Design of a Fiber-Optic Sensing Mosquito Trap

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***Abstract*— Mosquito traps offer researchers and health officials a reasonable estimate of mosquito abundances to assess the spatial and temporal occurrences of mosquito-transmitted pathogens. Existing traps, however, have issued efficient design to detect mosquito and energy consumption of the device. We designed a novel mosquito collection device that sensitively detects the presence of a mosquito via a fiber-optic sensor. In this prototype, a pushing capture mechanism selectively powers and efficiently captures live mosquitoes without destroying identifying morphological features of the specimens. Because the trap sensor selectively powers the capture mechanism, it allows for greatly reduced power consumption when compared with existing continuously operated devices. With appropriate programming, the fans ON and OFF based on the triggering of a fiber-optic sensor detected and counted each mosquito that entered the trap. This trapping platform can be used with a variety of power sources including renewable sources (e.g., solar, wind, or hydroelectric power) in remote settings. The experimental results show a high success ratio 93%–100% for detection of live mosquitoes.**

***Index Terms*— Mosquito trap, solar powered, fiber optic sensor, prototype device, target detection.**

I. INTRODUCTION

MOSQUITOES spread a variety of human pathogens, including malaria, dengue virus, and West Nile virus that cause considerable morbidity and mortality [1], [2]. Disease control officials monitor mosquito abundance as well as pathogen prevalence in mosquitoes in order to assess effective interventions to avoid epidemic disease [2], [3]. A variety of mosquito traps have been created to monitor as well as eliminate vector populations (reviewed by Silver 2008) [4]–[7]. The degree to which these devices represent the true abundances of mosquito populations differ based on the inherent biases of the trap's lure mechanisms and efficiency of specimen collection.

Most existing mosquito trap devices such as the CDC light trap, first described by Sudia and Chamberlain [8], employ a continuously operated suction "pulling" fan to capture specimens. Continuously operated suction devices have several disadvantages for mosquito capture: 1) air-borne insects such as mosquitoes are extremely sensitive to minute changes in air flow and are likely deterred by continuous suction, 2) continuously operated devices consume power inefficiently. In fact, Sensor-based traps prevent continuous consumption of power. Various types of sensors have been designed for multiple applications like low-velocity gas flow detection and volatile compound detection which could be used for insect detection [9], [10]. For these reasons we designed a mosquito trap that uses a fiber-optic sensor to trigger a "pushing" and a "pulling" fan that collect, retain, and count live mosquitoes. The contributions of this study are 1) to design and build first sensing mosquito trap system and 2) to evaluate the efficiency of the fiber-optical sensor in detecting live mosquitoes.

The remainder of this paper is organized as follows. Section II provides a review of the existing methods of mosquito traps, and relevant technologies. In Section III, we present the overall proposed design and modules for the detection of mosquito. In Section IV, we describe the main circuit module and sensory module. In Section V, we show the experimental performance of detection. And Section VI ends up with conclusion.

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II. BACKGROUND OF RELEVANT STUDIES

The primary objective of this study is to design and test a novel sensing trap for the capture of live mosquitoes for research and monitoring purposes. Captured mosquitoes can be classified based on different criteria such as their species and type of diseases they transmit [2], [4]. We will survey the relevant studies in subsections A to C: Existing Mosquito Trap, Power and Energy for Smart Trap, and Design Sustainability.

A. Existing Mosquito Traps

Various types of mosquito traps exist and many have had modifications and improvements over time [11]–[15]. Most mosquito traps exploit the habits or needs of one or more different mosquito life stages such as host-seeking, resting after blood-feeding, or egg-laying. Host-seeking mosquito traps utilize host cues, such as CO_2 or lactic acid, to mimic live hosts to lure mosquitoes into the trap's capture mechanism. Traps that capture resting mosquitoes mimic natural and artificial surfaces that mosquitoes seek as safe refuge when digesting a blood meal or escaping weather events. Finally, egg-laying or "gravid" traps target gravid female mosquitoes as they attempt find a suitable habitat to lay their eggs.

Though there are a variety of reasons and methods to capture mosquitoes, portability and power efficiency are the primary limitations of active mosquito collection devices. Traps are powered by gas and electricity. Though gas-powered traps have the advantage of relatively long duration of power and low maintenance, their use may be interrupted in adverse weather conditions (e.g. rain and wind) and they pose a low fire risk [12]. Electric-powered mosquito traps often use batteries or transformers to run the trap [8], [16]. Though batteries do offer enhanced portability, continuous maintenance of batteries and loss of battery charge over relatively short periods of time are drawbacks of their use. Despite these disadvantages, the most widely used mosquito traps for monitoring are electric-powered and battery operated [17].

