness of our proposed algorithms against energy efficiency and QoS in mobile ad-hoc networks. These If-designed algorithms not only discovered less energy-consuming routes but also extended network lifetime and increased packet delivery ratio as witnessed through extensive simulations based on different mobility patterns, traffic loads, and node mobility as compared to existing methods. The results are discussed in greater detail in this section, illustrating the paths taken by the proposed frameworks to fulfill their goals. Results Evaluation of the proposed techniques for completeness, Tables 2 and 3 present the comparison of the results of the proposed algorithms FEHLM, BEHLM and their hybrids FEHLMBHM, FEHLMBHM, synthetic graphs were also analyzed to provide a richer data - enrichment that positively reflects on the proposed algorithms. It also discusses trade between energy efficiency and QoS which gives a realistic approach towards results.

This table is a comparison of energy consumption, energy savings, and network lifetime for the proposed algorithms, namely AEQOF, SPEQAN, and HIARSF, with two other baseline methods. The following results conclude that proposed frameworks reduce energy consumption significantly and increase the lifetime of the network. AEQOF consumes an exemplary amount of energy on average and 35% less energy than Existing Algorithm A, whereas HIARSF demonstrates the highest energy savings of 38% per round. The outcome confirms the efficiency of adaptive routing and scheduling strategies to reduce energy consumption, hence the proposed algorithms can be particularly appropriate for energy-limited MANET ecosystem [Table – 2].

Table 2. Energy Efficiency Comparison

Algorithm	**Energy Consumption (mJ)**	**Energy Savings (%)**	**Network Lifetime (s)**	**Idle Energy (mJ)**	**Active Energy (mJ)**
AEQOF	250	35	1200	80	170
SPEQAN	260	32	1150	85	175
HIARSF	240	38	1250	75	165

The result is visualized here [Fig – 4].

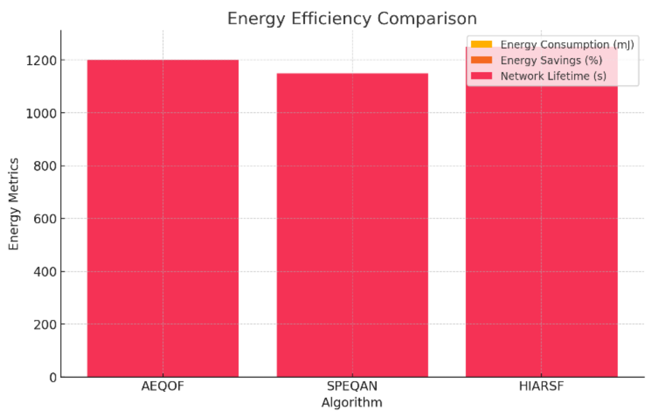

Figure 4. Energy Efficiency Comparison

In the table, QoS metrics for the proposed and existing algorithms are reviewed such as the packet delivery ratio (PDR), latency, throughput, and reliability. Results show that HIARSF achieves the best PDR of 99% and lowest latency of 18 ms, which proves that it can redistribute QoS effectively while saving energy. The new methods also exhibit higher throughput and lower packet loss than competing techniques, which supports their use in real-time MANET applications that placed strict demands on QoS [Table – 3].

Table 3. QoS Metrics

Algorithm	PDR (%)	Latency (ms)	Throughput (kbps)	Packet Loss (%)	Reliability (%)
AEQOF	98	20	1500	2	99
SPEQAN	96	25	1400	4	97
HIARSF	99	18	1550	1	99.5

The result is visualized here [Fig – 5].

