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Innovative UAV Applications for Vector Surveillance and Disease Control: A New Horizon

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Abstract— As the global public health landscape evolves, the urgency to mitigate and control the spread of infectious diseases is paramount. To enhance our capability in this endeavor, this paper explores the innovative use of Unmanned Aerial Vehicles (UAVs) in vector surveillance and disease control. We discuss how advanced UAV technologies such as multispectral imaging, spatial data acquisition, real-time monitoring, and precision delivery systems offer a significant opportunity to revolutionize vector-borne disease control strategies. A key focus is on the potential of UAVs in areas of difficult accessibility, real-time data collection, and rapid delivery of preventative measures. We evaluate several case studies and pilot programs that have successfully used UAVs for vector surveillance, including malaria and Zika virus control, thus demonstrating the practical and effective utility of this technology. The paper also examines the challenges, legal, ethical, and socio-technical implications of UAV deployment in public health contexts. The findings underscore the promise of UAVs as a transformative tool in our global disease control arsenal, setting a new horizon for enhanced surveillance, prevention, and control strategies. Further research and policy direction should aim at establishing frameworks for their efficient, safe, and equitable use.

Keywords— Unmanned Aerial Vehicles (UAVs), Vector Surveillance, Disease Control, Public Health Technologies.

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I. INTRODUCTION

Vector-borne diseases remain one of the most formidable public health challenges worldwide, causing considerable morbidity and mortality, particularly in low-income and hard-to-reach regions. These diseases, transmitted by vectors such as mosquitoes, ticks, and fleas, have traditionally been challenging to monitor and control due to the complexities of vector ecology, human behavior, and environmental factors. With the emergence of novel technologies, new and promising avenues have opened up to tackle this persistent problem.

Within the realm of these novel technologies, Unmanned Aerial Vehicles (UAVs) or drones have surfaced as a highly potent tool with significant potential for combating vector-borne diseases. These sophisticated devices, equipped with features like multispectral imaging, real-time data acquisition, and precision delivery systems, can transcend geographical barriers and logistical constraints, thereby revolutionizing the way we approach disease surveillance and control.

This paper aims to explore the promising intersection of UAV technology and disease control in detail. We will delve into the various ways in which UAVs can contribute to public health, such as high-resolution vector habitat mapping, real-time disease surveillance, rapid dissemination of preventative measures, and much more. Through a detailed exploration of several case studies and pilot programs, we will demonstrate the practical implications and successes of UAV deployment in the context of diseases such as malaria and Zika virus.

Simultaneously, we will critically assess the challenges, legal, ethical, and socio-technical implications surrounding the use of UAVs in disease control. Our objective is not just to spotlight the potential of UAVs but also to foster an informed discourse that ensures their safe, effective, and equitable use. By unveiling this new horizon in disease control strategies, we aim to contribute towards a more comprehensive, tech-enabled approach to tackle vector-borne diseases globally.

II. BACKGROUND & LITERATURE REVIEW

A. *Previous Work*

The first author has made extensive contribution in the field of design, development and control of unmanned aerial vehicles. In the design and development of UAVs for fixed wing and rotorcraft-based types, the work of the author has been reported in [3, 20, 27-28, 37-39, 56]. The parameter identification for modelling and control for such vehicles has been studied and conducted using various approaches. The work on modelling and simulation for the UAVs was reported in [9, 17, 29-30,32,54-55]. A new approach for modelling was reported in [59] using quasi-steady and nonuniform inflow aerodynamic and using DE and artificial neural network in [74-76, 91-92]. In [77] and [86], the authors used the model for safety analysis of the UAVs. Comprehensive

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reviews of UAV technologies were presented in [5, 7-8], recently [23] for UAV-based surveillance for control of infectious diseases and [94] for environmental monitoring.