One example of a widely used mosquito trap is the BG-Sentinel trap [18]–[20]. By manipulating the mechanical portions of their design, the BG-Sentinel Trap uses air currents to both attract mosquitoes into the trap with attractants and to suck them into the trap. By use of a mechanical design, the mosquitoes cannot leave the trap once entered.

To our knowledge, no sensor-selectively powered mosquito trap is available in the commercial marketplace. All existing traps utilize continuous suction and do not detect the presence of a mosquito. Though several patents applications over the past 2 decades have described the use of sensors to detect the presence of a mosquito [21], [22], to our knowledge none have published data on the efficacy of their detection mechanism. Reiter's patent [21] described a collection device that captured mosquitoes by triggering a fan when a mosquito interrupted an infrared beam. Tests of Reiter's sensing mechanism were never published and the device was not made available.

B. Power and Energy for Smart Trap

Existing mosquito traps use a variety of energy sources including gas, battery, electric-outlet, or solar. One of the problems with gas powered and battery powered traps is the replacing the energy source. Gas powered trap is considered more energy efficient than battery powered, which raises the cost of former one [23]. If traps must be plugged in an electrical outlet power, portability is compromised. As for existing solar powered mosquito traps, there exist many advantages [24].

Solar power is now widely used for self-operating sensor devices, such as solar powered motion sensors. For example, many floodlights are powered using solar energy developed by SmartHome [25]. Solar power mainly consists of the conversion of sunlight into electricity, usually done with photovoltaic cells. There are many advantages to the use of solar power such as a renewable energy source, which means less maintenance. However, it is obviously not as effective during the night [24]. There is a battery powered version, but the cost of it is higher and the batteries are not rechargeable. This is one of the concerns, whether to have a higher sustainability with proportional cost or a lower sustainability with a lower cost.

A sensor based selective power option prevents the misuse of energy on further extent. Detection sensors have been developed for the last decades [26]. Range finder, for example, covers the relatively wide dynamic range, measuring the distance between the target and the sensor. Although this is ideal to detect the target, the laser used for range finder consumes a large amount of power [27]. Sonar sensor, on the other hand, uses minimum power consumption, but the signals to detect target are very noisy [28]. However, fiber optic sensors use optical signal interrupt for detection and has efficient energy consumption [29]. Fiber optic sensory mechanism is extensively used in a wide variety of applications for measuring displacement, acceleration, pressure, temperature and so on [30], [31].

To make our proposed design more power efficient, the prototype can charge the battery and run the device in sunlight simultaneously. In the absence of sunlight, the battery supplies power to the device. Suction fans consume most of the energy in mosquito traps. We use a fiber optic sensor to reduce consume power of suction fans only when a mosquito passes the sensor. This design of power usage can reduce its consumption in the absence of mosquitoes. As a result, the device can be operational for more cloudy days and nights. The details of the sensor used in this design are explained in Section IV.

C. Design Sustainability

Since the materials chosen as well as the energy source can last for long periods of time without maintenance (3–4 weeks), the prototype device is nearly self-sustaining. Most mosquito monitoring programs monitor mosquito traps daily or weekly. Our trap is designed to operate without human intervention for periods up to one month. If the trap is operated with chemical lures such as octenol, these lures may need to be replaced or recharged at greater frequency [32] than the trap needs maintenance. . This is why the ultraviolet LED's were chosen as the second attractant.

Health and safety are considered to this design project as well as for any other mosquito traps [33]. This design will contemplate about any possible diseases that can be transmitted by either touching the design or if a nearby mosquito that did get blown into the mosquito trap bites a person. Another concern will be the materials used for the project [34], whether or not it can affect a person's health.

Rust can be prevented with periodic maintenance of wiping down the aluminum bars. Aluminum 6061 was specifically picked since it has a high resistance to rust [35]. Rust can cause the collapse of design, as most of the materials used to keep the design together are aluminum. If the design collapses, then the spill of octenol can affect the environment [1].

Considering the hazard that might involve, leak proof battery will be picked up [36]. Another chemical that is dangerous is lead acid. To make a less maintenance-required device, materials chosen should have less environmental risk [37].

To increase efficiency of this prototype design, we have primarily focused on the electrical design of the trap. Other possible alternative energy sources can increase the self-sustainability of the design and will be contemplated during the final stage of this design.

III. Overall Modules Design

Overall module of this mosquito trap consists of three major modules–(1) power sources (a-b), (2) sensor and controller (c-d), and (3) electronic devices (e-f) as shown in Fig. 1.