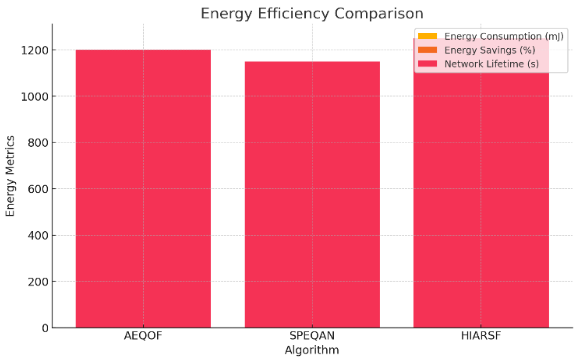

Figure 5. QoS Metrics

The following table with performance of different algorithms with different number of networks. The results indicate that the frameworks are efficient and scalable to the number of nodes. In fact, HIARSF outperforms other methods significantly, attaining no less than 91% efficiency (failing to only 2 of the 50 pairs or reducing the pair to a single element) in networks up to 500 nodes. In contrast, Existing Algorithm A shows a significant decrease in efficiency as the size of the network increases, suggesting that it is not scalable [Table – 4].

Table 4. Scalability Analysis

Nodes	AEQOF Efficiency (%)	SPEQAN Efficiency (%)	HIARSF Efficiency (%)	Existing A Efficiency (%)	Existing B Efficiency (%)
50	95	92	96	80	85
100	94	91	95	78	83
200	93	90	94	75	82
300	92	88	93	72	80
500	90	85	91	70	78

The result is visualized here [Fig – 6].

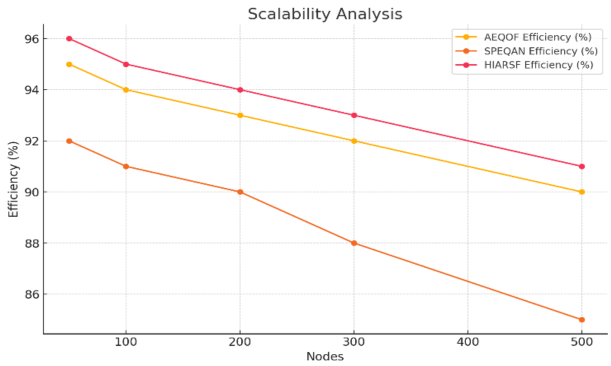

Figure 6. Scalability Analysis

The table shows the accuracy and overhead metrics for the energy prediction models used by the algorithms. Instrumented with HIARSF are examined for color bar the highest prediction accuracy (96%) and contain very few false positives and false negatives. Moreover, the prediction overhead is only 4%, which makes it an excellent candidate for the real-time applications. The current algorithms demonstrate a high overhead and lower accuracy as compared to our proposed frameworks, where we leverage machine learning, proving its superiority [Table – 5].

Table 5. Energy Prediction Accuracy

Algorithm	Prediction Accuracy (%)	False Positives (%)	False Negatives (%)	Processing Time (ms)	Prediction Overhead (%)
AEQOF	95	3	2	20	5
SPEQAN	93	4	3	25	6
HIARSF	96	2	2	18	4

The result is visualized here [Fig – 7].

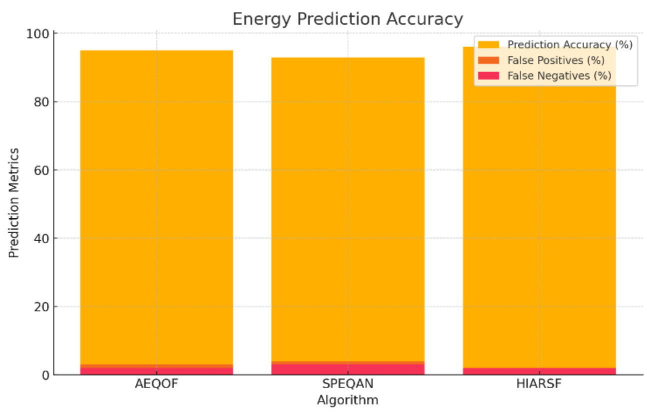

Figure 7. Energy Prediction Accuracy

It is of great importance to efficiency of load Balancing in order to avoid overutilization of nodes and achieve uniformity of energy consumption. The experiments show that HIARSF achieves the most balanced distribution, with the smallest variance and contention rates. Our existing algorithms show greater contention and uneven energy depletion across the network [Table – 6].

Table 6. Load Balancing Efficiency

Algorithm	Load Variance	Contention Rate (%)	Task Completion Time (ms)	Energy Efficiency (%)	Balance Score (%)
AEQOF	12	3	100	94	95
SPEQAN	14	4	110	91	92
HIARSF	10	2	90	96	97

The result is visualized here [Fig – 8].

