TOWARDS AN EFFECTIVE DRONE-BASED TECHNOLOGY TO COMBAT MOSQUITO BREEDING SITES

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Abstract. Drones have become an important technological tool to support health surveillance teams in locating and eliminating mosquito breeding sites in urban areas, since they allow the acquisition of aerial images with high spatial and temporal resolutions. However, such images are often analyzed through manual processes, consuming a lot of time in the inspections. Thus, researchers from different parts of the world have proposed computer vision technologies to enable automatic identification of mosquito breeding sites with the use of drones. However, despite the advances achieved, many of these technologies have some limitations that difficult their use in practical situations. This study is focused on such technologies aiming to investigate their potential, limitations and scalability. The literature review carried out shows that some proposed computer vision approaches could easily compose low-cost softwares to be used in tasks aimed at combating mosquito breeding sites with the use of drones, optimizing time and human resources. Despite that, works addressing software development from the proposed computational approaches are very rare. Other limitations found in the present study are the non-identification of water in the detected targets (suspicious objects and scenarios) and the non-provision of accurate geolocation of them. In addition, in the case of Brazil, the lack of public policies to adequately support the use of the investigated technologies can also be seen as a limitation.

Keywords: Mosquito. Aedes aegypti. Automatic Visual Inspection. Drone.

1 Introduction

Every year, several cases of diseases transmitted by mosquitoes are recorded in the world. The Aedes aegypti, for example, is the mosquito that transmits dengue, Chikungunya, Zika and yellow fever. For the World Health Organization (WHO), this is a matter of great concern, since more than 3.9 billion people, in more than 129 countries, are at risk of contracting dengue, with the possibility of occurrence of 40,000 deaths per year [1]. In the Americas, more than 1.6 million cases were reported in the first five months of 2020 alone, most of them in Brazil [2]. According to the Brazil's Ministry of Health (BMS), from January 2 to June 4 of 2022 there were 1,104,732 probable cases of dengue with an incidence rate of 517.9 cases per 100,000 inhabitants [3]. If compared to the same period in 2021, there was an increase of 197.9%. Regarding chikungunya, 108,730 probable cases were reported (incidence rate of 51 cases per 100,000 inhabitants), with the highest rates in the northeast and central-west regions. As for the Zika data, 5,599 probable cases were reported in the country (incidence rate 2.7 cases per 100,000 inhabitants). Finally, with regard to yellow fever, 1,267 probable cases were reported [4].

Malaria is another disease transmitted by mosquitoes that causes great social and economic damage, especially in low and middle-income countries. In 2020, 627,000 deaths were attributed to malaria, being that 595,000 (95%) occurred in Africa. Approximately 476,000 (80%) are related to children under 5 years of age [5].

Currently, the WHO considers the control and elimination of potential mosquito breeding sites an important preventive measure to face these diseases and increase efforts to eliminate them [6]. However, health authorities often see this challenge increased, especially in areas where a considerable part of the population does not have access to adequate housing structures or well-managed basic services, such as water, sanitation and solid waste disposal, which are determinant factors for the risk of mosquito-borne diseases [1,2,7]. Furthermore, as the global population becomes increasingly urban, the socioeconomic and physical consolidation of vulnerable human settlements proves to be an ongoing challenge [8], making it critical to develop new technologies that can support vector control in cities characterized by high spatial and social complexity.

The BMS, with the objective of combating the Aedes aegypti mosquito, annually launches advertising campaigns that involve state and municipal managers and the population. In 2019, for example, the federal government spent around R$22 million on the advertising campaign to combat the Aedes aegypti mosquito. In addition, a survey carried out estimated that the damage to the Brazilian economy due to the transmission of dengue, zika and chikungunya only in 2016, the year in which Brazil had almost 2 million cases of diseases related to Aedes aegypti, reached R$ 2.3 billion including direct and indirect costs [9].