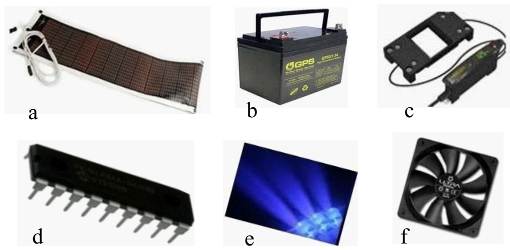


Fig. 1. Modules of design. (a-b) Power sources used. (c-d) Sensor and Controller used to determine outputs. (e-f) Electronic devices used to attract and capture mosquitoes.

Solar power an endless source of energy, has particular advantages over other sources [24]. In this design, a solar film, which produces 12 volts in the presence of sunlight, is used as a source of power. Moreover, the design prototype comprises a battery that can be charged through the solar film while supplying power to device simultaneously. It has been theoretically observed that perpendicularly incident ray leads to maximum efficiency of solar film, whereas efficiency decreases with the increase of the incident angle reducing the effective area. In the absence of sunlight, then, battery is the only source of power.

Since live mosquitoes are essentially small flying particles, fiber optic sensors, designed to detect small particles, seem to be an appropriate choice to detect mosquitoes. Apart from detecting object as small as 1.5mm, the sensor can count the number of object that passes through with its programmable function. Its integration to the microcontroller enables the selective running of other parts of circuit only when an object breaks the sensory field. The microcontroller gets an interrupt signal as soon as the field is broken. In response to the interrupt, it drives the fans and other electronic devices required for the capture of the flying insect. In this design, two fans are activated: one is a blowing fan used to force mosquitoes down the net, and another is a suction fan used to further blow them into the bottom of the net.

Other electronic devices are also controlled by a microcontroller. For example, ultra-violet lights (UV lights) are used to attract mosquitoes as they are in other designs [38]. In our design, five ultra-violet laser LEDs are placed in the middle of the trap to increase the number of mosquitoes attracted. Chemical substances, such as octenol, are often existing traps [39]–[41] and may be used in our design as well.

Fig. 2 shows the compact design of the trap with all of the modules combined. In Fig. 2(a), solar film is placed on top of the trap, and this compact structure is movable. Fig. 2(b) shows the fiber optic sensor module of the trap. In this part, Plexiglas has a hole (3.5 cm $\times$ 3.0 cm) where mosquitoes fly into the trap. The canopy contains the electrical components such as a microcontroller, sensors, and other circuit components. To control the air flow inside the trap efficiently, two fans are synchronized with the help of microcontroller programming.

This design prototype powered by the solar energy in the presence of sunlight and uses the battery for power in the absence of sunlight. Moreover, a fiber optic sensor helps to reduce power consumption of the circuit. A blowing "pushing" fan and suction "pulling" fan collect the mosquitoes without any significant morphological damage.

(a) (b)

Fig. 2. Solar-powered mosquito traps design. (a) Solar panel outlook. (b) Fiber optic sensor part of the Trap.

IV. Transformative Design Details

Construction of the proposed trap shown in Section III is illustrated in the following four subsections. First, the air flow system inside the trap is critically important as the air-flow directs the mosquito into the net. Second, circuit design includes assembling all the electrical components along with sensors, microcontrollers, and fans in a single PCB board. Third, the microcontroller itself is programmed to drive the fans on and off. Finally, integration of the sensor with the microcontroller is performed to minimize power consumption. Each of the modules is described in detail, respectively.

A. Airflow

Airflow in the prototype mainly depends on the mechanical design of the device. We have modified several versions of the device design for efficient airflow. The first version contained one "pushing" fan and a double funnel-system (Fig 3.a.). This design has a body of 6 inch PVC cylinder with two holes so that mosquitoes can enter. Weak airflow in this design reduced the chance of successfully capturing mosquitoes. Later the design was modified with a single hole instead of two and the addition of a "pulling" suction fan in a 5 inch transparent Plexiglas body. These modifications maximized the airflow and consequently conserved energy. Successful attempts of blowing the mosquitoes into the net increase by maximizing airflow. The desired airflow needs to prevent mosquitoes to fly out of the trap.

To determine the maximum airflow for the design, produced voltage is observed when the second fan turns its blades due to the airflow of the first fan. The distance between top and bottom fan is adjusted for maximum voltage. Thus, the maximum air flow is ensured at a distance such as, 12 cm from the position of first to second fan.

