Using Unmanned Vehicles With Instrumented Bug Zappers To Detect & Eliminate Mosquitoes

Mary C. Burbage, An Nguyen, Kyle Walker, Nhan Phung, Vinh Truong, Erik Van Aller and Aaron T. Becker

***Abstract*— Mosquitoes are a vector for several deadly diseases, including the Zika virus that is currently spreading rapidly in Latin America. Mosquito-borne diseases kill millions of humans each year. Popular methods to control mosquitoes such as pesticides or adulticides are effective, but they introduce long-term damage to the environment. Traditional electrified screens (bug zappers) use UV light to attract pests, but have an large bycatch of non-pest insects. This paper introduces techniques using a electrified screens (bug zappers) mounted on unmanned vehicles to autonomously seek out mosquitoes in their breeding grounds and eliminate mosquitoes. Instrumentation on the bug zapper logs the GPS location, altitude, weather details, and time of each mosquito elimination. Mosquito controllers can use this information to analyze the insects' activities. The device can be mounted on a remote controlled or autonomous unmanned vehicle. If autonomous, the vehicle can use the data collected from the electrified net as feedback to improve the effectiveness of the motion plan. This paper examines design considerations, presents a working prototype system of drone and instrumented bug-zapper, and introduces a simulator for swarms of mosquitos and a mosquito-eliminating drone.**

I. Introduction

Mosquito-borne diseases kill millions of humans each year. Popular methods to control mosquitoes such as pesticides or adulticides are effective, but they introduce long-term damage to the environment. Traditional electrified screens (bug zappers) use UV light to attract pests, but have a large bycatch of non-pest insects. This paper introduces techniques using bug zapper mounted on unmanned vehicles to autonomously seek out mosquitoes in their breeding grounds such as ponds and swarms and effectively eliminate mosquitoes. Instrumentation on the bug zapper log the GPS location ,altitude, weather details, and time of each fried mosquito. Mosquito controllers can use this information to analyze the insects' activities. The device can be mounted on a remote controlled or autonomous unmanned vehicle. If autonomous, the vehicle can use the data collected from the electrified net as feedback to improve the effectiveness of the motion plan.

This is accomplished by simulating a large number of mosquitoes within a rectangular area. Each mosquito obeys a biased random walk flight pattern. Each mobile robot is capable of eliminating any modeled mosquito that intersects its path. The mobile robots can detect the time each mosquito is eliminated, share this information with neighboring drones, and use this data as feedback for a motion policy.

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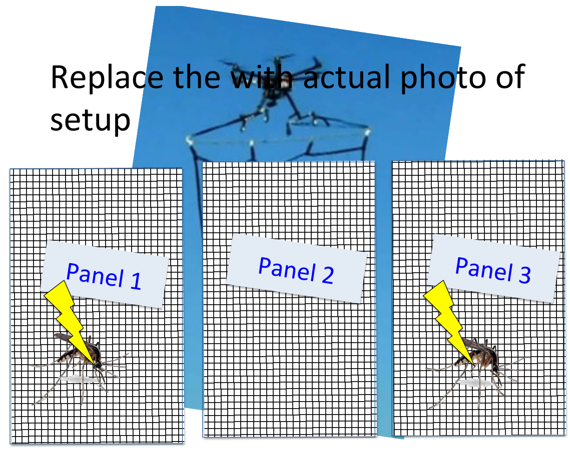

Fig. 1. A multi-copter drone carrying a high-voltage, instrumented bug-zapping screen. An onboard microcontroller monitors the voltage across the screen and for each mosquito strike records the time GPS location, altitude and weather information.

II. Related Work

A. Mosquito Control Solutions

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we need someone to read these papers
(saved in the github) and give 1
sentences summaries of each.
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For an overview, see [1]
larvicide [2]
genetic [3] [4]
mosquito-electrocuting traps [5] What is this?

