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Optimizing CO_2-Based Mosquito Control via Anaerobic Plant Fermentation and Molasses Dose Recommendation

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Mosquitoes pose a serious threat due to the diseases they transmit, such as dengue, malaria, and chikungunya. In the Philippines, dengue remains the most prevalent, with 437,089 cases reported annually. Studies show that UV traps are less effective when used alone and tend to attract non-target insects, disrupting ecosystems and increasing disease vector risks. These limitations highlight the need for more effective and sustainable mosquito control solutions. This study introduces a dual-output device that enhances fermentation-based systems by producing both CO_2 for mosquito attraction and a fermented juice fertilizer for urban gardens. A Gradient Boosting algorithm was used to develop a molasses recommendation system, optimizing CO_2 and fertilizer output. The system incorporates various sensors and an ESP32 microcontroller to monitor and control the fermentation process. Comparative testing with a UV trap was conducted in an urban garden in Sta. Rosa City, Laguna, Philippines. A one-tailed t-test yielded a t-value of 1.7889, indicating superior mosquito elimination performance. The Gradient Boosting model achieved an R^2 score of 93.23 % and a Mean Squared Error of 1002.6486, demonstrating strong predictive reliability. This study presents a sustainable approach to mosquito control, offering added agricultural benefits through organic fertilizer production.

1. Introduction

Vector-borne diseases are illnesses brought by vectors such as mosquitoes and are considered to be one of the most pervasive diseases, accounting for 17 % of all diseases and causing 700,000 deaths annually (World Health Organization, 2024). Mosquitoes are considered a threat primarily due to the diseases they transmit, such as dengue, malaria, and chikungunya. The Philippine Statistics Authority (2023) released records of dengue, malaria, and chikungunya cases for the past few years show that dengue remains the most prevalent mosquito-borne disease in the country, with hundreds of thousands of cases reported annually. Dengue had its peak of cases in 2019 with 437,089 cases, malaria in 2015 with 5,208 cases, and chikungunya in 2016 with 6,241 cases (Del Prado, 2023).

The breath humans exhale from respiration is rich in carbon dioxide (CO_2), which attracts mosquitoes as it signals that a host is nearby. Metabolism, which controls raising and lowering body temperature, also plays a factor along with genetic makeup, which accounts for 85 % of the factors that make an individual attractive to mosquitoes (Fernández-Grandon et al., 2015). Because of this natural attraction to humans, researchers and inventors have developed different methods or solutions, including repellents, protective clothing, protective nets, and mosquito traps, to prevent mosquito bites and eliminate mosquitoes (Fernández-Grandon et al., 2015). A study in Laguna, Philippines, states that the most used method for preventing mosquito bites is window screens and nets (Quinto et al., 2020). These serve as barriers against mosquitoes and other insects that may potentially harm the residents of a house (Onen et al., 2023). However, nets and window screens degrade over time. They may begin to have holes large enough for mosquitoes to enter, which is why it is recommended to check their condition to maintain efficiency regularly. In the same study, the second most used method for prevention is repellents, which come in different forms. Natural repellents come in the form of oils that are not only repulsive to mosquitoes but also to other potentially harmful insects. Another repellent mainly used in Filipino households is mosquito coils. These are spiral incense that aim to repel or kill mosquitoes in indoor

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environments. When burned, the evaporated materials will act as a repellent. Some mosquito coils from China and Malaysia have been tested and found to be contributors to home pollution equivalent to the same amount of particulate matter 2.5 mass burning of 75-137 cigarettes or formaldehyde from burning 51 cigarettes (Liu et al., 2003). Furthermore, the issue with repellents is apparent as soon as the effectiveness wears off after a certain time; the mosquitoes that have been repelled continue to harbor the potential to spread disease among the household residents. On the other hand, most solutions that kill mosquitoes also have their drawbacks. Types that involve the use of chemicals like pesticides are also one of the solutions that most Filipinos are familiar with; however, these pose significant threats to the residents, especially children. Acute leukemia in children was found to be strongly associated with the use of chemical pesticides in homes (Zhang et al., 2015). Ultraviolet (UV) traps are widely available in the consumer market; however, their effectiveness varies across mosquito species. Baik et al. (2020) found that day-active mosquitoes are attracted to a broad light spectrum, while night-active species avoid UV light during daylight hours. The National Environment Agency of Singapore (2020) reported that UV traps are ineffective against Aedes mosquitoes, the primary vector of dengue. Studies suggest that UV traps are more effective when combined with other attractants such as CO_2 or natural chemicals. However, McDermott and Mullens (2018) noted that UV traps also attract non-target insects, disrupting local ecosystems and potentially drawing more vectors into human environments. In contrast, CO_2 is a natural and broadly effective mosquito attractant (Becker et al., 1995), highlighting the need for sustainable, household-friendly alternatives that reduce environmental impact and improve safety.