Fig. 3 shows airflow design concepts of the initial design and the modified one with two fans. The two fan design produce the most cubic feet per minute (CFM) air to blow down. The top fan pushes mosquitoes down, while the bottom fan prevents mosquitoes from flying out the entry portal. Mosquitoes are transported down to the retention container.

The proposed design is compact and Plexiglas renders the opportunity of visibility inside the device. Also instead of using two entrances for mosquitoes to fly in, cutting down

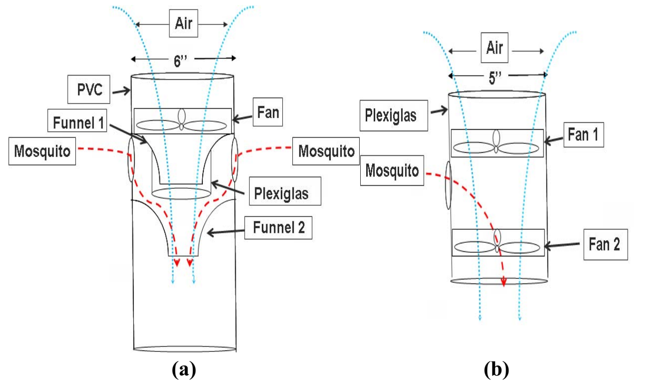


Fig. 3. Airflow design concepts. (a) Shows first version with only one fan. (b) Second version, which incorporates two fans associated with a Plexiglas body part, has single entrance hole to guarantee maximum efficiency in air flow.

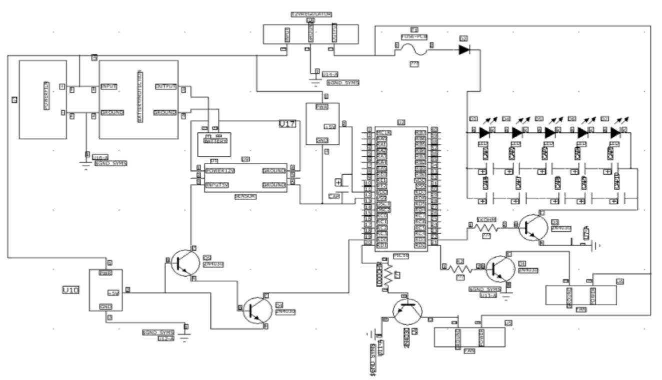


Fig. 4. Circuit Schematic. The right side shows the use of the LED's fans. The main middle block is the microcontroller. To the left of it is the sensor.

it down to one hole also ensures maximum efficiency for the air flow. As shown in Fig. 2, we also use a plastic flap as a mesh funnel. For example, the plastic flap is good to capture the majority dead mosquitoes or the ones don't have the ability to fly back out. The plastic flap for the funnel works well for trapping mosquitoes because most mosquitoes stay stationary on the netting of the device.

B. Circuitry

The main part of the circuit is the microcontroller. Here, PIC18LF4553-I/P is used as the microcontroller. The sensory output voltage varies up to 9 volts, but microcontroller uses 5 volts as an interrupt. Sensory voltage is passed through a Bipolar Junction Transistor (BJT) acting as a switch. The BJT ensures 5 volts interrupt at microcontroller's input. Driving the fans using the microcontroller is a crafty solution because fans operate at 12 volts, and the output of the microcontroller is 5 volts. A BJT switch instead connects the fans only when the microcontroller has the output of 5 volts. Two sets of five capacitors are used to light up UV LEDs with diodes that allow discharging of the capacitors only through the LEDs. Moreover, by having the fuse between the input voltage and capacitors, backflow from the capacitors to the PIC18LF4553-I/P is prevented. The circuit is designed using PADS Layout Editor shown in Fig. 4.

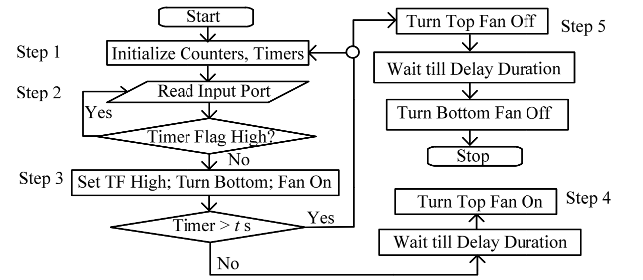


Fig. 5. Flow chart for the program shows that process microcontroller carry out instruction. Starting from the initialization of counters and timers, reading input ports and performing logic operation to the output voltage to run the fans (TF = Timer Flag).