B. Robotic Pest Management

Eradication mosquito breeding sites: [6]
Photonic (active laser) fence for mosquitos [7], [8]
A wireless sensor system for monitoring mosquito populations [9]

C. Robotic coverage

Robotic coverage has a long history. The basic problem is to design a path for a robot that ensures the robot visits within r distance of every point on the workspace. For an overview see [10]. This work has been extended to use multiple coverage robots in a variety of ways, including using simple behaviors for the robots [11], [12]. The key difference in mosquito coverage problem is that the mosquitos can move and so a cleared area can again become contaminated. We instead have a probability of coverage, as in [13] This

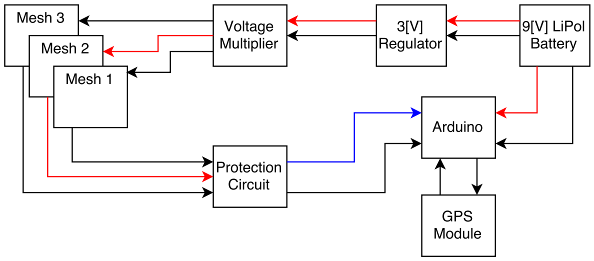

Fig. 2. Block diagram of microcontroller and bug-zapper: The system is powered by a 9 [V] Lithium Polymer battery applied directly to the power jack of the Arduino. The 9 [V] is also regulated down to 3 [V] where it is applied to the voltage multiplier circuit that will power the mesh of the net, as shown in Fig. 3. The net outputs a high voltage that is brought down by a protection circuit to a suitable level for the ADC of the Arduino. The Arduino will utilize a GPS shield for monitoring the location and altitude, as well as a real time clock to timestamp each data point collected from the system.

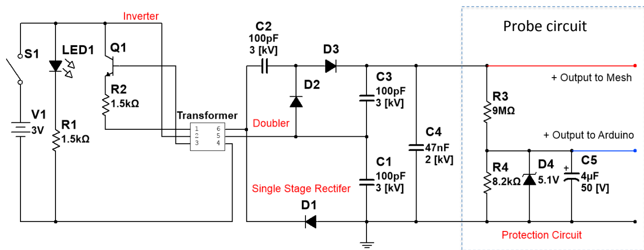

Fig. 3. Circuit diagram of bug-zapper and probe circuit. **Bug-zapper:** (from left) using a BJT (Q1) and center tap transformer a DC input voltage is inverted to AC and applied to the primary winding of the transformer where it is stepped up (1:1000). The voltage at the secondary winding of the transformer is boosted and rectified to a high voltage output capacitor that is applied to the inner layer of the mesh. **Probe:** (right) a voltage divider is used to lower the voltage so that it can be monitored by the microcontroller and a Zener diode (D4) is placed in parallel to protect the ADC input.

is closely related to the art gallery problem [14], but with limited range of visibility.

III. Design

A. Electronics

block diagram of microcontroller and zapper Fig. 2Circuit diagram of bug-zapper and probe circuit Fig. 3

Oscilloscope trace from mosquito elimination

Math describing the size of screen that can be caried

B. Energy Budget

how many mAh to keep an LxL screen charged? How many mAH to kill one mosquito: describe the experiment procedure and extrapolate the results

C. Location of screen

The drone must carry the bug-zapping screen, and the location of this screen determines the efficacy of the mosquito drone, measured in mosquitos eliminated per second of flight time.

To hover, the drone must push sufficient air down with velocity v_d to apply a force that cancels the pull of gravity. The drone has mass m_d and has a square-shaped cross

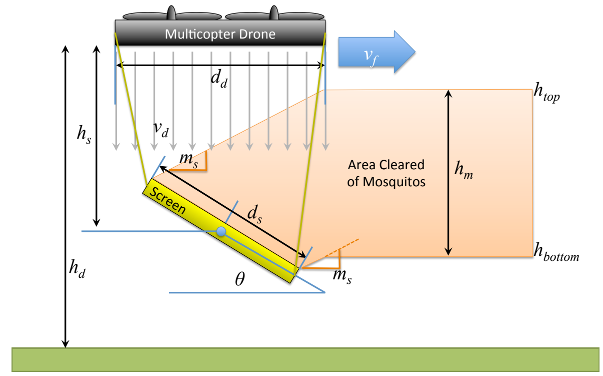

Fig. 4. The drone suspends a square bug-zapping screen beneath it. Propwash pushes incoming mosquitos downwards, and the drone clears a volume $h_m \times d_s \times v_f$.