The inspection and control of potential mosquito breeding sites in Brazil is usually carried out by health agents, through visual analysis of suspicious objects and scenarios, such as water tanks, drums, flowerpots, old tires, among others, besides inorganic waste comprising small objects that can retain stagnant water [10]. According to Grubesic et al. [11], such activities are usually expensive, time-consuming, dangerous, in addition to being temporally and spatially limited, resulting in the lack of accounting for large portions of urban space. In addition, it is common for health agents to find properties that are closed, abandoned or with access not allowed by the owner, affecting actions to combat the proliferation of mosquitoes.

Thus, tools allowing the rapid location and elimination of potential mosquito breeding sites are needed, in order to prevent outbreaks in complex urban contexts − which are characterized by high demographic densities and frequent spatial changes [12]. In this sense, several technological efforts have been carried out, mainly in areas with limited accessibility to health agents. One of these efforts is the use of unmanned aerial vehicles (UAVs), also known as drones, to acquire aerial images in places with a higher incidence of mosquito-borne diseases [12-15]. With this equipment, it is possible to obtain images with high spatial and temporal resolutions, allowing the detection of small objects on the earth's surface and the perception of changes in a given region, in a short period of time. In addition, this technology requires much less financial resources than manned aircraft missions.

Indeed, the high-resolution images provided by drones make them a powerful instrument to support interventions to eliminate mosquito breeding sites and consequently prevent diseases such as dengue or malaria [12]. Furthermore, Tun Lin et al. [16] showed that, in the case of dengue vector control, eliminating only the main breeding sites (about 50%) can be as effective as inspecting all sites at the same time, saving human and financial resources.

In fact, drones have already been used to support vector control through remote sensing [12-15, 17, 18-20,]. Thus, there has been an increasing number of studies proposing drone-based technologies that allow the automatic identification of potential mosquito breeding sites. However, despite the advances achieved, the technologies proposed in these works have some limitations that make their use in practice difficult.

In this context, the present work aims to investigate the potential and limitations of drone-based technologies proposed in the literature for the automatic identification of potential mosquito breeding sites, considering the way in which field inspections are carried out by health agents and the current regulation for the use of drones in Brazil.

2 Theoretical Background

2.1 Aedes aegypti mosquito

Aedes aegypti is the scientific name of a mosquito that transmits dengue, urban yellow fever, as well as zika and chikungunya. It has a characteristic that differentiates it from other mosquitoes: the presence of white stripes on the trunk, head and legs [3, 21].

Native from Africa, it was already eliminated in Brazil in the 1950s, returning in 1976 due to failures in the coverage of control actions [22]. It is likely that its insertion occurred through borders and ports and reached high infestations in households located in regions with high temperatures and humidity, especially in the rainy season and in the summer, which is the hottest season, typical of tropical countries such as Brazil.

The mosquito life cycle is divided into 4 phases, namely: egg, larva. pupa and adult. The places where the female usually lays her eggs are humid and warm, specifically in containers such as potted plants, tires, drums, gutters, swimming pools, uncovered water tanks, inorganic garbage in the open or any other object that can accumulate water [3, 21, 22]. Aedes aegypti has diurnal habits, lives an average of 30 days and the female usually lives inside houses in dark and low environments with temperatures ranging between 24 and 28°C. It can lay between 150 and 200 eggs and they do not put them all in a single container, which makes the work of larval prevention and control difficult [3, 21, 22].

The regions most affected by the proliferation of the mosquito are usually regions with disorderly urban growth, peripheral places where the population has a lower income, being places with greater probability of the existence of objects that are characterized as potential mosquito breeding sites, such as uncovered water tanks, tires, bottles and inorganic waste in the open sky [3, 4, 21, 22].

To control and combat the proliferation of the mosquito, the BMS and each municipality work to raise awareness of the population through campaigns, and with inspections conducted by health agents through actions of home visits to identify and contain larval foci [3, 4]. However, these inspections are expensive, time-consuming and dangerous, in addition to not guaranteeing the coverage of large urban spaces.

