DEVELOPMENT OF A COST EFFICIENT INSECT CONTROL SYSTEM BASED ON THE DOPPLER SOUND EFFECT PRINCIPLE.

David M. Kirima, Kiroe Anthony, Ominde Calvine F., Elphas M. Khata

Abstract— The twenty first century has experienced has experienced swift changes in the development and advanced of different bio-insecticide and electr- insecticide based insect management tactics. This is with an aim of controlling various diseases spread by various insects. One such disease is malaria caused by the plasmodium parasite spread through female mosquito bites. However, the current methods employed to control insect's population in both private and public places are limited in various ways. First, aerosols have known side effects to the people if over exposed, secondly ultrasonic based systems emit high frequency waves known to have side effects o either hearing or human brain when over exposed. There is still ample need for these methods which are easily accessible, convenient to develop and could be economically commercialized to be modified. One way is by integrating a system that will ensure instantaneous operation unlike continuous operation which over exposes people to such side effects. By using this proposed system, either type of insectcides will only be triggered when necessary hence cost effective. This proposal takes a case study of mosquitoes and how they can be controlled since they make the largest part of the insects with adverse effects to human population. Both experiemental and simulative methods will be used to collect data necessary to come up with the desired algorithms and system design based on Doppler Effect technique. This will facilitate the implementation of the proposed integrated module. The module will incorporate sensors, central processing unit, actuator unit, display unit and data storage/retrieval unit. The completed module will be expected to be triggered only a mosquito reaches the Doppler distance estimated from the Doppler frequency. More so, the system can work for other insects by adjusting the Doppler frequency from the user panel.

Index Terms— Doppler Effect, Mosquito control, Malaria, Mosquito control, Insect Control

1 Introduction

The Doppler effect is a change in the pitch of sound that occurs when a source of the sound is moving relative to a listener. Waves emitted from a moving source are perceived at higher or lower frequency by a stationary observer. For example, besides police radar, the Doppler Effect is used by meteorologist to track storms. Doctors use Doppler Effect to diagnose heart problems. By exploiting mosquito's wing beats and using the Doppler equation it is possible to calculate their buzzing sound and using the perceived sound to record the activity or passage of mosquitoes [16]. Female mosquitoes make a higher pitched sound than males. Most people never interact with the male mosquito because it does not bite. Male mosquito locates female by the sound of their wing beat. Female can beat their wings up to 500 – 600 times per second and the male pick out the higher frequency of those beats when seeking a mate [15].

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Diseases spread by mosquitoes such as malaria, dengue and zika kills over half a million people each year [28]. Management of these diseases has posed a great challenge in recent times, mostly due to global warming, climate change and resistance to drugs. The main challenge is to find efficient and affordable systems that could be used to manage the mosquitos. Possible options being explored include mosquito control mechanisms: altering their breeding, destroying breeding grounds, mosquito repelling systems etc.

This paper seeks to contribute to the mosquito control efforts by the principles of Doppler Effect to detect the frequency of a mosquito by use of the frequency sensor which gives out an instantaneous analogue signal. The frequency signal is then feed into a microcontroller programed to compare it with the known frequencies range data for the action to be triggered. If the detected frequency is found to be within the known range, a control mechanism shall be activated. This means, therefore, that the control mechanism shall be used only when necessary hence; minimal the usage of aerosols and other insect repellants guaranteed that the mosquito will die.

Mosquito frequency i.e. wing beat measurement has been experimented in different scopes and instruments for sound recordings. Examples include: Use of microphones to enable wide-spread acoustic mosquito surveillance and elimination [20]. In this piece of work, microphones were used as detectors/receivers in the investigation of the sound frequencies in the location and elimination of the mosquitoes. Use of Doppler technique to identify mosquito species and the distance to the microphone has proven a possibility in experimental procedures such as acoustic counting of mosquitoes in the field [28]. This provides a good ground for this investigation.

Pates and Curtis [23] suggest that effective indoor residual spraying against malaria vectors depends on whether mosquitoes rest indoors i.e. endophilic behavior. This varies among species and is affected by insecticidal irritancy. Optimum effectiveness of insecticide-treated nets presumably depends on vectors biting at hours when most people are in bed. Time of biting varies among different malaria vector species, but so far there is inconclusive evidence for these evolving so as to avoid bed nets. They acknowledge that the use of an untreated net diverts extra biting to someone in the same room who is without a net.