section of size $d_d \times d_d$. The mass flow of air through the drone's props is equal to the produce of the change in velocity of the air, the density of the air ρ_a, and the cross section area. We assume that air above the quadcopter is quiescent, so the velocity change of the air is v_d m/s.

$$\text{Force gravity} = (\text{mass flow}) \cdot \text{air velocity}$$
$$m_d \cdot g = (v_d \cdot \rho_a \cdot d_d^2) \cdot v_d \tag{1}$$

This means the velocity of air beneath the drone (the propwash) is

$$v_d = \sqrt{\frac{m_d g}{\rho_a d_d^2}} \tag{2}$$

The drone testing site in Houston Texas is 15 m above sea level. At sea level the density of air ρ_a is 1.225 kg/m^3. The 3DR Solo drone weighs 2 kg with diameter 0.71 m[1]. The acceleration due to gravity is 9.871 $\frac{m}{s^2}$. These values in (2) give $v_d = 5.6$ m/s.

For manufacturing ease, the electrified screen is square, size $d_s \times d_s$. The mosquito species we are initially targeting are low altitude flyers, so the screen is suspended a distance h_s beneath the drone flying at height h_d. Suspending this screen beneath the drone also requires less weight that a rigid frame to hold the screen above the drone. This screen can be suspended at any desired angle θ in comparison to horizontal, as shown in Fig. 4. A key question is what distance h_d the screen should be suspended from the drone, and the optimal angle θ. The goal is to clear the greatest volume of mosquitos per second, a volume defined by the drone forward velocity v_f and the cross sectional area $h_m \times d_s$ cleared by the screen, as shown in Fig. 5.

Due to propwash, a mosquito in level flight will fall relative to the drone at a rate of v_d/v_f. As shown in Fig. 4, we can extend lines with slope v_d/v_f from the screens

[1]https://3dr.com/solo-gopro-drone-specs/

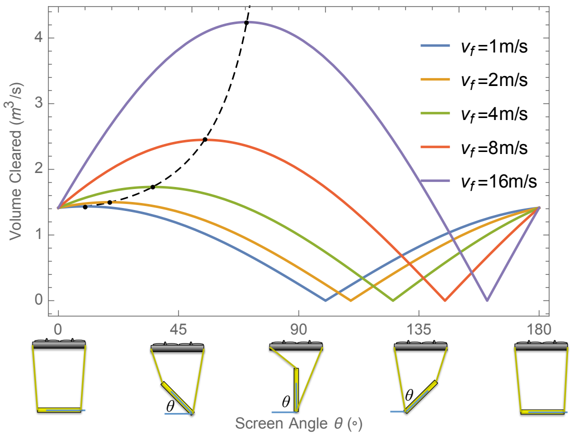

Fig. 5. The volume cleared by a drone is a function of screen angle θ and forward velocity v_f. The dotted line shows the optimal angle given in (4).

trailing edge to h_{top} and from the leading edge to h_{bottom}

$$h_{top} = h_d - h_s + \frac{d_s}{2}\sin(\theta) + \frac{d_d + d_s\cos(\theta)}{2}\frac{v_d}{v_f}$$

$$h_{bottom} = h_d - h_s - \frac{d_s}{2}\sin(\theta) + \frac{d_d - d_s\cos(\theta)}{2}\frac{v_d}{v_f}$$

$$h_m = h_{top} - h_{bottom} = d_s\left(\frac{v_d}{v_f}\cos(\theta) + \sin(\theta)\right) \quad (3)$$

The optimal angle is therefore a function of forward and propwash velocity:

$$\mathrm{ArcTan}\left(\frac{vf}{v_d}\right) \quad (4)$$

To ensure the maximum number of mosquitos are collected, the screen must be sufficiently below the drone $h_s > \frac{d_s}{2}\sin(\theta) + \frac{d_d + d_s\cos(\theta)}{2}\frac{v_d}{v_f}$ and the bottom of the screen must not touch the ground, $h_d > h_s + \frac{d_s}{2}\sin(\theta)$.