Yeast fermentation has long been employed in mosquito elimination devices due to its ability to produce CO_2, a known mosquito attractant. However, fermentation is more commonly used in the production of food, beverages, and organic fertilizers rather than for pest control. Fermented organic fertilizers present a sustainable solution for urban gardeners, enhancing plant growth while promoting renewable resource use. Wong et al. (2017) investigated food waste composting as a means to produce organic fertilizer while reducing greenhouse gas emissions, an approach that aligns with the objectives of the present study. Similarly, Colussi et al. (2012) developed a process model using anaerobic digestion of winery waste—such as grape stalks, grape marc, and wine lees—to generate methane and CO_2. In this study, a comparable method is applied by fermenting fruit peels, plant materials, and leafy greens with molasses to produce carbon dioxide, which functions as a mosquito attractant while simultaneously generating organic fertilizer.

The growth of urban gardening has inadvertently created favorable habitats for mosquitoes due to damp conditions and stagnant water. Addressing mosquito presence in these areas is essential for reducing mosquito-borne disease transmission and improving public health. Developing a mosquito elimination device tailored for urban gardens can reduce reliance on harmful chemical pesticides, promote eco-friendly pest control, and support environmental conservation through the utilization of plant waste. Most CO_2-based mosquito traps depend on non-renewable attractants and do not generate sustainable by-products; this study proposes an eco-friendly system that uses plant-fermented CO_2 and fan-induced dehydration—preventing mosquitoes from feeding once trapped—to achieve effective elimination while producing organic fertilizer for urban gardens. Furthermore, by addressing the limitations present in available solutions in the market, the study will play a role in the betterment of public health and promoting green and environmental solutions as a contribution to the Sustainable Development Goals (SDGs).

2. Methodology

This chapter presents the methodology used to achieve the research objectives, including site selection, research design, system development (hardware, software, and algorithm), prototype testing, and statistical evaluation of results. A quantitative comparative approach was employed, testing the device and a commercial UV trap under similar conditions. Data were analyzed using both descriptive and inferential statistics to assess device effectiveness.

2.1 Hardware and Software

The hardware development of the sustainable mosquito elimination device will revolve around the integration of different sensors (carbon dioxide sensor, humidity and temperature sensor, pressure sensor) and mechanical components (computer fan, DC mini air pump, electric mini solenoid valve, and check valve) connected to ESP32 microcontroller that will function together to eliminate attracted mosquitoes and assist the user in anaerobic fermentation of organic fertilizers through Internet-of-Things (IoT) monitoring in a local server. As shown in Figure 1, the prototype consists of three primary components: a fermentation box, a CO_2 accumulator container, and a mosquito trap. The fermentation box is divided into six compartments—three for fermentation containers and three for storing the resulting organic fertilizer. It is insulated with reflective foil to minimize temperature fluctuations that could affect the fermentation process. Each container holds up to 2 L of extracted

fermented liquid and is equipped with a DHT22 sensor to monitor internal temperature and humidity. Sensor data are transmitted to a local server via an ESP32 microcontroller, which serves as the central control unit.

(a) (b)