2.2 Regulation of drones in Brazil

The regulation of drones in Brazil is defined by the following organs: National Telecommunications Agency − ANATEL, National Civil Aviation Agency − ANAC, Department of Airspace Control − DECEA and Ministry of Defense − MD [24─26].

The ANAC is one of the most important because it regulates of the use of drones in Brazil taking into account the Brazilian Civil Aviation Special Regulation (RBAC-E nº 94). This regulation was published in 2017 and is based on international practices and standards. This organ is also responsible for registering the drone, that can be done through the "Unmanned Aircraft System − SISANT", being mandatory for drones with a take-off weight greater than 250 g [24]. Recently, there have been some updates to the aforementioned regulation, through an amendment which is in effect since November 30, 2021. One of the main changes was the exemption of pilots' licenses, in the case of aircraft up to 25 kg.

3 Methodology

This study can be framed as a qualitative research, with descriptive and exploratory approaches [27]. According to Triviños [28] descriptive research aims to describe facts and/or phenomena of a given reality. On the other hand, exploratory research aims to familiarize with the phenomenon to be investigated [29]. According to Martins Júnior [27], in general, qualitative and exploratory studies are conducted when the subject to be investigated is still little explored, as is the case of the subject investigated here.

Thus, the present study was conducted through a literature review aiming to analyze the state of the art of drone-based technologies for automatic identification of potential mosquito breeding sites, as well as to guide discussions about the potential and limitations of such technologies. The searches were carried out in the Web of Science, SCOPUS, ScienceDirect, IEEE and Springer databases, considering the period 2012 to 2021 and using the keywords "drone", "unmanned aerial vehicle" and "mosquito" in a combined way, and allowed the identification of related works, being the 12 most relevant works categorized and detailed in the following section.

4 Results and discussion

Among the works found in the literature research conducted in this study are those proposed by [12, 13, 14 30, 31, 32] which, although adherent to the theme investigated here, do not propose technologies for the automatic identification of potential mosquito breeding sites. Among them, the work of Hardy et al. [32] deserves to be highlighted for presenting the Zanzibar Malaria Elimination Program (ZAMEP), a concrete example of how public authorities can employ drones to map mosquito habitats from water bodies to direct malaria management efforts. However, the images acquired in this study with the use of drones result in orthomosaics whose analysis is done manually using the QGIS software.

Other studies such as [15, 19, 33-35] investigated computational technologies for mosquito breeding sites identification based on the analysis of the characteristics of water bodies (seas, rivers, lakes, puddles, etc.) imaged by drones. The combat strategy in the aquatic phase is cited by some studies as the best opportunity to avoid the proliferation of mosquitoes, including the Aedes aegypti [22]

Carrasco-Escobar et al. [15] for example, proposed the use of drones to identify breeding sites of the *Nyssorhynchus darlingi* mosquito in four communities in the Peruvian Amazon. Haas-Stapleton et al. [19] investigated the quantification of surface water accumulated in a 0.54 km^2 tidal swamp in San Francisco Bay (USA) to provide information for inspections focusing on potential mosquito breeding sites and to identify areas where existing trenches needed improvements to ensure water drainage. Minakshi et al. [33] and Stanton et al. [34] explored the use of drones to detect malarial mosquito habitats in bodies of water, in a peri-urban agrovillage in northern Uganda and in Kasungu District – Malawi, respectively. Suduwella et al. [35] explored the identification of possible water retention areas through drone imagery, where a human cannot access. However, this work does not present details about the proposed approach nor about the acquired images.

Finally, there are studies that propose drone-based technologies for the automatic identification of objects and scenarios suspected of being mosquito breeding sites, among which we can mention [17, 18, 36-40].