Pörschmann and Störig [25] suggests that temporal loudness changes, binaural cues and Doppler shift can all influence distance perception of moving sound sources. This research proposes to analyze different auditory distance perception cues of moving sound sources. In psychoacoustic experiments, the subjects were presented with dichotic and diotic stimuli of a set of real-life recordings taken from a passing passenger car and then asked to determine the velocity of the object and its minimal distance from the listener [25]. The results of the listening experiments allow us to separate monaural distance perception cues from binaural ones, and thus show that binaural cues contribute significantly to the perception of velocity. For short distances and high velocities, the presentation of binaural cues causes a decrease in the perceived velocity while for long distances and low velocities this causes a clear increase.

By estimating the minimal distance from the passing object, one observes a significant difference between dichotic and diotic presentation, which can be explained by an increased loudness of dichotic stimuli due to the Binaural Masking Level Difference (BMLD). Furthermore, it is shown that the main parameter for distance determination is the maximum sound pressure level at the listener's position. However, dynamic cues e.g. change of sound pressure level over time and Doppler shift are of considerable importance for the plausibility of the auditory scene [25].

Gibson and Russell [7] classified the reports that male mosquito feathers attract female mosquitoes. In Aedes aegypti and Aedes albopictus, 466 Hz and 462 Hz female mosquito frequency sounds generated respectively. From the experiments of [6], the sounds produced by the thoracic flight machinery of bees and flies appear to be composed of two main vibration modes. The lower frequency one corresponds to the wing beat frequency.

Fourier analysis of the sounds gives only harmonics of the wing beat frequency. However, oscillograms of the waveforms show that the higher frequency vibration is nearly independent of wing beat frequency. The high frequency vibration is probably important in bee communication. Speculation is that, it is due to skeletal vibration which is relatively undamped by muscular and aerodynamic loading.

2 Theoretical Consideration

2.1 Doppler Effect

The Doppler Effect also called the Doppler shift describes the frequency change of a wave in relation to an observer who is moving relative to the wave source. For example, the change of pitch heard when a car sounding a horn approaches and recedes from an observer. When compared to the emitted frequency, the perceived frequency is higher during the approach, identical at the instant of passing by, and lower during the recession [8].

According to [22], the reason for existence of the Doppler Effect is that when the source of the waves is moving towards the observer, each successive wave crest is emitted from a position closer to the observer than the crest of the previous wave. Therefore, each wave takes slightly less time to reach the observer than the previous wave. Hence, the time between the arrivals of successive wave crests at the observer is reduced, causing an increase in the frequency. While they are traveling, the distance between successive wave fronts is reduced, so the waves compress together [11]. Conversely, if the source of waves is travelling away from the observer, each wave is emitted from a position farther from the observer than the previous wave, so the arrival time between successive waves is increased, reducing the frequency. The distance between successive wave fronts is then increased, so the waves retracts out [11].

Study by [8], argues that for waves that propagate in a medium, such as sound waves, the velocity of the observer and of the source are relative to the medium in which the waves are transmitted. The total Doppler Effect therefore result from motion of the source, motion of the observer, or motion of the medium. For waves which do not require a medium, such as light or gravity in general relativity, only the relative difference in velocity between the observer and the source needs to be considered.

2.2 Doppler Equation

A summary work done by [29], entails the noble work of 1842 when Christian Doppler hypothesized that sound frequencies change, relative to the observer, when emitted from a moving sound source. From the Doppler's Hypothesis it is observed that as the sound source approaches, the waves seem shorter and the frequency becomes higher than when the source moves away from a respective stationary listener. Much of this was experimented by [31] in the analysis of inverse Doppler Effect. Equation 1 shows the formula for determining the observed frequency during the Doppler Effect experiments or phenomena as the source moves towards the observer as depicted in described analogy.

$$f_o = \left(\frac{V}{V - V_s}\right) f_s \tag{1}$$

Where: f_o is observed frequency, v is speed of sound in air, v_s is velocity of the source (negative if it's moving toward the observer), f_s is the emitted frequency of the source. Once the ambulance passes the frequency of the sound decreases or sound 'lower'. The same equation is performed to determine the observed frequency, except in this case v is positive. A similar change in frequency is observed if the observer is moving towards a stationary sound source. In this case the formula for determining the observed frequency of sound is given by Equation 2. The change in the equation is basically focusing on the parameter that describes the velocity of the receiver or the observer.

$$f_o = \left(\frac{V+V_r}{V}\right) f_s \quad (2)$$

Where: v_r is the velocity of the receiver, i.e. the observer (This is negative if the observer is moving away from the source). We can also calculate the observed frequency if both the source sound and the observer are moving towards each other. In this case, the formula relating observed frequency and source frequency is given by Equation 3.

$$f_o = \left(\frac{V+V_r}{V+V_S}\right) f_S \quad (3)$$

Sound waves seem to compress or elongate with moving sound source. Moving forward causing the waves in front to seemingly compress and waves in the back to seemingly elongate. The sound of an approaching ambulance siren will have a higher pitch than when it's moving away from you. This is a very practical by-product of sound physics. This Doppler Effect enables one to know when to differentiate between an approaching ambulance and a retreating one and hence give way.