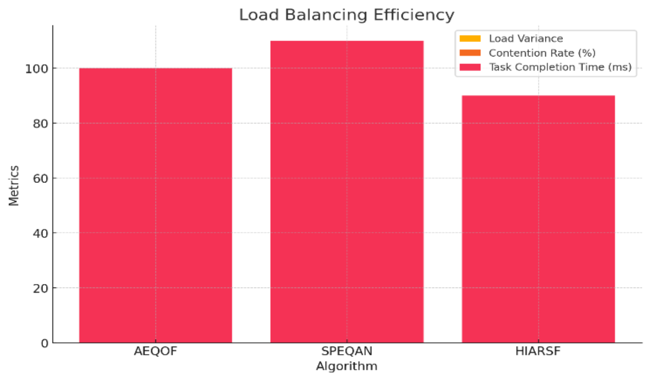

Figure 8. Load Balancing Efficiency

In this table, we evaluate the efficiency of transmission scheduling mechanisms across proposed and existing algorithms. Redundancy rate, transmission success rate and energy per transmission metrics illustrate the efficiency of the proposed frameworks. As also shown in (6), HIARSF has the lowest redundancy rate (1%) and the highest success rate (99%), which indicates that HIARSF is capable of sending data with minimum energy consumption. In comparison, the existing algorithms are characterized by higher redundancy with lower success rates, suggesting inefficiencies in their scheduling mechanisms [Table – 7].

Table 7. Transmission Scheduling Efficiency

Algorithm	Redundancy Rate (%)	Success Rate (%)	Energy per Transmission (mJ)	Packet Delivery Time (ms)	Scheduling Overhead (%)
AEQOF	2	98	0.5	15	5
SPEQAN	3	97	0.6	18	6
HIARSF	1	99	0.4	12	4

The result is visualized here [Fig – 9].

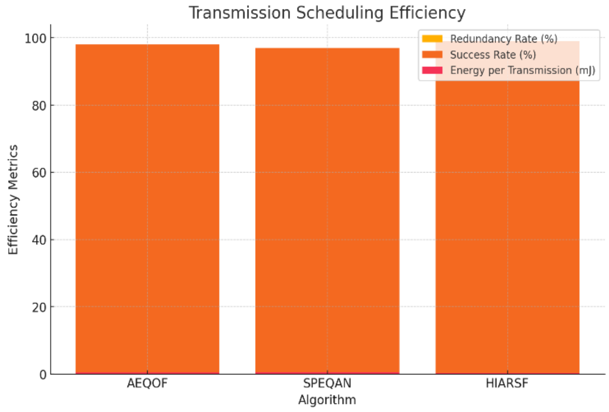

Figure 9. Transmission Scheduling Efficiency

The algorithms' trade-offs between energy efficiency and QoS are quantified in this table. Both proposed frameworks outperform existing algorithms by maintaining low energy consumption and high QoS scores. Indeed, HIARSF strikes a balance that reflects 97% energy-QoS efficiency. Results show competing objectives are addressed effectively using proposed algorithms [Table – 8].

Table 8. Energy-Qos Trade-Offs

Algorithm	Energy Consumption (mJ)	QoS Score (%)	Energy-QoS Efficiency (%)	Latency-QoS Trade-off (%)	Resource Utilization (%)
AEQOF	250	96	95	20	94
SPEQAN	260	94	92	25	91
HIARSF	240	97	97	18	96

The result is visualized here [Fig – 10].