C. Microcontroller Programming

Fig 5 shows a flow chart of the program how the microcontroller circuit works as a whole in order to give a proper response to the output voltage from the sensor. In the flow chart, operations are listed as the five representative steps which the microcontroller needs to perform. At the start-up of the device, counters and timers associated with the logic operations are reset. In the presence of a target through the fiber optic array, the sensor produces an output voltage which is eventually fed in to the microcontroller as an input signal. While the input port reads the high voltage, a check is done to find the status of timer flag: if high, no further action is taken, otherwise by setting timer flag high, the output port is set high to provide enough voltage to gate of the transistors.

When the transistor gets a voltage at its gate, it connects the circuit of the fan to ground turning the fan on. A delay is introduced to set a time gap between the start-up of the top and bottom fans. This delay is designed to enhance the efficiency of mosquito capture. The timer counts up to t sec, by this time it is expected that the target is driven into the net of the trap, before it stops and resets the output port to turn the fans off. If the sensor counts any other objects during the fans running, the microcontroller ignores its input interrupt from the sensor as the timer flag is high. The brief summary of programming steps is shown below.

Programming Steps:

Step 1: Initializing Counters and Reset Timers
Step 2: Reading Interrupt Port
Step 3: Updating Timers and counters based on interrupt
Step 4: Provide desired voltage that will derive the fans
Step 5: Provide desire voltage that will turn fan off after a time t second.

The main portion for the programming of the PIC18LF4553-I/P lies in the use of timers and interrupts to receive input from the sensor to turn on the fans. The PIC18LF4553-I/P also controls the charging of the capacitors. By using the timers, whenever the sensor detects the mosquitoes, the two fans can be controlled by the PIC18LF4553-I/P [42]. The two fans get triggered but do not turn on at the same time. The bottom fan turns on first, and then the top fan blows down. After a certain period of time t sec, the fans are turned off and this time altering the order from the top fan first to the bottom fan later. During that given time period, the microcontroller sends no further interrupt although, if there is any input interrupt from the sensor. Ignoring the input interrupts during the time the fan is on avoids wasting the power.

D. Optical Fiber Sensory

This fiber optic sensor has the ability to detect and count very small object that passes through its entrance (∼1.5 mm). The mosquito size ranges from 1 mm to 15 mm. Whenever, the mosquitoes enter the hole, the sensor detects them and sends an output signal as an interrupt to the microcontroller that triggers the fans and LEDs to work.

In this project, the D10 Expert for Small Object Counter [43] is used to detect the mosquitoes entering the small window. The D10 Expert sensor is a high-performance plastic fiber optic amplifier that has been optimized for small object counting through the use of beam fiber optic arrays. The main application of the D10 Expert is used in the pharmaceutical industry for counting Gel-Caps in pharmaceutical bottling as well as high-speed soybean counting [48].

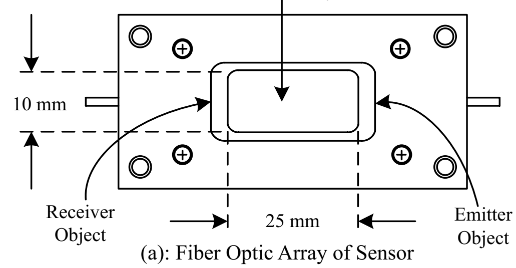
The physical principle of the D10 fiber optic sensor device is described as follows: D10 fiber sensor measures the intensity of light, and only a simple source and detector are required. The source emits light, which is then passed through the input fiber (fiber that connects the emitter with the fiber optic array). When light enters the fiber optic array (sensing medium) having a different refractive index than the core of the fiber, it diverges into a cone with a semi apex angle. The fraction of light coupling from one fiber (emitter end) to the other end (receiving end) depends on the transmittance, Fresnel loss, and divergence of light beam leaving the fiber. Effective transmittance depends on the refractive index of the sensing medium. If the refractive index is altered, the fraction of coupled light can be changed from the receiving end's fiber to the receiving port of the sensor. Due to the array of fibers in the sensing medium, a precise threshold of the refractive index can be implemented for reliable detection of small objects [47].

The fiber optic arrays shown in Fig. 6 are very reliable detection of objects in the size of 1.5 mm. The D10 Expert Counter has an object on the right side is the fiber optic arrays. It has an open window that allows the small objects to pass through as it breaks the fiber optic signals in detecting the small object. The object on the left side is the D10 Expert receiver. It has a screen and two buttons in which the setting can be adjustable according to the circumstances. D10 Expert offers variety of options that can be useful in different type of situations such as adjusting Threshold Offset Voltage, Dynamic Even Stretcher, Display Mode, Speed and Power Combination.