B. Literature Review

The employment of Unmanned Aerial Vehicles (UAVs) in the surveillance and control of vector-borne diseases, particularly malaria, has been the subject of multiple studies. Amenyo et al. (2014) discussed the role of low-cost UAV multicopter drones in mosquito vector control for malaria management[1], while Hardy et al. (2017) and Stanton et al. (2021) focused on using low-cost drones for mapping malaria vector habitats[40,79]. Kahamba et al. (2022) further emphasized the importance of ecological observations in improving malaria control in areas where Anopheles funestus, a malaria vector, dominates[48].

Multispectral imaging capabilities of UAVs for high-accuracy detection of malaria vector larval habitats were reported by Carrasco-Escobar et al. (2019) [24], substantiating the potential for drone-based imagery in larval source management (Mukabana et al., 2022) [67]. Hardy et al. (2022) emphasized improvements in drone imagery use for malaria vector control, with Dias et al. (2018) reporting on the autonomous detection of mosquito-breeding habitats using UAVs[42,33].

The literature also acknowledges the societal implications of UAV use in malaria control. Hardy et al. (2022) explored community perceptions of drone use in malaria control in Zanzibar, finding conditional trust depending on the UAV's benefits and potential impacts. Technology-assisted digitizing was emphasized as a key element of improved drone imagery application (Hardy et al., 2022) [42].

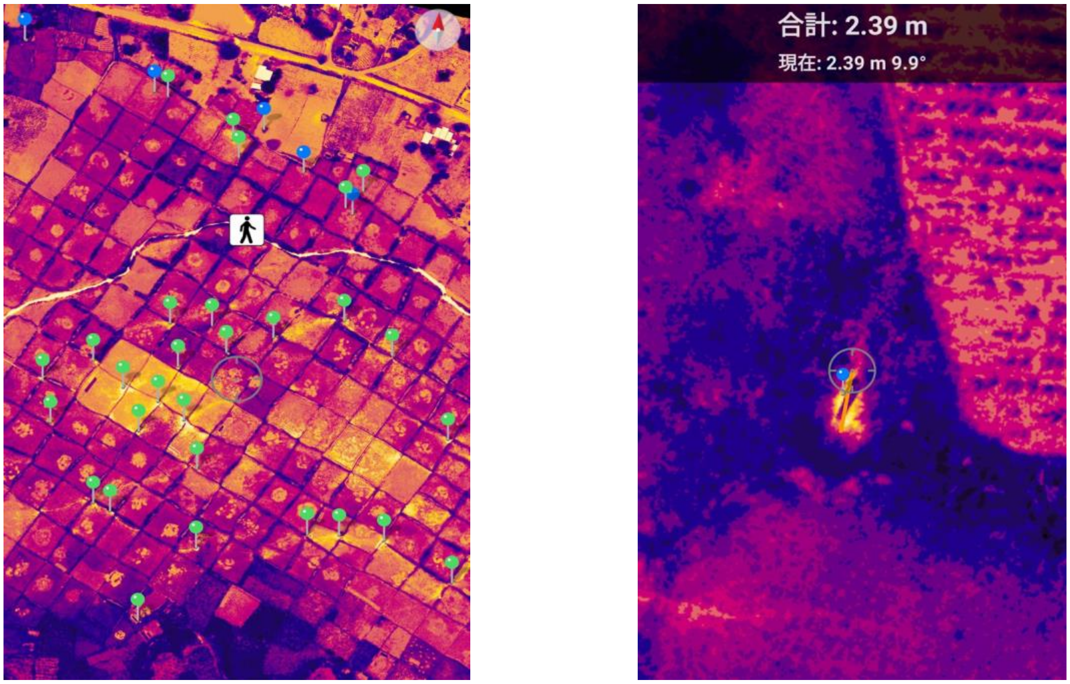
Studies also highlighted UAV use in controlling other diseases. For example, Carrasco-Escobar et al. (2022) documented drone use in mosquito surveillance and control, a strategy applicable to multiple mosquito-borne diseases[25]. Poljak and Šterbenc (2020) and Peckham and Sinha (2019) overviewed drone use in clinical microbiology and infectious diseases, discussing current statuses, challenges, and barriers[70-71].