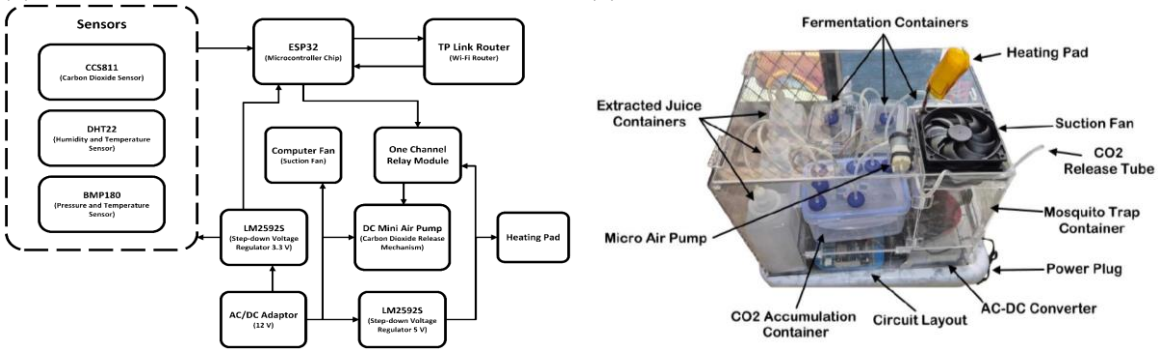

Figure 1: Hardware of (a) Block Diagram; (b) Prototype

CO_2 generated during fermentation is channeled through tubing into the accumulator container. An airlock system—achieved through water and tube positioning—prevents backflow of gases into the fermentation box. A DC mini air pump, located at the top of the accumulator, activates automatically when CO_2 levels (detected by a CCS811 sensor) or air pressure (measured by a BMP180 sensor) exceed threshold values. The accumulated CO_2 is then released through a tube into the mosquito trap.

The trap features a heating pad to attract mosquitoes and a computer fan to draw them into a mosquito trap container, where they are held until they die from dehydration. The main ESP32 microcontroller and associated circuitry are housed in the lower section of the prototype, facilitating overall system monitoring and communication.

For the software, the user is considered the primary entity and initiates the process by entering login credentials into the web application. Upon verification, they are transferred to the main dashboard page, as shown in Figure 2a. The user then has the option to begin a new fermentation trial, where the amount of available plant resources is asked for, as shown in Figure 2b. This information is then processed by the system through a machine learning model to recommend the best amount of brown sugar or molasses that will produce ample CO_2 while maintaining the quality of the fermented organic fertilizer. Once the fermentation process has begun, the sensors will start reading environmental data such as temperature, air pressure, humidity, and CO_2 from the containers, which will be sent to the local server through the ESP32 chip. This sensor data is then displayed to the IoT dashboard on the web application, providing the user with the current status of the fermentation parameters. When a reading reaches a certain threshold, such as air pressure or CO_2 level on the CO_2 accumulator container, the system will send a control signal to the ESP32 chip to activate the air pump and release the accumulated CO_2 on the container. The previous trials page features a simple list display of the recorded previous trials that the user can quickly glance at, read through, and provide valuable insights on past trials. Each list item shows only the crucial information associated with the trial, such as the date the fermentation process began and ended, the amount of plant resources and molasses used, the type of fermentation product, and the amount of fermented organic juice extracted.

(a) (b)

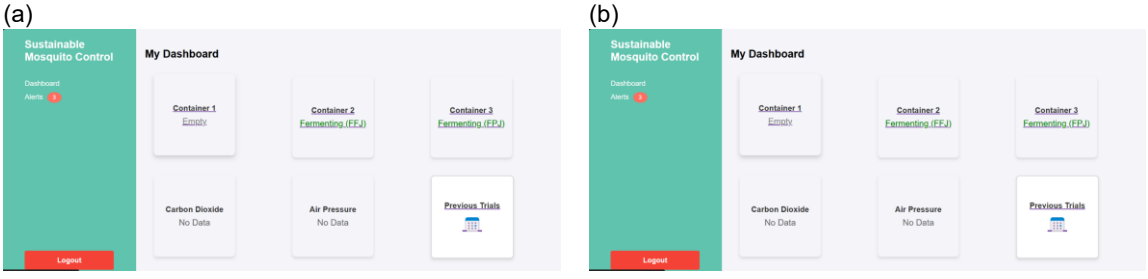

Figure 2: Web Application of (a) Dashboard Page; (b) Container 1 Display Page

2.2 Algorithm Development

Gradient Boosting Regression is a machine learning model used to predict an output variable. The simple models in Gradient Boosting Regression are Decision Trees that transform data into tree representations where

internal nodes are attributes and leaf nodes are class labels. It involves residual, which is the difference between the target value and the current prediction value that is added to the model input, therefore allowing each iteration to be more accurate as the predicted values become closer to the target value (Dhiraj, 2024).

