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Leveraging Drone Technology and AI for Precision Agriculture in Resource-Limited Farming Communities

Mary Opeyemi Adebote
Virginia Tech, Blacksburg, VA, USA

Samuel Aremora
Austin Peay State University, Clarksville, TN, USA

Abayomi Taiwo Fashina
Austin Peay State University, Clarksville, TN, USA

Jennifer Bakowaa Sarfo
Software Engineer, Google Inc. New York.

Kehinde M. Balogun
Austin Peay State University, Clarksville, TN, USA

Abstract: Farmers in resource-scarce settings struggle to attain optimal crop yields and sustainable agricultural practices due to factors such as climate change, limited access to inputs, and infrastructural shortcomings. Precision agriculture (PA), enabled by advances in drone technologies and artificial intelligence (AI), offers a promising chance to break these barriers by optimizing resource utilization and enhancing crop management. This paper explores the potential for the application of drone technology and AI to facilitate precision Agriculture in such resource-poor regions. We reflect on the evolution and application of drones and AI in agriculture, with specific regard to such particular tools as multispectral imaging and machine learning. The potential impact on resource-scarce communities is examined in terms of more accurate crop monitoring, more efficient use of resources, and support to agricultural research and extension services, with the assistance of relevant case studies. We also address the adoption barriers and challenges, including cost, accessibility, infrastructure limitations, technological literacy, and ethics. We then present future directions and recommendations, including potential technology innovations, policy propositions, how to surmount existing challenges, and the roles of various stakeholders, to unleash the transformational power of these technologies to foster productive and sustainable agriculture among resource-constrained farming communities.

Keywords: Precision agriculture, drone technology, artificial intelligence, resource-limited farming, sustainability, food security.

1. INTRODUCTION

Poorly resourced farming communities, notably in Sub-Saharan Africa as well as certain parts of Asia, are instrumental to world food security yet face a host of interrelated issues [1], [2], [3]. These issues include the mounting effects of climate change expressed through changed weather patterns as well as heightened incidences of extreme weather events [4], [5], restrictions on access to essential resources such as water, fertilizers, as well as pesticides, coupled with infrastructure deficits such as transportation systems as well as internet connectivity [6], [7], [8]. Ecological, frequently hand-operated, agricultural methods used in such places often cause inefficiency, ecological degradation, as well as low yields, further contributing to food insecurity as well as economic stagnation [6].

Precision agriculture (PA), the use of data-driven technologies for optimizing site-specific crop management, offers a great scope for revolutionizing agricultural practice in settings with low resources [9], [10], [3], [11]. By allowing farmers to make evidence-informed choices on the basis of real-time information and analytics, PA can yield higher efficiency of resources, healthier crops, as well as enhanced productivity with minimal environmental degradation [9], [3]. At the forefront of the so-called agricultural revolution is the deployment of drone technology coupled with artificial intelligence (AI) for cost-effective, scalable, as well as low-foot-print solutions for acquiring, analyzing, as well as supporting decision-making activities [8], [12], [13], [14], [15], [16].

The purpose of this paper is to offer a holistic discussion of how drone technology and artificial intelligence can be made to effectively enable precision agriculture among farm communities that are resource-constrained. Our objectives are: (1) reviewing advancements in drone technology and artificial intelligence affecting agriculture; (2) analysing how the technologies have the ability to affect crop monitoring, resource utilization, and agricultural research within underserved areas; (3) outlining the main challenges and impediments to the adoption of the technologies; and (4) suggesting future directions and recommendations to enable the successful inclusion of drone technology and artificial intelligence into farm systems that are resource-constrained, ultimately improving food security and sustainable development.

2. Advancements in Drone Technology and AI for Agriculture

Sustained advances have been made over time in aerial platforms, sensors, navigation systems, as well as operational autonomy, for drones [17], [18], [19], [20], [21], [22]. Drones can be mounted with a broad set of sensors such as multispectral, hyperspectral, thermal, as well as RGB cameras, allowing for high-resolution information capture for varied aspects of crop as well as field health [13], [14], [15], [16], [23]. The sensors can capture helpful information on vegetation indices, chlorophyll, plant stress, diseases, as well as soils [13], [14], [15], [16], [24]. In addition, improvements in battery technology as well as drone development are increasingly

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extending operational ranges as well as flight durations [13], [14].