Finally, future trends in vector control strategies were explored by Fornace et al. (2021) in the context of changing landscapes, with Chibi et al. (2023) and Mechan et al. (2023) systematically reviewing emerging technologies for malaria control[35,26,64]. The intersection of disease control, epidemiology, and UAV use was also discussed by Fornace et al. (2014), emphasizing the potential of UAVs in mapping infectious disease landscapes[36].

III. UAV TECHNOLOGY & IT'S APPLICATIONS

A. Overview of UAV Technology & Tools

Unmanned Aerial Vehicles (UAVs), more commonly known as drones, have advanced exponentially in recent years, presenting an array of capabilities that make them ideal for applications in various fields, including public health.



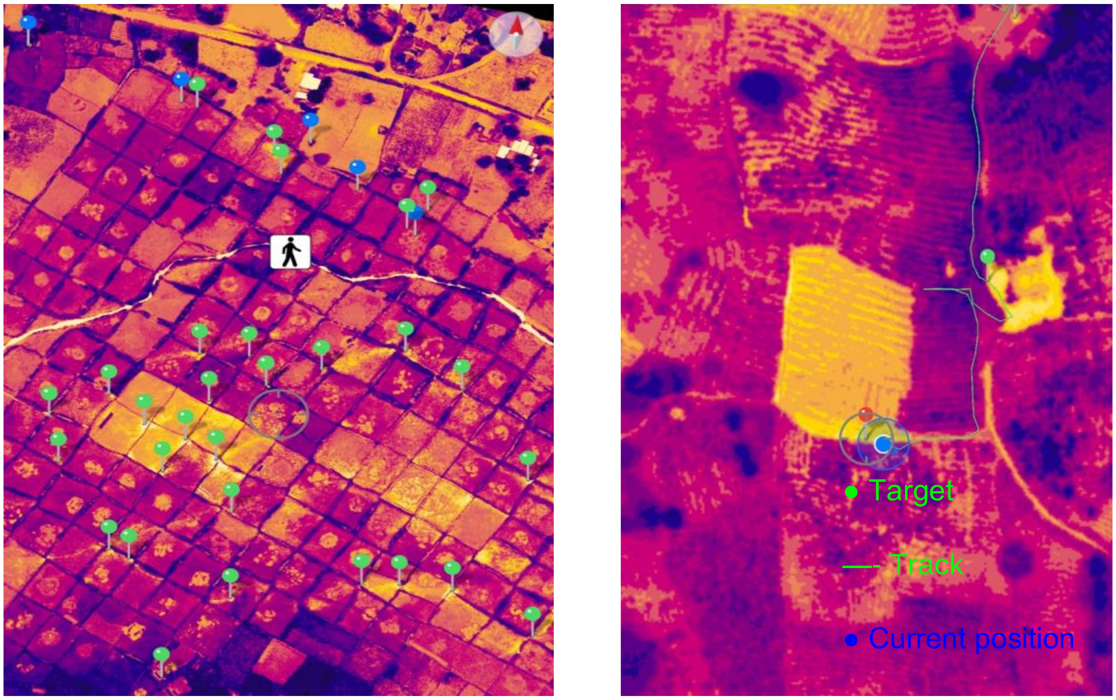
a. **Pin bright areas** (possibly puddles) in advance

b. Estimation of the size of a puddle matched well with the actual measurement.

Fig 1. Using NDWI to Identify Puddles

At their core, UAVs are remotely piloted or autonomously operated systems that can navigate through the air without an onboard pilot. They come in various forms, including fixed-wing, rotary-wing, and hybrid designs, each with its unique benefits and suited to different types of missions.