Agarwal et al. [17] presented an approach to detect and visualize possible mosquito breeding sites that includes three steps: evaluation of image quality; image classification using the Bag of Visual Words (BoVW) technique combined with the Support Vector Machine (SVM) classifier taking into account the descriptor Scale Invariant Features Transform (SIFT); and the visualization of breeding sites from heat maps to indicate the regions with the highest risk. In experiments involving the classification of 500 images, an accuracy of around 82% was obtained. In Mehra et al. [18] a framework based on images from Google and several other devices (digital cameras, smartphones and drones) was proposed. For feature extraction, the BoVW technique was used with the Speed-Up Robust Features (SURF) descriptor and the classification was performed by Bayesian Networks. In the experiments performed, the authors obtained an accuracy of 90%. In these two works, the proposed approaches analyze an image, indicate whether or not it contains a suspicious scenario and provide a pair of geographical coordinates of the image.

Dias et al. [36] proposed an intelligent system to recognize and geolocate suspected scenarios from videos captured by drones. They also considered detecting of water in the images using an approach proposed by Prasad et al. [41]. According to the authors, in the tests performed, they reached an overall accuracy above 99%. However, as in the work of Agarwal et al. [17] and Mehra et. al [18], only one pair of coordinates (latitude and longitude) is associated to each image regardless of the number of objects and/or scenarios detected in it, making it difficult to precisely locate them. In addition, the explanation of the experiments on the detection of water does not make it possible to know whether the algorithm used is capable of identifying the existence of water in small objects.

Passos et al. [37] explored the detection of Aedes aegypti mosquito breeding sites from aerial videos acquired by drones in simulated environments. However, in their experiments using different models of convolutional neural networks (CNN) they obtained a maximum accuracy of 78%. Although the authors have created a dataset of videos for carrying out the experiments, unfortunately it has not been made available in the literature.

Amarasinghe and Wijesuriya [38] presented a system that allows detecting stagnant water from images acquired by drones, and thereby identifying mosquito breeding sites. In their experiments, they obtained an accuracy of 91%. Despite the good results, in some cases the proposed system classifies the treetops as water.

Rossi, Backes and Souza [39] proposed an approach for automatic detection of gutters from images acquired by drones in order to identify Aedes Aegypti mosquito breeding sites. In addition to considering only gutters, disregarding other objects and scenarios that may be potential breeding sites for the mosquito, the authors did not present quantitative data measuring the results obtained and also did not provide the dataset of acquired images.

Bravo et al. [40] proposed approaches based on BoVW and CNN techniques for automatic detection and location of objects and scenarios suspected of being breeding sites of the Aedes aegypti mosquito in aerial images acquired by drones, which produced the following results in terms of mAP-50: 96.51% and 90.28% in the detection of objects and scenarios using a CNN, and 64.53% in the detection of scenarios using the BoVW technique. However, in addition to the authors having used a specific architecture of CNN for each type of target (objects or scenarios), as in other works the proposed approaches did not result in a software capable of generating maps and/or reports with precise geoinformation. In this sense, the authors suggest the development of an easy-to-use software built from a unique CNN architecture to detect both suspicious objects and scenarios. Nevertheless, they warn of the need for the computer system to produce accurate georeferenced indications of detected targets.

Table 1 summarizes the studies found in the literature proposing technologies for automatic identification of potential mosquito breeding sites. The literature survey also allowed us to identify the following potentialities and limitations of the proposed technologies:

Potentialities:

- Drones are low-cost technologies when compared to manned aircraft and allow obtaining images with high spatial and temporal resolutions. In other words, they allow the detection of small objects on the earth's surface from closer flights to the ground, and the perception of changes in a given region, in a short period of time;
- The use of drones allows surveillance teams to conduct inspections in hard-to-reach places, including properties that are closed, abandoned or with unrestricted access by the owners;
- The proposed automatic visual inspection technologies are generally implemented with open source libraries, enabling the design of free or low-cost softwares;
- Most of the proposed computational approaches allows the development of softwares that can be executed in real time, allowing the launch of larvicides during drone flights;
- Innovations produced from researches involving the use of drones to combat mosquito outbreaks can impact solutions to other problems related to public safety, such as theft and robbery.