Since the amount of molasses added to plant-based materials significantly affects the fermentation process, it is necessary to develop a data-driven recommendation system, based on historical trials, to optimize molasses input to achieve sustained CO_2 production, high fermented juice yield, and a pH level within the usable range. While a 1:1 ratio of plant material to molasses is commonly recommended for producing fermented plant juice (FPJ) and fermented fruit juice (FFJ), this guideline focuses solely on juice fermentation. It overlooks CO_2 production, which is crucial to this study. To identify the optimal molasses amount for varying plant volumes, a Gradient Boosting Regression model was utilized.

Due to the absence of suitable existing datasets, particularly those including CO_2 measurements during fermentation, the researchers constructed a custom training set for the machine learning model. The dataset involves four continuous features: plant material amount or amount of plant material used in grams, molasses amount or the initial amount to be added in milliliters, average CO_2 produced or the mean amount of CO_2 generated during the fermentation for seven days in parts per million (ppm), and juice yield or the amount of juice extracted in milliliters. These features were used to train the machine learning model along with the target variable of optimal molasses quantity. A total of 55 fermentation trials were conducted under the limited amount of time available for completion of the study. The trials were divided into two groups: 27 were fermented plant juice (FPJ), and 28 were fermented fruit juice (FFJ), differing only in the type of plant material used, with FPJ consisting of greens and vegetables, and FFJ consisting of fruits. To make a new projection for the data, Eq(1) was used. In Eq(1), υ stands for learning rate, which is usually between 1 and 0, while Eq(2) is the output value of each leaf.

$$F_m(X) = F_0(x) + \upsilon \sum_{j=1}^{J_m} \gamma_{jm} I(x \in R_{jm}) \quad (1)$$

$$\sum_{j=1}^{J_m} \gamma_{jm} I(x \in R_{jm}) \quad (2)$$

2.3 System Testing

The device was evaluated for its effectiveness in reducing mosquito populations in a residential urban garden, alongside a commercial UV trap for comparison. Both devices operated concurrently under identical environmental conditions across 30 one-hour trials. During each trial, the number of mosquitoes captured or killed by each device was recorded. The collected data were tabulated and analyzed using inferential statistics to determine whether the differences in mosquito elimination rates were statistically significant.

A one-tailed independent samples t-test was employed to compare the mean performance of the two devices (National University, 2024). The null hypothesis (H_0) posited that the device's effectiveness was less than or equal to that of the UV trap. In contrast, the alternative hypothesis (H_1) proposed that the device was significantly more effective. The analysis involved calculating the sample means, variances, and degrees of freedom to assess whether observed differences could be attributed to the device's superior performance or random variation.

Functionality testing was performed to determine the functionality and effectiveness of the mosquito elimination and fermentation monitoring device. Specifically, the sensors serve a crucial role in the monitoring aspect of the device by capturing and monitoring their corresponding fermentation parameters. The sensor underwent 30 trials to evaluate its measurement accuracy by comparing its readings to those of a commercially available reference device. Before testing, the sensors were calibrated, either through environmental exposure or software correction, to enhance accuracy and ensure reliable environmental readings. To be specific, the CCS811 sensors for CO_2 monitoring were calibrated by ambient air exposure for a total of 48 hours as indicated on the datasheet. On the other hand, the DHT22 sensors for humidity and temperature monitoring were calibrated through the implementation of correction factors in their readings, with the measurement device serving as a reference, since these sensors are factory calibrated and can only be corrected through software correction. Similar to the DHT22 sensors, the BMP180 sensors for pressure and temperature monitoring were also factory calibrated. However, it did not require software correction as its readings were not significantly different from the measurement device. A two-tailed t-test will be used to assess whether the sensor readings significantly differ from those of the reference measurement device. The null hypothesis (H_0) states that there is no significant difference between the sensor and device readings, while the alternative hypothesis (H_1) asserts that a significant difference exists.

Both one-tailed t-test and two-tailed t-test use the degrees of freedom to determine the critical value from the t-distribution table. If the computed t-statistic value is greater than the positive or less than the negative critical value at the 0.05 alpha level, the researchers are allowed to reject the null hypothesis and support the alternative

hypothesis. On the other hand, if the t-statistic value is within the critical range, then the sensor readings are not significantly different from the measurement device or equipment readings, therefore not allowing the researchers to reject the null hypothesis and support the alternative hypothesis.