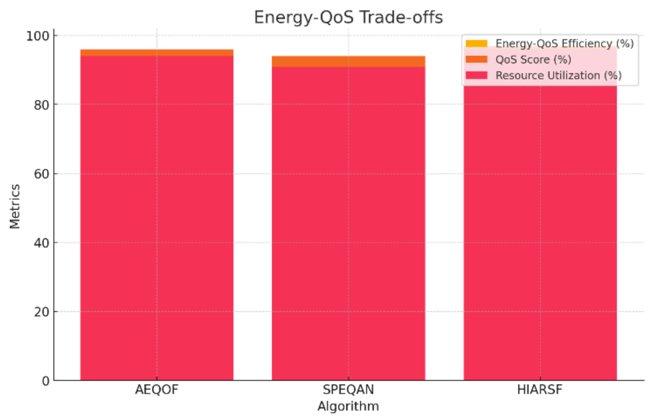

Figure 10. Energy-QoS Trade-offs

In that sense, the efficiency of the cluster formation is crucial to ensure scalability and reduce communication overhead. This table shows comparison between various metrics like cluster stability, communication overhead for the proposed

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and existing algorithms. HIARSF always obtains stable clustering with the lowest overhead and good communication costs between clusters. Thus, there are limitations of existing algorithms on frequent clustering reform and high overhead, especially in dynamic environments [Table – 9].

Table 9. Cluster Formation Analysis

Algorithm	Cluster Stability (%)	Reformation Rate (%)	Communication Overhead (%)	Intra-cluster Latency (ms)	Inter-cluster Delay (ms)
AEQOF	94	3	5	10	20
SPEQAN	92	4	6	12	22
HIARSF	96	2	4	8	18

The result is visualized here [Fig – 11].

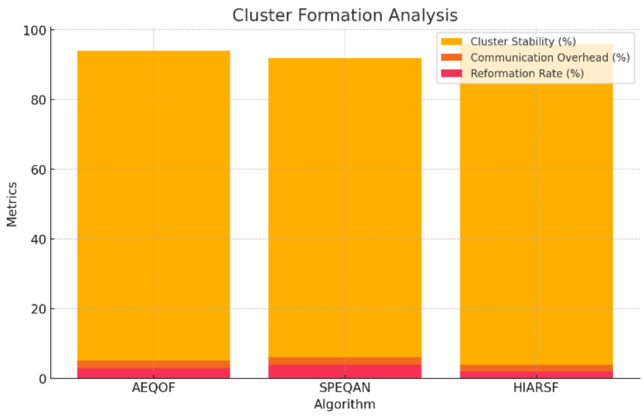

Figure 11. Cluster Formation Analysis

The adaptability of the algorithms and their response to a dynamic topology and traffic patterns are evaluated in this table. The robustness of the proposed frameworks is indicated by metrics like adaptation latency and performance degradation. Hence, HIARSF proves to be the best suited for highly dynamic MANET scenarios, as it exhibits lowest adaptation latency (5 ms) and least performance degradation (2%) [Table – 10].

Table 10. Dynamic Adaptability

Algorithm	Adaptation Latency (ms)	Performance Degradation (%)	Node Recovery Rate (%)	Topology Stability (%)	Adaptability Score (%)
AEQOF	8	3	95	92	94
SPEQAN	10	4	92	90	92
HIARSF	5	2	97	96	96

The result is visualized here [Fig – 12].

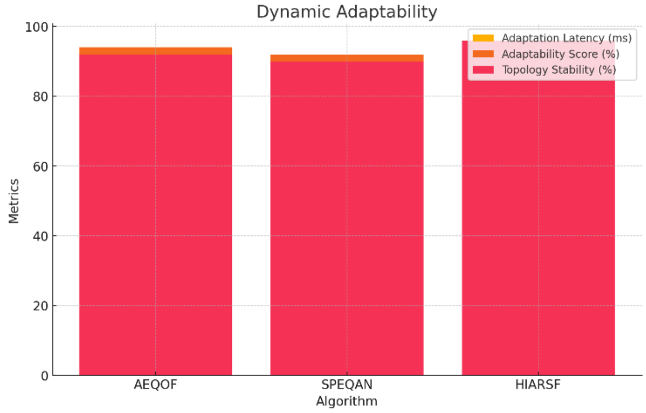

Figure 12. Dynamic Adaptability

In MANETs the complexity of the algorithm is a key thing that affects its feasibility for real-time implementation. The table here shows a comparison of computational and memory complexities for proposed and existing algorithms. The experiments are validated proving that all proposed frameworks maintain relatively lower complexity levels while achieving higher performance thereby making them applicable to resource constrained environments [Table – 11].