Key among UAV features is their ability to carry different payloads, including high-resolution cameras, multispectral imaging sensors, LiDAR (Light Detection and Ranging) systems, and even cargo for delivery purposes. High-resolution and multispectral imaging capabilities allow for detailed surveillance and mapping of vector habitats, vital for understanding disease transmission dynamics. With LiDAR systems, UAVs can generate accurate 3D maps of environments, providing detailed information about vector breeding sites and potential risk areas. Fig. 1 shows the example of using the puddle map in the field work.

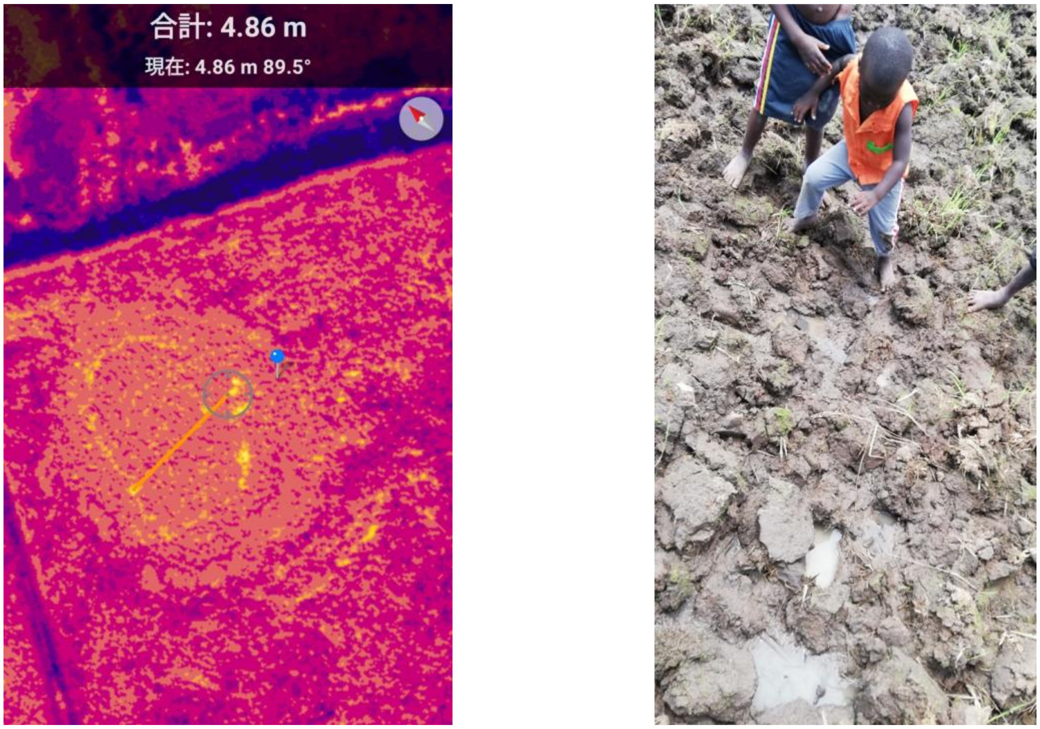


a. Navigation route to the puddles

b. Target vs. track

Fig. 2 Field survey using GIS

Utilizing Geographic Information System (GIS) software on smartphones during field surveys, especially with the incorporation of a puddle map, has significantly enhanced the precision and efficiency of data collection processes. This technology facilitates direct navigation to specified puddles, as shown in Fig. 2. As researchers traverse the terrain, the application allows for the detailed examination of the map through zooming functionalities. Furthermore, it provides tools to document one's walking trajectories, incorporate Points of Interest (POI), attach photographs, and annotate with relevant notes. An additional feature includes the accurate measurement of distances and dimensions, ensuring a meticulous and comprehensive data gathering procedure.



a. A place with many small water holes in a horseshoe shape

b. The actual scene showed in the close-up NDWI map

Fig. 3 Comparison between NDWI prediction and the actual scene.