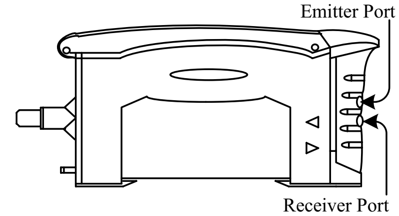
Table I shows some specifications of Fiber Optic Sensor D10 Expert along with other three sensors. We have adopted the fiber optic sensor due to its advantages over the other sensors mainly because the output response time is smallest among the other three sensors [44]–[46].

The D10 Expert is designed to have four different display modes such as health mode, percentage mode, signal mode, and counter mode. Health mode indicates whether the system operates optimally and in what extent. Percentage mode signifies in what ratio the object goes through the window and breaks the beam of fiber optic arrays. Signal mode implies how many signals the small object breaks in the fiber optic arrays. Counter mode counts the number of objects that have gone through the fiber optic array. In the counter mode, Dynamic Event Stretcher feature prevents multiple counting of small objects passed through the fiber optic arrays. The D10 features either two NPN or two PNP outputs, depending on the model. In our design, we have used Counter Mode and PNP outputs [43].

The fiber optic sensor is used to record the number of mosquitoes caught as well as acted as a trigger for the fans to turn on. In the circuit, the fans stay off (false) and then as soon as the fans receive the signal (true) from microcontroller, the fans will be turned on. This logic applied is simple Boolean logic. To reset the counter or the sensor itself, the power of the sensor needs to be disconnected.



(a): Fiber Optic Array of Sensor



(b): Physical Structure of D10 Expert Sensor

Fig. 6. (a) Shows fiber optic array for small object counter having dimension area 10 × 25 mm which can detect any object as small as 1.5 mm in size. (b) Shows physical diagram of the D10 Expert sensor where emitter port is for detecting emitter object in Fiber array and receiver port is for receiver object as well.

TABLE I
SPECIFICATION OF SENSOR

Characterization Parameter	Fiber Optic	Laser [27]	Photoelec tric [28]	Ultrasonic [29]
Supply Voltage (V)	12 ~ 24	10 ~ 30	10 ~ 30	10 ~ 30
Supply Current (mA)	< 65	35	< 40	< 50
Ripple Voltage	0.1	0.1	0.1	0.1
Temperature (°C)	-20 ~ +55	-10 ~ +50	-20 ~ +55	-40 ~ +70
Relative Humidity(%)	90	90	90	NA
Response Time (μs)	150 *	500	3000	2000
Power-up Delay (ms)	< 1000	1000	300	100
Max. load (mA)	150	150	300	150

Note : * indicates Programmable

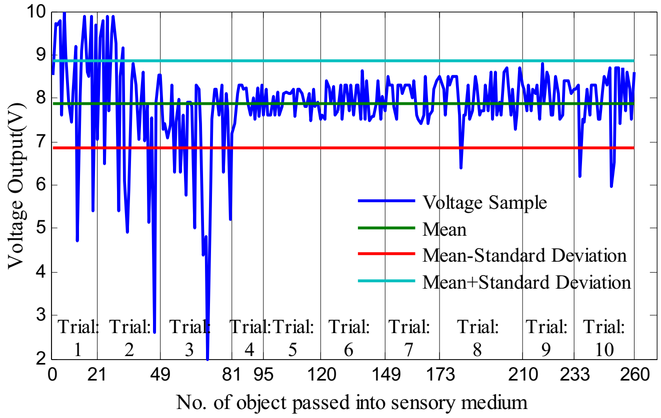


Fig. 7. The output voltage measured at sensor output line with respect to the target counted each time in 10 different trials. In the measurement, the target was counted every time when there was a target passed through the fiber optic array of the sensor.

TABLE II
SENSOR PERFORMANCE THROUGH OUTPUT VOLTAGE

Trial #	Total # of objects	Total # of Object Detected	Success Ratio (%)	Mean of Output Voltage (V)	Standard Deviation of Output Voltage(V)
1	21	21	100	8.47	1.45
2	28	28	100	7.71	1.76
3	32	32	100	6.95	1.45
4	14	14	100	7.95	0.34
5	25	25	100	7.92	0.26
6	29	29	100	7.93	0.38
7	24	24	100	8.03	0.39
8	37	37	100	8.00	0.51
9	23	23	100	8.10	0.39
10	27	27	100	7.91	0.39