Mosquitos are not distributed uniformly vertically. Gillies and Wilkes performed a series of experiments measuring the number of mosquitos caught in suction traps at 0,0.5,1,1.5,2,3,4,5,6m above ground. the traps were operated in open grassland in the Gambia from 20:30 to 2:00 during the night [15]. The *Mansonia spp.* flies close to the ground, while the *Cx. poicilipes* prefers to fly higher in the air. Changing the flying height of our drones will target different mosquito populations.

IV. Simulation

This simulation runs in MATLAB. One thousand mosquitoes are randomly placed within a square area one hundred meters on a side. Each mosquito moves according to a biased random walk at a speed up to 0.4 m/s and with a direction heading biased toward the greenest of the pixels surrounding its current position. This imitates the live mosquitoes preference for vegetative areas. In order to allow the mosquito positions to be more natural, the mosquito movement routine runs five thousand times, simulating 1.4 hours of flying time, before the robot begins to search. Because mosquitoes do not care about boundaries, the toroidal

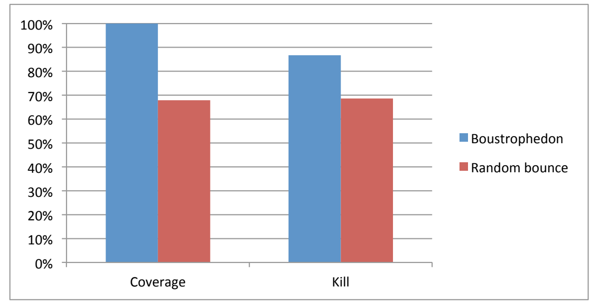

Fig. 6. Comparison of percentage of area covered and percentage of mosquitoes killed for the boustrophedon and random bounce coverage patterns.

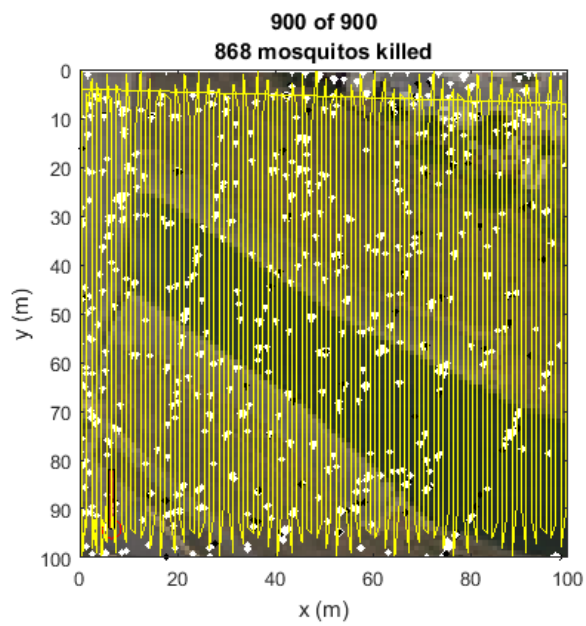

Fig. 7. Boustrophedon robot path (yellow lines) overlaid upon a 100x100m image. The robot (red circle) and the area swept out by the bug-zapping net in a time step (red rectangle) are shown along with a population of a thousand mosquitoes. Those that were killed during the simulation are shown in white, and those that survived it are shown in black.