3 Problem Statement

Despite their importance, mosquito control like any other insect control systems that are available in form of Bio-insecticides and electro-insecticides come with limitations. This includes negative impacts like toxic residues in food, water and air as well as effect on non-targeted organisms. In some cases, the developed resistance to some insecticides becomes an extreme wastage of resources when certain unregulated insect control methods are used. For instance, uncontrolled aerosol spraying, over exposure of UV lanterns and ultrasound insect repellants. Therefore, this research proposes an integrated module designed based on Doppler sound effect that will activate/trigger the said systems only when necessary. Besides, it will ensure proximity accuracy when aerosols are used. An embedded algorithm will be used to control the module's operation with utmost preciseness.

4 Methodology

Both experimental and simulative design approaches were used to achieve the research objectives. The method was further subdivided into stages as described:

i. Modelling of simulation environment parameters for Doppler Effect principle at ambient temperature using Atmel 328p software suite in Figure 1.
ii. The parameters obtained in step (i) were utinlised to design the flowchart shown in Figure 2. They included the frequency f_0 and f_s.
iii. A code that shall manage the microcontroller action was developed and uploaded onto the microprocessor. The code analysed the sound was detected as an analogue value. This enables us to get the instantaneous sound frequency values useful for switching action.

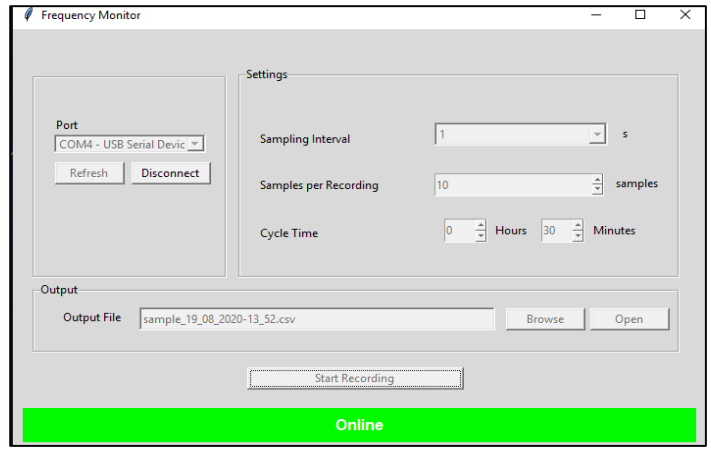

Figure 1. Atmel 328p software suite

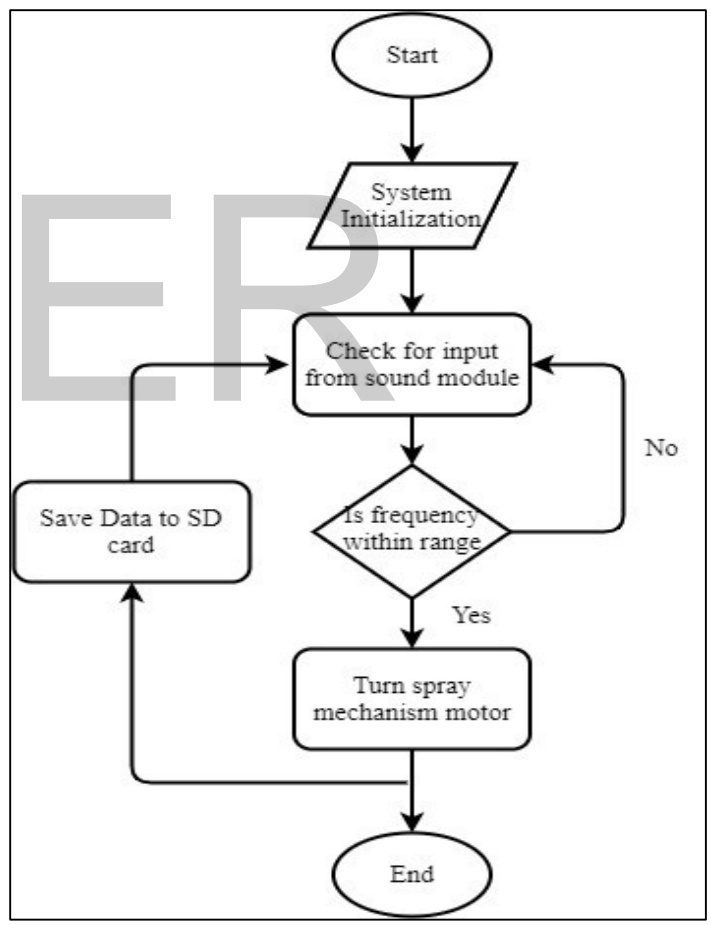

Figure 2. Flowchart

iv. The code was used to compare the range of the input frequency with the experimental data in order to eliminate other sounds and to take action only when the desired frequency was in range, the mosquito's buzzing frequency.
v. To start the frequency detection and recording process: -
    1. Connect the Arduino to a USB port

2. Select the serial port to be used (The Combobox labeled Port)