Fig. 3 displays the comparison between prediction by NDWI and the actual scene. The left image provides a detailed view of the NDWI (Normalized Difference Water Index) map. Brightly colored regions, particularly those appearing in orange hues, hint at potential puddle locations, signifying small water surfaces. Contrasting this, the right image offers a visual depiction of the actual environment represented in the NDWI close-up. Here, one can discern multiple small water surfaces, likely formed by the activity of cattle. Through comparing the predictive capacity of the NDWI with the on-ground reality captured in the right image, we can evaluate the accuracy and relevance of NDWI in identifying puddle formations. Fig. 4 depicts the detection quality as function of image size.

予測

9 個のオブジェクト

an_larva	0.9152058	0.92
an_larva	0.8840909	0.88
an_larva	0.83927214	0.84
an_larva	0.8260675	0.83
an_larva	0.8032308	0.80
an_larva	0.69686085	0.70
an_larva	0.6454673	0.65
an_larva	0.60123557	0.60

9/10＝90%

```
予測
6 個のオブジェクト
  an_larva                0.8322057  0.83
  an_larva                0.798637870.80
  an_larva                0.7807882  0.78
  an_larva                0.7489527  0.75
  an_larva                0.714599   0.71
  an_larva                0.689369260.69
```

6/7 =85.7%
down left

Fig 4. Improving Detection Rate

Table 1 Detection Rate Versus Image Size

Detection rate	Input image size (vs learning size)
90%	400%
50%	100%
15%	25%

Table 1 presents an analysis of the detection rate in relation to the input image size as a percentage of the learning size. A clear trend emerges from the data: as the input image size increases relative to the learning size, the detection rate also improves. Specifically, when the input image is four times the size of the learning image (400%), the detection rate peaks at 90%. However, when the input image size matches the learning size (100%), the detection rate drops significantly to 50%. The detection rate further declines to a mere 15% when the input image size is just a quarter (25%) of the learning size. This suggests that the efficiency of the detection mechanism is strongly influenced by the relative size of the input image to the learning size, with larger input images yielding more favorable results.

In addition to the above payload, UAVs come equipped with advanced navigational systems, often involving GPS and onboard computers, allowing for precise flight control, waypoint navigation, and the ability to operate in variable weather conditions. Some UAVs even possess AI capabilities enabling autonomous operations, enhancing their effectiveness and efficiency.

The potential of these technologies in UAVs extends far beyond just flight and data collection. UAVs can be used for targeted delivery of interventions such as larvicides or even healthcare supplies in hard-to-reach areas, thus enabling a prompt and precise response to disease outbreaks.

The diverse array of capabilities that UAV technology offers presents significant opportunities for its application in vector surveillance and disease control.

B. UAVs Used in Disease Control

1. **Multispectral Imaging in Disease Control :**
   Multispectral imaging is a powerful tool for vector surveillance. By capturing image data at specific frequencies across the electromagnetic spectrum, and integrating it with image processing algorithms, we can generate valuable insights about the environment that are not visible to the naked eye. For instance, water bodies, which are breeding grounds for mosquito vectors, can be accurately identified using specific spectral bands. Additionally, variations in vegetation, soil, and moisture conditions can be

discerned, helping to map out potential vector habitats. When combined with epidemiological data, these habitat maps can significantly enhance our understanding of disease transmission patterns and help in the formulation of targeted intervention strategies.

2. **Spatial Data Acquisition and Real-Time Monitoring :**
   Real-time spatial data acquisition using UAVs can revolutionize disease surveillance. UAVs, equipped with advanced sensors and imaging capabilities, can acquire high-resolution, geo-referenced spatial data. This can enable real-time monitoring of environmental variables, vector populations, and even human activities that contribute to disease transmission. This capability significantly shortens the time between data acquisition and decision-making, allowing for timely interventions during disease outbreaks. Furthermore, continuous monitoring can help in early detection of potential outbreaks, enabling preventative measures to be taken.
3. **Precision Delivery Systems :**
   The incorporation of precision delivery systems in UAVs opens up new possibilities for direct disease control interventions. UAVs can be used to deliver public health materials, such as vaccines, medical supplies, or insecticides, directly to areas of need. The precision of these systems allows for targeted interventions, reducing wastage and increasing efficiency. For instance, UAVs can be used to precisely spray larvicides in identified mosquito breeding sites. Additionally, in remote or hard-to-reach areas, where transportation infrastructure is limited, UAVs can ensure the delivery of essential healthcare supplies, contributing to improved health outcomes.