assumption keeps them in the workspace. Two different routines handle the robots path. The first uses a random bounce algorithm. The robot begins in the center of the workspace and moves with a heading that varies randomly up to ± 0.2 rad off of its previous heading and bounces off the perimeter of the workspace with a random heading equally biased around all points of the circle except for those outside the workspace. The velocity is set at a prescribed speed. The second algorithm uses a boustrophedon path. The robot begins in one corner of the workspace and methodically progresses back and forth, advancing one screen width at each turn. If it covers the entire field in the allotted time, it begins covering the field again. In order to keep the routines comparable, the robots use the same speed and same number of iterations. These simulations used 12 m/s and fifteen minutes of flying time. They also used the same image for biasing the mosquito flight. For the main body

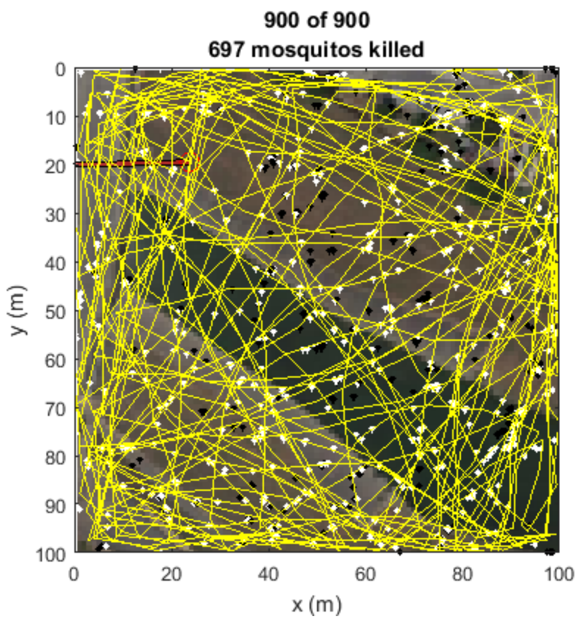

Fig. 8. Random bounce robot path (yellow lines) overlaid upon a 100x100m image. The robot (red circle) and the area swept out by the bug-zapping net in a time step (red rectangle) are shown along with a population of a thousand mosquitoes. Those that were killed during the simulation are shown in white, and those that survived it are shown in black.