In addition, artificial intelligence (AI) including machine learning (ML) as well as deep learning (DL) algorithms have proved to be a key facilitator for the analysis as well as interpretation of the expanse of data captured by drones [9], [10], [8], [12], [13], [14], [15], [24], [25], [5]. The tasks of crop identification, detection of diseases as well as pests, identification of weeds, prediction of yield, as well as spatio-temporal representation of soil nutrients can be carried out by ML algorithms with higher accuracy [5], [9], [12], [17], [24], [25], [26]. DL algorithms, specifically convolutional neural networks (CNNs), have shown spectacular success for image analysis applications, paving the way for accurate as well as autonomous evaluation of crop as well as field condition from drone imagery [13], [24], [25], [26], [27].

Emerging trends for integrating drone technology and AI in agriculture are the creation of drone swarms for big-scale information gathering and automation of tasks, utilization of AI-managed navigation and control systems for autonomous flight as well as information gathering, as well as the implementation of edge computing for real-time information analysis and decision-making within drones.

Case studies demonstrate the transformative power of such technologies. For example, multispectral imagery based on drones, integrated with ML algorithms, have seen successful applications for early disease identification for rice crops within Southeast Asia, allowing for timely targeted interventions [28]. In Latin America, drone imagery have been used for reliable yield prediction in maize and soybean crops through the application of AI algorithms, giving farmers crucial information for market planning as well as resource usage (Karthik et al., 2020). Drone technology has also made precision spraying of fertilizers and pesticides possible, minimizing the cost of inputs as well as environmental degradation within different agricultural environments (Subeesh & Mehta, 2023).crops through the application of AI algorithms, giving farmers crucial information for market planning as well as resource usage [29]. Drone technology has also made precision spraying of fertilizers and pesticides possible, minimizing the cost of inputs as well as environmental degradation within different agricultural environments [30].

3. Impact on Resource-Limited Farming Communities

The adoption of drone technology and AI has the potential to bring about significant positive impacts on resource-limited farming communities across several key areas:

3.1 Enhanced Crop Monitoring and Management

Sensors mounted on drones can provide farmers with bird's-eye views of their crops, so crop stress, diseases, infestations, and deficiencies can be identified much earlier than they could be through observation from the ground. By examining images from drones, artificial intelligence algorithms can provide actionable insights into crop health so farmers can make interventions as early as possible and as precisely as needed, for instance, targeted applications of treatments, or adjustments to irrigation scheduling [28], [29]. This is particularly critical where there are limiting resources, as early intervention can prevent a substantial loss of yields, as well as minimize the use of broad-spectrum, typically expensive, treatment

3.2 Improved Resource Efficiency

Precision agriculture, empowered by drone-aided data and artificial intelligence (AI) analytics, allows for optimised usage of resources such as water, fertilizers, and pesticides. Drones carrying thermal sensors can locate water-stressed areas, allowing for targeted irrigation control and substantial water savings [31]. AI analysis of the state of the soil and crop nutritional requirements, based on multispectral and hyperspectral images, allows for variable rate fertiliser application, providing fertilizers for where and only where they are required, minimizing waste, as well as environmental runoff [32]. In like manner, AI-enabled pest and weed identification from drone images aids targeted herbicide and pesticide application, reducing chemical consumption, as well as for enhancing sustainable agriculture [30].

4.0 Case Examples of Successful Initiatives

There are several such initiatives that prove the successful implementation of drones and AI for applications across analogous contexts. In Africa, AI-driven drone technologies are being implemented for crop observation, pest identification, and soil health evaluation with support from seed funding schemes and capacity-building initiatives [34]. These initiatives embrace collaborative design processes and the adoption of ethical considerations for ascertaining local appropriateness as well as inclusivity [35]. Forecasting yield models powered by artificial intelligence, using aerial images and meteorological information, have been adopted in Latin America for market access support and planning for smallholder farmers [36]. Drone-enabled mapping and analysis have, in turn, identified the best places for planting individual crops depending on geographical terrain and soil content [37].

5.0 Challenges and Barriers

Despite the significant potential, several challenges and barriers hinder the widespread adoption of drone technology and AI in resource-limited farming communities:

5.1 Cost and Accessibility Concerns

The upfront cost of drones, sophisticated sensors, and artificial intelligence software can be out of budget for many smallholder farmers operating within resource-constrained environments. In addition, access to appropriate drones, sensors, as well as the technical know-how for deployment and maintenance, can be scarce within such environments [38], [39]. New business models, including Drone-as-a-Service (DaaS) through which farmers do not require advance capital outlays for access to drones, have the capability to solve such issues [38].

5.2 Infrastructure and Connectivity Issues

The successful deployment of drones and artificial intelligence depends on sufficient infrastructure, such as a consistent electricity supply for drone charging and information processing, and internet for moving information, cloud analytics, and communication with market information and weather data [33]. These infrastructure facilities are scarce or unavailable for most of the resource-constrained agricultural communities, thus being a main impediment for technology adoption [40]. The soon-to-be-established 5G, and the emergent 6G mobile networks, have the capacity to improve some of its challenges [2].