C. *Case Studies & Pilot Programs*

1. Case Studies in Vector Surveillance and Disease Control:
   One notable application of UAVs in disease control was in Brazil during the Zika virus outbreak in 2016 [5]. Brazil's Ministry of Health used UAVs equipped with thermal cameras to identify potential breeding sites of the Aedes aegypti mosquito, the primary vector for Zika. The UAVs were able to scan large areas quickly and effectively, highlighting bodies of stagnant water and other potential mosquito breeding grounds.

   Another example of UAV deployment was in malaria control programs in Zanzibar [9-11, 14-15]. Here, UAVs were used to generate high-resolution maps of rice paddy fields, a primary breeding ground for malaria-transmitting mosquitoes. Using multispectral imaging, the UAVs could identify areas of water even in dense vegetation. This enabled public health officials to better target their interventions, including the precise spraying of insecticides.

   Malawi (to assist Integrated Vector Management - IVM): A three-phase UAV approach was adopted. Initially, high-resolution mapping of water surfaces was achieved using NDWI-evaluated multispectral imagery. Subsequently, ultra-high magnification aerial photography enabled direct remote observation of anopheline larvae. Finally, AI analytics facilitated automated detection of larvae, optimizing insecticide application areas and density estimations [Masuda 2023] [63].

2. Analysis of Results and Benefits:
   In the Brazil case, the use of UAVs significantly improved the speed and accuracy of identifying potential mosquito breeding sites, allowing for swift mitigation actions. This technological approach contributed to enhanced surveillance and response capabilities during the Zika outbreak, proving instrumental in controlling the disease's spread.

   In Zanzibar, the UAV-assisted mapping of mosquito breeding habitats led to more effective and efficient insecticide spraying. The targeted approach reduced unnecessary exposure of non-target areas and organisms to insecticides, contributing to environmental preservation. Moreover, it allowed for better allocation of resources, saving time, and costs. These case studies demonstrate that UAVs can bring about significant improvements in disease surveillance and control, suggesting their vast potential in advancing global public health efforts.

   In Malawi, UAV methods accelerated the process of mapping water surfaces to detect malaria vector larvae, achieving a rate ten times faster than conventional techniques while significantly reducing fieldwork hours. Given the variability of malaria vector sources, prior estimation of control measures was challenging. However, this UAV-assisted approach enabled precise larvicide application planning, followed by post-intervention evaluations to strategize subsequent interventions. This enables a quantitative, evidence-based IVM cycle.

D. Implications & Challenges

Implications. The deployment of Unmanned Aerial Vehicles (UAVs) in public health initiatives, especially in vector surveillance and disease control, carries significant implications that intersect legal, ethical, and socio-technical domains. Table 2 summarizes the implications of UAV deployment of UAVs in public health initiative.

Table 2 Implications of UAV Deployment for Public Health Initiatives

Category	Key Concerns
Legal Implications	Compliance with local aviation regulations
Ethical Implications	Privacy, data security, informed consent
Socio-technical	Community acceptance, infrastructure, technological literacy

1. **Legal Implications :** UAVs operate within complex legal frameworks that can vary considerably by region and country. It is crucial that any UAV deployment adheres to local aviation regulations, including restrictions on altitude, time of flight, and areas of operation. Failure to comply with these regulations could result in legal repercussions and hinder public health initiatives.