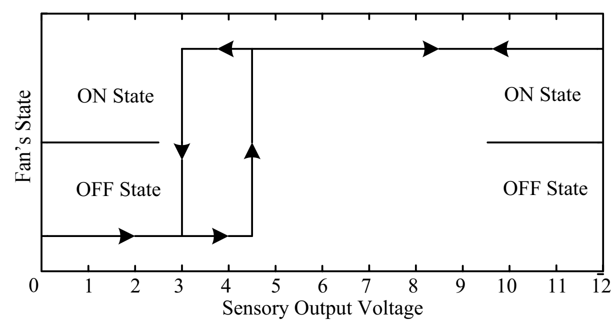


Fig. 8. Fan's state for variable sensory output voltage. Voltage was varied in ascending as well as descending order whereas threshold for ascending is 4.5 volts to turn fan on and for descending is 3 volts to turn fan off.

V. RESULTS

We evaluated each of the modules described in Section IV with the evaluation experiments for testing the proto-typed trap by V.A. Optical Fiber Sensor, V. B. Microcontroller, V.C. Trap Ratio, and V.D. Battery Life.

A. Optical Fiber Sensory Evaluation Using Plastic Particle Target Objects

Fig 7 shows voltage of sensory outputs when the target objects pass through the fiber optic array of the sensor. The first experiment of target objects used artificial man-made plastic particles with the average size of 1.5 mm so that the sensor could be evaluated in more reserved conditions. We conducted 10 trials with random experiments summed up to 260, shown in Target Number of Fig. 7. Objects were passed vertically through fiber optic array of dimension 10 mm by 25 mm. We plotted the sensory output voltage in Fig 7.

Fig. 7 shows that the output voltage had a mean value 7.8615 with a standard deviation 1.015 over 10 trials. Smaller standard deviation indicates stability of sensor performance over a wide range of 260 samples. We configured sensor in counter mode which enable to observe detection performance. The output voltage was fed into the microcontroller input, and the microcontroller operated at 5 volts. In the case of plastic particles, sensor counted all target objects with 100 percent success ratio in total of 260 experiments, as shown in Table II. We defined a metric success ratio defined as the ratio of detected object count and objects passed through the fiber optic array.

Table II summarizes results in 10 consecutive trials of random number of experiments with artificial objects. In each experiment we recorded sensory output voltage and calculated mean and standard deviation of voltages for a particular trial.

B. Microcontroller

In this experiment microcontroller PIC18LF4553-I/P decided when to drive fans depending on sensory output voltage. We were interested in finding the range of this output voltage which eventually fed in interrupt port of microcontroller. At first, we swept the voltage in ascending order from 0 to 12 volts. When input sensory voltage reached 4.6 volts, the fan's state changed from off-state to on-state and kept on for subsequent increase in voltage.

However, from Section V.A. we had mean value of sensory output about 8 volts. So, we chose 12 volts as a limit considering safety margin. We, then, gradually decreased the voltage to 0 volt and this time fans did not switch to off-state until voltage fell below 3 volts. We concluded from this result that a turned on device was sensitive to voltage as low as 3 volts.

Fig. 8 shows changes in fan's state derived by microcontroller depending on sensory output voltage. We again performed 10 identical trials with random number of objects detected by the sensor, this time with an additional microcontroller circuit part. Success ratio, here, is ratio of successful attempts of driving fans and counted object detection.

The results described in Table III mirror what is depicted in Fig. 8. Sensory output, ranged from 6.9 to 8.5, yielded microcontroller output to 4.6 volts, required to activate the circuit responsible for turning on the fans. 100 percent success ratio inferred for a high overall success ratio, which is described in sub-section V.C. The remaining issue includes

TABLE III
MICROCONTROLLER PERFORMANCE FOR SENSOR OUTPUT VOLTAGES

Trial #	Total # of Object Detected	Average Sensor Output(V)	Average Microcontroller Output(V)	Total # of Times Fan On	Success Ratio (%)
1	22	8.51	4.6	22	100
2	31	7.60	4.6	31	100
3	25	6.92	4.6	25	100
4	20	7.74	4.6	20	100
5	28	7.94	4.6	28	100
6	35	8.00	4.6	35	100
7	19	8.04	4.6	19	100
8	33	7.97	4.6	33	100
9	26	8.01	4.6	26	100
10	21	7.99	4.6	21	100

TABLE IV
MOSQUITO TRAP RATIO

Trial #	Total # of runs	Total # of mosquitoes	Number of Mosquitoes Trapped	Success Ratio (%)
1	9	20	20	100.0
2	15	30	28	93.3
3	11	16	16	100.0
4	12	28	27	96.4
5	8	15	15	100.0
6	10	24	24	100.0
7	13	20	20	100.0
8	14	26	25	96.2
9	10	21	21	100.0
10	8	16	16	100.0

how the sensor triggers the microcontroller as soon as the sensor detects live mosquitoes.