Limitations:

- The non-identification of water in the detected targets (suspicious objects and scenarios) is a severe limitation since the existence of stagnant water is an essential condition for the mosquito to develop and breed;
- Deficiency in geolocation of detected targets: most proposed computational approaches do not provide accurate geolocation of detected targets. This is normally done after the automatic analysis of the image, in a manual way, using geographic information systems (GIS);
- Lack of software that can be easily operated by a health agent through an interactive interface;
- The lack of image databases difficult the proposition and testing of new computational approaches;

Table 1. Summary of works proposing the use of technologies for automatic identification of potential mosquito breeding sites

Work	Types of objects/scenarios identified	Is there a software proposition?	Provides accurate geolocation?	Provides an image database?	Results	Weak points
Carrasco-Escobar et al. [15]	Water bodies	No	No	No	Precision between 86.73% and 96.98%	Identifies only aquatic scenarios
Haas-Stapleton et al. [19]	Water bodies	No	No	No	Accuracy between 52.8% and 94,1%	Identifies only aquatic scenarios
Minakshi et al. [33]	Water bodies	No	No	No	Precision up to 99%	Identifies only aquatic scenarios
Stanton et al. [34]	Aquatic vegetation	No	No	No	Accuracy up to 99%	Identifies only aquatic scenarios
Suduwella et al. [35]	Stagnant water (puddles)	No	No	No	Precision of 81%	Identifies only aquatic scenarios
Agarwal et al. [17]	Tires, water tanks, potted plants	No	Partially	No	Accuracy of 82%	Does not identify the existence of water in the target objects
Mehra et al. [18]	Tires, pools, puddles, potted plants	No	Partially	No	Precision of 90%	Does not identify the existence of water in the target objects
Passos et al. [37]	Bottles, buckets, swimming pools, tires and water tanks	No	No	No	Maximum accuracy of 78%	Does not identify the existence of water in the detected objects
Dias et al. [36]	Small portions of water, water tanks, tires	No	Partially	No	Accuracy of 99%	Does not identify the existence of water in the detected objects
Amarasinghe and Wijesuriya [38]	Stagnant water (puddles)	No	No	No	Accuracy of 91%	Identifies some treetops as water
Rossi, Backes and Souza [39]	Gutters	No	No	No	Does not present quantitative results	Does not identify the existence of water in the gutters. Does not identify other objects that may be breeding grounds
Bravo et al. [40]	Tires, swimming pools, puddles, pots, inorganic waste	No	No	Yes	mAP-50 of 96.51 and 90.28 using CNN and 64.53 using BoVW	Does not identify the existence of water in the detected objects

It is important to emphasize that some of the aforementioned limitations have been treated as research gaps in many recent studies and, therefore, very soon they may be overcome.

5 Conclusions

Drones constitute an invaluable tool for public health agents to carry out interventions to combat mosquito breeding sites, especially in peri-urban areas where essential services (garbage collection, water and sanitation infrastructure) are scarce or even non-existent. Some of the automatic methods presented in this work could be easily transformed into software capable of geolocating mosquito breeding sites, optimizing time and human resources. The low cost of drone-based technologies allows for constant monitoring, providing data with unprecedented spatial and temporal resolutions that are crucial not only for public health but also for other areas such as urban planning. Despite of this, the scalability of such methods can be an issue due to limitations in terms of the geographic extent that can be covered by a single drone. However, recent examples show that it is indeed possible to cover an area as large as the entire Island of Zanzibar [32].

The high-resolution geographic information obtained with the drones could be used to support community outreach and therefore encourage their participation in reducing mosquito populations through bottom-up action plans. However, some requirements such as security and privacy provided for the current ANAC regulation for the use of drones in Brazil may difficult large-scale inspections, especially in denser urban regions. A clear example is the requirement that the distance of the drone cannot be less than 30 meters horizontally from persons not involved in the flight and not consenting to the operation. In addition, the fact that drone technology is not yet fully integrated into society and the lack of training for people to operate this equipment can generate complaints regarding people's privacy. These analyses suggest that the success of drone-based technologies also depends on the proposition of adequate public policies.

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