2. **Ethical Implications:**
   - **Privacy :** UAVs often collect imagery and spatial data, raising concerns over privacy infringement. Detailed imagery could inadvertently capture personal information, such as individuals' faces or private property details, creating ethical dilemmas.
   - **Data security :** Data collected by UAVs need to be securely stored and transmitted to prevent unauthorized access, particularly when dealing with sensitive health-related data.
   - **Consent :** Ensuring informed consent from communities prior to UAV deployment is vital to respect individual and communal rights. It is ethically important to educate communities about the purpose, method, and potential risks and benefits of UAV deployment.

3. **Socio-Technical Implications :**
   - **Community acceptance and trust :** The successful deployment of UAVs in public health initiatives requires buy-in from the local community. Trust can be built through transparency, continuous dialogue, and demonstrating the tangible benefits of UAV use in disease control.
   - **Infrastructure :** Deploying UAVs requires robust technical infrastructure, such as reliable electricity supply, maintenance facilities, trained personnel, and strong communication networks. In regions with limited infrastructure, the effectiveness of UAV deployment could be compromised.
   - **Technological literacy :** The effectiveness of UAV deployment also depends on the level of technological literacy among the public health workforce and the local community. Training and capacity building programs can help address this challenge.

In summary, while UAVs offer promising opportunities for disease control, it is crucial to consider and address these legal, ethical, and socio-technical implications to ensure successful and sustainable deployment.

Challenges. Implementation of Unmanned Aerial Vehicles (UAVs) in disease control initiatives does not come without challenges. These challenges span across economic, technical, and social domains as summarized in Table 3.

Table 3 Challenges of UAVs Implementations for Diseases Control

Category	Key Concerns
Economic Challenges	Initial costs, operational costs, cost-effectiveness
Technical Limitations	Battery life, data management, weather conditions, GPS reliance
Social Acceptance	Privacy concerns, fear and misconceptions, noise pollution
Operational Challenges	Application limitations, regulatory concerns, market and material constraints, safety and legal issues

1. **Economic Challenges :**
    - **Initial costs :** Procuring UAVs, along with the requisite control systems and sensors, can pose a significant initial cost. This is particularly pertinent for low-resource settings that might stand to benefit the most from UAV-based disease control initiatives.
    - **Operational costs :** Beyond the initial investment, UAVs require maintenance, repairs, and periodic upgrades, all of which add to ongoing operational costs. Furthermore, trained personnel are necessary for UAV operation and data interpretation, adding to the cost factor.
    - **Cost-effectiveness :** To justify their use over traditional methods, UAVs must demonstrate cost-effectiveness. This requires robust, long-term studies to compare the cost and benefits of UAV use versus traditional disease control methods.
2. **Technical Limitations :**
    - **Battery life and payload:** UAVs have limited battery life and payload capacity. This restricts their flight duration, range, and the types and number of sensors they can carry.
    - **Data management:** UAVs generate substantial amounts of data, requiring robust data management systems for storage, analysis, and interpretation.
    - **Weather and environmental conditions:** UAVs are often susceptible to adverse weather conditions, such as rain and wind, which can hamper their operation and efficiency.
    - **GPS reliance:** Most UAVs rely heavily on GPS for navigation, making them vulnerable to GPS signal loss or interference.
3. **Social Acceptance:**
    - **Privacy concerns**: As previously discussed, the potential invasion of privacy remains a significant issue affecting social acceptance of UAV technology.
    - **Fear and misconceptions:** Fear and misconceptions about UAVs can hinder their acceptance by the local community. This may be related to fears about surveillance, data misuse, or just general fear of unfamiliar technology.
    - **Noise pollution:** UAVs can produce considerable noise during operation, which may lead to nuisance or disturbance for local communities.
4. **Operational Challenges:**
    - **Application Limitations and Regulatory Concerns:** The use of UAVs for indoor insect targeting and in restricted areas due to military or national security concerns requires a blend of UAV and traditional methods. Additionally, obtaining necessary flight permissions may prove challenging, especially when UAVs are equipped with certain high-powered or flammable equipment. Similarly, special licenses may be needed for larger UAVs used during outbreaks.
    - **Market and Material Constraints:** Current limitations in the UAV insecticide market mean spraying is conducted on a small, experimental scale compared to agricultural use. Also, only insecticides that are approved for aerial spraying can be used, thus narrowing down the range of effective control measures.
    - **Safety Considerations and Legal Challenges:** The increased risk of accidents in urban environments, due to potential UAV interaction with infrastructural elements like power lines and buildings, necessitates advanced safety management and contingency plans. Furthermore, addressing the legal issues involved in UAV deployment requires proactive, cross-