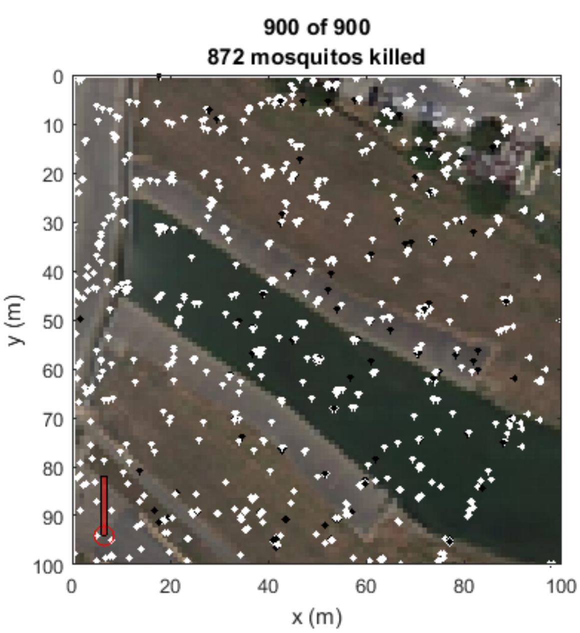

Fig. 9. A 100x100m image with the robot (red circle) and the area swept out by the bug-zapping net in a time step (red rectangle) shown along with a population of a thousand mosquitoes. Those that were killed during the simulation are shown in white, and those that survived it are shown in black.
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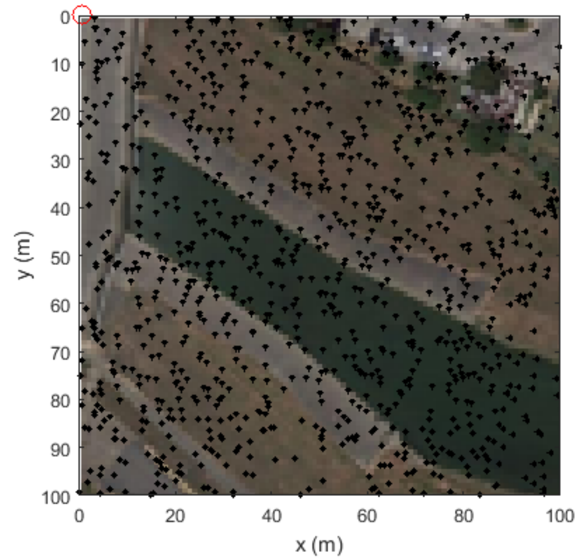

Fig. 10. A 100x100m image with one thousand simulated mosquitoes (black markers). The mosquitoes have had 1.5 hours to bias themselves toward green areas of the image. The robot (red circle) is shown at the upper left corner, preparing to start a bug-zapping run .

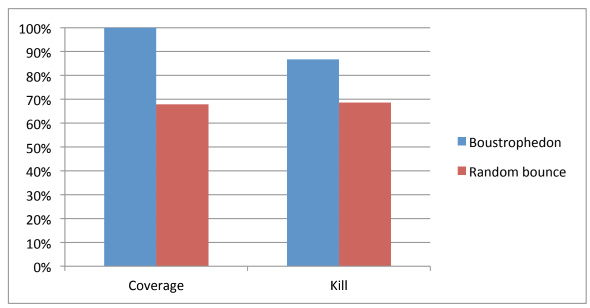

Fig. 11. To calibrate the system, three instrumented bug-zappers were carried on a 2.5 m pole.

of the simulation, a loop runs a series of iterations in which each mosquito moves one step and the robot moves one step. In that step, the path traced by the bug-zapping screen is calculated, and any mosquitoes in that path are considered to have been killed.

Results One hundred trials were performed with each coverage path. The boustrophedon successfully covered the entire field in every trial (μ=100%, σ=0%) and exhaustively covered a portion of the area a second time, while the random bounce covered only 67.9% of the field (μ=67.9%, σ=1.0%) with an unknown amount of overlap. As a result, the boustrophedon killed significantly more mosquitoes (μ=87.7%, σ=1.1%) than the random bounce (μ=68.6%, σ=2.7%). In fact, the smallest number of mosquitoes killed in 100 trials by the boustrophedon (84.1%) was considerably larger than the largest number killed by the random bounce (75.1%).

V. Experiment

VI. Conclusion and Future Work

Covering the field thoroughly leads to a higher success rate when killing mosquitoes. Because the mosquitoes move

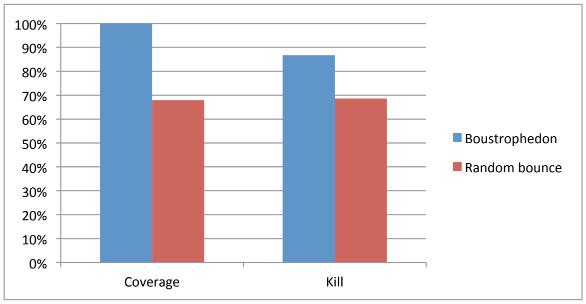

Fig. 12. map with GPS path and kill locations superimposed

around, the robot will not kill all the mosquitoes in a single trial as some can fly into a previously covered area as the robot approaches them, but the chances of killing the mosquitoes increase as the coverage increases.

There are a number of refinements to the algorithm that could be pursued in future work. The mosquito biasing algorithm could be made less near-sighted and look at an array of pixels further from the current location of the mosquito. Some modifications to the robot flight may force it to take turns more slowly or handle environmental disturbances. A bias away from the robot may be added to the mosquito heading. The model may be expanded to three dimensions. An alternative search path that looks for mosquitoes randomly then exhaustively covers areas dense in mosquitoes may be compared to the existing algorithms. These and many other considerations may be included to make a more realistic model for future work.

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