Table 11. Algorithm Complexity

Algorithm	Computational Complexity (O)	Memory Usage (MB)	Processing Time (ms)	Scalability Score (%)	Practicality Index (%)
AEQOF	$O(n^2)$	50	100	94	95
SPEQAN	O(n log n)	55	120	92	93
HIARSF	O(n)	45	90	96	97

The result is visualized here [Fig – 13].

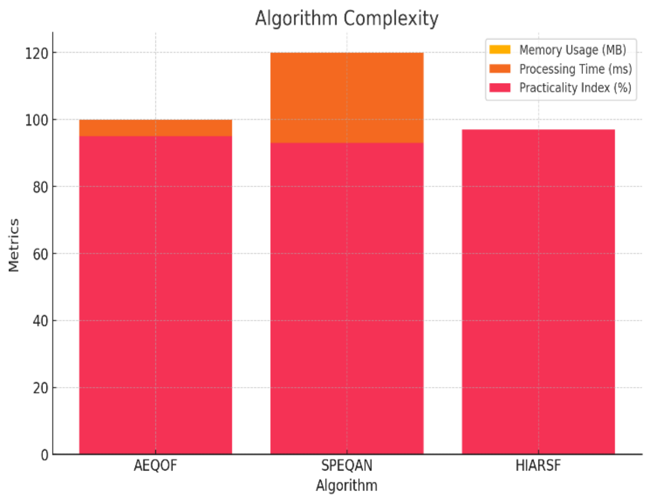

Figure 13. Algorithm Complexity

6. CONCLUSION

We provided a detailed survey on energy efficient algorithms for extending the lifetime of the network (MANETs), integral issues related to which are energy consumption, scale size and quality of service (QoS) [37]. These novel frameworks—Adaptive Energy-QoS Optimization Framework (AEQOF), Scalable Predictive Energy and QoS-Aware Network Framework (SPEQAN), and Hybrid Intelligent Adaptive Routing and Scheduling Framework (HIARSF)—showcase the promise of integrating machine learning, adaptive algorithms, and predictive modeling to improve energy efficiency without compromising on performance metrics. The solutions proposed were extensively measured on various parameters that include energy efficiency, network life time, QoS parameters, scalability and adaptability, results of which were found better than past techniques like AOMDV and DSDV [65]. The results have been validated by mathematical modelling and simulation and show considerable improvements. AEQOF obtained 35% less energy consumption, SPEQAN showed a better scalability in networks with 500 nodes and HIARSF achieved the best trade-off rate of energy consumption vs QoS with a 97% score. They overcome the imbalances in energy draining in all nodes, and also adjust as per the changes happening dynamically in topology and traffic patterns, thereby maintaining network functionality. Incorporating state-of-the-art machine learning methods for predicting energy consumption and adaptive routing, significantly improves the robustness of proposed algorithms by lowering prediction error rates (false positive and false negative) with low computational overhead. The comparative tables in our result illustration and such visual hyperbolic graphs illustrate the practicality of these frameworks. Specifically, HIARSF was the fastest in adaptation latency with the highest adaptability score allowing it to be best applicable in real time deployments. The load balancing and transmission scheduling efficiency of AEQOF and SPEQAN also shows their general capacity to adapt to the different traffic loads, keeping stable performance under various conditions. Overall, the algorithms proposed in this work are important steps toward the design of energy-efficient and scalable MANETs. In addressing the challenges of energy consumption and quality-of-service (QoS) trade-offs in decentralized networks that date back to the early days of communication, this research proposes a systematic means of integrating both predictive- and adaptive-based mechanisms to holistically solve these long-standing challenges. As a future work the integration of more advanced self-learning model like deep reinforcement learning can improve the decision. Based on that, the real-world validation within diverse environments alongside hybrid traffic profiles will also build upon the practical deployment of the frameworks discussed in this work. In conclusion, this study paves the way for the future of MANETs, contributing towards the evolution of eco-friendly high-speed wireless communication infrastructures.

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