governmental efforts, such as the establishment and evaluation of special implementation zones.

Despite these challenges, with appropriate mitigation strategies and community engagement, the benefits of UAVs in disease control and public health initiatives can still be realized. However, careful planning, thorough cost-benefit analysis, and strong legal, ethical, and social considerations should precede their deployment.

E. Policy Recommendations & Future Research

1. Proposal of Policy Directions for the Use of UAVs in Disease Control

To fully exploit the potential of UAVs in disease control, several policy directions could be considered. First, there should be clear regulatory guidelines to address safety, privacy, and ethical concerns related to UAV usage, and to clarify procedures for obtaining necessary permits and licenses. These should strike a balance between facilitating UAV operations and protecting public interests.

Second, there should be an effort to establish interdisciplinary partnerships among public health agencies, regulatory bodies, research institutions, and UAV industry representatives. These partnerships could foster shared understanding, facilitate the development and implementation of UAV-based strategies, and inform policy decisions.

Third, investment in capacity-building is critical. This should involve training public health practitioners on the use of UAV technology and the interpretation of UAV-derived data. Similarly, awareness programs should be conducted to inform the public about the benefits and limitations of UAVs in disease control.

Finally, policies should encourage innovation and the development of cost-effective UAV technologies that are specifically tailored for public health applications. Incentives could be provided to companies and researchers to push the boundaries of what is possible with UAVs in disease control.

2. Suggestions for Areas of Future Research

Future research should focus on various fronts to optimize the use of UAVs in public health. Studies could explore the development of advanced sensors and technologies to enhance the precision, accuracy, and capabilities of UAVs in vector detection, surveillance, and control.

More research is also needed to evaluate the cost-effectiveness of UAVs compared to traditional methods. This includes not only the initial costs of UAV deployment but also the long-term costs associated with operation, maintenance, and data processing.

Additionally, research could investigate ways to integrate UAV-derived data with other data sources, such as ground-based surveillance data and satellite imagery, to create more comprehensive and robust disease prediction models.

Lastly, studies should examine social acceptability and ethical aspects of UAV usage in public health, which could significantly impact the successful implementation of UAV-based strategies. Understanding these aspects can help inform policies and guidelines that address public concerns while maximizing the benefits of UAV technology.

IV. CONCLUSION

The evolving landscape of vector-borne disease control calls for innovative strategies that can overcome the limitations of traditional methods. This study underscores the significant potential of Unmanned Aerial Vehicles (UAVs) as a transformative tool for disease control. With their ability to collect high-resolution spatial data and provide targeted interventions, UAVs could revolutionize vector surveillance and disease control, rendering these processes more proactive, precise, and efficient. However, the full exploitation of UAV potential in public health is not without challenges. From operational difficulties to legal and safety issues, various aspects need thoughtful consideration and careful planning. Our proposed policy directions aim to provide a roadmap for the safe, ethical, and effective implementation of UAVs in disease control. Moreover, future research plays a critical role in expanding our understanding of UAV applications and in optimizing their usage. Continued exploration of advanced technologies, comprehensive cost-effectiveness analyses, and studies on data integration and public acceptance are imperative to fully harness the power of UAVs for disease control.

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