C. Trap Ratio

Live, field-collected *Culex pipiens* mosquitoes were used as a target objects to evaluate the overall success rate in the prototype of Fiber-optic Sensing Mosquito Trap system. Table IV shows the results obtained from the counter of fiber optic sensor. The high success ratio in table indicates that the sensor was able to detect almost all the mosquitoes trapped in to optical fiber trap array. Each trial consisted of several runs where in each run random number of the mosquito was introduced to the trap entry portal by being blown by a manual insect aspirator. Shown in Table IV, this fiber optic sensor had perfect detection ratio 7 out of 10 trials when the mosquito passes through the sensor. Those cases to miss the perfect detection ratio included the case the mosquito escaped the trap, although most of them were actually blown into the bottom net.

Some were in the trap itself, but were caught in between each of the fans. When multiple mosquitoes were introduced to the fiber-optic array simultaneously the sensor successfully counted each mosquito. However, the counter counts mosquitoes as they enter the trap as well as those that escape through the entry portal. To avoid this problem, a more efficient fan capture and retention system should prevent mosquitoes from escaping. A sample demonstration video is available in [49].

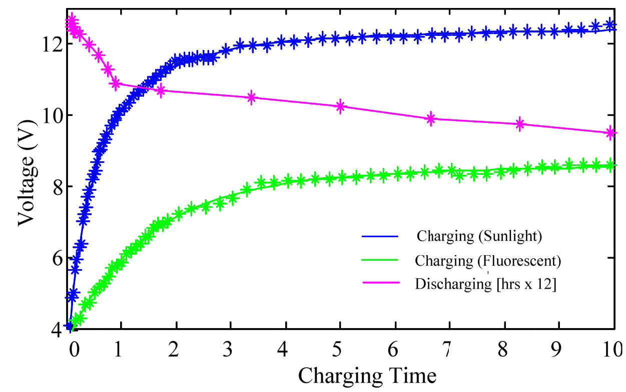


Fig. 9. Discharging and charging of battery. Discharging plot refers to the voltage output when device drives the fans continuously. Other two curves show charging through solar panel both indoor (fluorescent light) and outdoor (sun light) condition.

D. Battery Life

Battery was evaluated for its depleting nature. A vital part of design was power absorption conducted by the fans. We speculated that worst case of this design would be when a mosquito entered the trap entry portal every 15 sec time interval. We used solar power to make the design energy efficient. We conducted experiments for charging battery with the help of solar panel both in sunlight (outdoor) and in florescent light (indoor). Fig. 8 shows that battery can be charged up to its maximum limit 12.5 volts through solar panel in sunlight, otherwise it can be charged under indoor fluorescent lights up to 8.5 volts. Charging time was 10 hours when the battery was initially charged up to 4 volts. Charging through the sunlight had also a faster rate than that of florescent light.

Fig 9 shows the discharging graph of the UPS battery assuming that all trap components are on. The trap used about 0.3 Amps per hour having voltage level down from 12.6 to 9 volts. Since the trap is designed to run only when the sensor was triggered by mosquitoes, actual discharge times depend on the frequency of mosquitoes entering the trap.

VI. CONCLUSION

We propose a new design of mosquito trap using a fiber-optic sensor. This prototype was designed to collect live mosquitoes more efficiently than existing traps. The selective power design feature of the fiber-optic sensor may decrease mosquito avoidance of the trap due to continuous airflow and make the trap more power efficient. Programming of the microcontroller drives the fans on and off based on the triggering of a fiber-optic sensor. The success ratio of trapping live mosquitoes was nearly 100 percent. Though the fiber-optic sensor detected and counted each mosquito that entered the trap, improvements to the capture and retention components of this design are warranted. The solar panel used was able to charge the battery up close to maximum 4 hours, and continued to drive fans by depleting battery with 3.6 volts for 5 days. A key improvement of the optical fiber sensor can be enhanced by designing a multilayer structure of the fiber optic array. This multilayered structure may increase the effective area of the array as well as the sensitivity of the sensor, which would maximize the probability of small particle detection. Further improvement should address the capture and retention of mosquitoes perhaps by using fans with higher CFM and utilize air actuated gates that ensure specimen retention. Another improvement include TiO_2 coated surface which will produce CO_2 in the presence of UV light to attract mosquitoes.

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