The molasses amount recommendation system was tested to see how well it could predict the right amount of molasses based on plant resources. To measure its accuracy, a statistical metric called R^2 was used, which shows how closely the model's predictions match real data. The dataset includes the amount of plant material, juice produced, and average CO_2 production, along with the ratio of juice to plant material and CO_2 to plant material.

Before training, the data was split into two parts—80 % for training and 20 % for testing. A Gradient Boosting Regressor model was used to learn patterns from the training data. Once trained, the model was tested by making predictions on the test data. Its accuracy was checked using the R^2 score and Mean Squared Error (MSE), with a higher R^2 score meaning better predictions. The final R^2 score helped confirm that the model can give practical molasses recommendations based on the input of plant resources.

3. Results and Discussion

The prototype was deployed on a residential urban garden in San Lorenzo, Sta. Rosa City, Laguna, Philippines. This location was ideal for deployment as it captures the intended operational location of the prototype, an urban residential garden environment. To compare the efficiency of the prototype and UV trap, the proponents used a frequency distribution table. After each hourly trial, the result showed that the prototype was able to kill a total of 16 mosquitoes, while the UV trap killed 8 mosquitoes. The results were analyzed using a one-tailed t-test, with the alternative hypothesis stating that the device is significantly more effective at killing mosquitoes than the UV trap. Since the calculated t-value of 1.7889 exceeds the critical value of 1.6715, the null hypothesis is rejected, indicating that the device demonstrates superior mosquito elimination compared to the UV trap.

Sensor readings were compared to those of commercially available devices over 30 trials to assess measurement accuracy and test for significant differences. The DHT22 sensor was evaluated against the FY-12 tester, yielding a t-value of 1.5865 for temperature and 1.9012 for humidity, both within the critical range of -2.0017 to 2.0017, indicating no significant difference. The BMP180 sensor was compared to the HT636 Digital Manometer Differential Pressure gauge, with a t-value of 0.1446, also within the critical range, supporting no significant difference. Lastly, CO_2 measurements from the CCS811 sensor and a portable indoor CO_2 reader resulted in a t-value of -0.1627, within the critical limits. These findings indicate no significant difference between the sensor readings and their respective reference devices, thus failing to reject the null hypothesis.

The Gradient Boosting Regression model showed favorable accuracy, with an R^2 score of 0.9323, meaning it could explain 93.23 % of the variations in molasses output. The MSE was 1,002.6486, indicating that the difference between the predicted and actual molasses amounts was relatively small. This suggests the model is highly reliable in making accurate predictions.

Several key factors influenced the determination of optimal molasses input for fermentation. The amount of plant material served as the foundation, while juice yield and average CO_2 production measured fermentation output. To enhance model accuracy, additional features such as juice-to-greens and CO_2-to-greens ratios were introduced to capture the efficiency of plant-to-output conversion. A logarithmic transformation was applied to CO_2 data to mitigate the effect of outliers and improve model stability. These engineered features enabled the machine learning model to more accurately capture the relationship between plant material and molasses requirements, resulting in a reliable recommendation system for optimizing sugar use based on available plant resources. The results might be affected by the size of the urban garden, the time of testing, and the interval of trials.

4. Conclusions

In response to the widespread availability of mosquito UV traps and the limitations of fermentation-based mosquito control devices, this design project introduces a sustainable solution that integrates mosquito elimination with organic fertilizer production. The prototype ferments plant or fruit materials with molasses to generate both fermented fertilizer and carbon dioxide, the latter serving as a mosquito attractant. Hardware components are integrated with software tools to enable real-time monitoring via a locally hosted web application. Functional testing demonstrated that the device, utilizing a combination of CO_2 emission and a heating pad, significantly outperformed a commercial UV trap in mosquito elimination. A one-tailed t-test confirmed the statistical significance of this improvement. Sensor accuracy testing, validated through a two-tailed t-test, indicated no significant differences compared to standard measuring instruments, confirming sensor reliability. Additionally, a Gradient Boosting Regression model was employed to optimize molasses input, achieving a high R^2 score of 0.9323 and an MSE of 1,002.6486, demonstrating strong predictive performance.

This project highlights the application of emerging technologies in developing practical, eco-friendly solutions for public health and urban agriculture. Future research may improve device efficiency through optimized mosquito control methods, prototype redesign, and cloud integration for better access and security. Exploring fermentation parameters could enhance fertilizer quality. Testing in varied environments may expand potential applications.

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