5.3 Technological Literacy and Training Gaps

The main challenge is that farmers themselves as well as agricultural extension workers lack technological literacy, as well as specialized skills needed for using drones, making sense of the compiled data, as well as using AI-aided analysis [34]. Implementing extensive training initiatives and intuitive interfaces is essential for closing the gap as well as making farmers competent enough for embracing as well as utilizing these technologies [41].

5.4 Ethical and Regulatory Considerations

The deployment of drones for agriculture involves a number of ethical and regulatory issues that must be addressed. Issues of privacy and security of the data, as well as of how spatial and potentially personal information is collected, must be handled carefully through strong data governance mechanisms [25]. Frameworks of regulation of drone flight, from the management of airspace, through flight approval, up to beyond visual line of sight (BVLOS) flight, must themselves be harmonized and fit for purpose for agriculture applications while safety is assured [37]. The possible effects of automation on the job market for agriculture must be considered as well [42].

6. Future Directions and Recommendations

To fully leverage the potential of drone technology and AI for precision agriculture in resource-limited farming communities, several future directions and recommendations are proposed:

Potential Future Developments

Future technologies must focus on reducing the cost, building drones that are durable, with longer-lasting batteries, and quality sensors appropriate for smallholder farmers' needs [30], [32]. There is a necessity for research on power-efficient AI algorithms deployable on low-power systems or processed under low-resource environments [41], [31]. AI-driven decision-making systems production using intuitive systems providing unambiguous, actionable, and understandable recommendations with the local language will enhance adoption [34]. Drone swarm, autonomous ground robots, and cooperative robots will provide an answer for labour-intensive, large-scale operations [26].

Recommendations

- ❖ Create targeted support mechanisms, including subsidy and micro-financing schemes, that can make drone technology as well as artificial intelligence solutions affordable for low-resource farmers [34].
- ❖ Invest in developing strong digital infrastructure, such as stable electricity and internet access, for rural agriculture areas [33].
- ❖ Implement extensive training of farmers and field-level workers on how to operate drones, interpret the data, as well as apply AI technology, integrating local knowledge as well as participatory techniques [26].
- ❖ Encourage the evolution of open-source software and data platforms as a cost-reducing approach to enhance collaboration for agriculture through AI [27].
- ❖ Encourage research and development of models of AI based on local crop types and environmental factors for better accuracy and pertinence [35].
- ❖ Design well-defined, supportive regulation for drone activities in agriculture, aligning safety requirements with the necessity of supporting technology uptake [37].
- ❖ Address ethical issues of data privacy, security, and possible socio-economic effects through a participatory and inclusive approach [25].

Strategies to Address Current Challenges

Strategies for dealing with short-term challenges must involve facilitating cooperation between agricultural scientists, technologists, policymakers, NGOs, as well as farm communities so that solutions are context-specific and tailored to the actual needs of farmers [42]. Public-private collaborations can become central for supporting research, infrastructure development, as well as providing training programs [43]. South-South as well as North-South knowledge transfer programs can help share best practices as well as lessons learned from implementing drone technology as well as artificial intelligence applications in agriculture [36]

The Role of Stakeholders

The donors, who are involved in agriculture, as well as non-governmental organizations (NGOs), must target funding digital agriculture initiatives in resource-scarce areas, with emphasis on technology transfer, capacity building, and ethical and inclusive adoption [44]

The technology companies must work towards creating cost-effective, durable, and user-friendly solutions for farmers operating with limited resources, addressing the unique requirements and challenges of farmers with limited resources, bearing in mind the local languages and low-connectivity settings [9].

Extension services and agricultural research need to undertake research of relevance at the local level, adopt tried technologies, and frame quality training packages as well as delivery mechanisms so that farmers can adopt the new technologies and practices [11].

The farmers must be engaged in technology solution designing and implementation, sharing their localized knowledge and providing feedback so that the technology becomes sustainable as well as pertinent [12].

7. Conclusion

In developing agriculture communities, the intersection of drone technology and artificial intelligence can have vast potential for changing agricultural practices and enhancing food security. These technologies can support farmers by increasing production, enhancing sustainability, and enhancing their ability to cope with the mounting pressures of climate change and increasing scarcity of resources through precise management of resources, allowing for timely and accurate access, as well as supporting agricultural research and extension. While numerous challenges exist, including cost, access, infrastructure, technology literacy, and ethics, such transformative technologies can be effectively adopted and scaled up with targeted interventions, strategic alliances, and a commitment to their specific needs.

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