3. If the serial port does not show up, click the Refresh button so that the program can pick up any newly connected devices on the serial port
4. Click connect to connect to the selected serial port
5. If the connection was successful, the status bar at the bottom should change from red to green and the text should change from 'Disconnected' to 'Connected'
6. Select the Sampling Interval from the provided Combobox. This is the time period between consecutive readings in a recording session
7. Select the Samples that should be taken per recording session
8. Select the cycle time. The time interval between sessions
9. Select the output file. (This has a default provided - Recommended)
10. Click 'Start Recording' to begin recording the data
11. Stop

vi. The Proposed designed system is given in Figure 3.

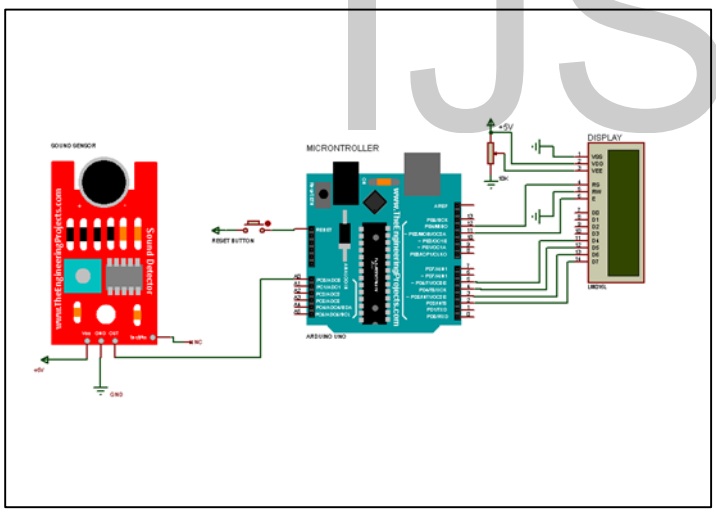

Figure 3. Proposed system design

5 Results, and Discussion

The following data was obtained based on the designed algorithm. The data in Table 1 and 2 represents simulated frequencies at different magnituds and instants for insects at random selection. From which a relation based on natral wingbeat frequency of mosquitoes and other recommended insects can be studied. It shows that as sound sound source closes in the magnitude of the frequency is high and opposite is true. This establishes a relationship between Doppler frequency and distance as illustrated by the speed of sound equation in air.

TABLE 1
SIMULATED MOSQUITO FREQUENCIES

Date	Time	Temperature	558Hz	589Hz	620Hz	651Hz	682Hz	713Hz	744Hz
19/08/202	12:17:45	20	10	5	5	5	3	3	5
19/08/202	12:17:51	20	34	28	35	25	1	17	19
19/08/202	12:17:57	20	0	0	0	0	0	0	2
19/08/202	12:18:03	20	3	1	4	5	5	3	9
19/08/202	12:18:09	20	4	1	5	2	3	5	3
19/08/202	12:18:15	20	3	4	0	5	3	1	4
19/08/202	12:18:21	20	7	4	16	13	7	9	17
19/08/202	12:18:27	20	2	7	4	4	3	6	2
19/08/202	12:18:33	20	12	0	10	2	5	2	11
19/08/202	12:18:39	20	5	4	2	6	0	2	2
19/08/202	12:19:45	21	0	3	33	93	54	3	0
19/08/202	12:19:51	20	4	2	35	95	55	2	8
19/08/202	12:19:57	20	7	4	26	82	45	1	4
19/08/202	12:20:03	20	3	4	32	77	44	0	4
19/08/202	12:20:09	21	4	5	22	70	30	1	4
19/08/202	12:20:15	21	3	2	24	94	47	3	2
19/08/202	12:20:21	20	4	3	28	84	47	0	2
19/08/202	12:20:27	20	6	3	30	90	53	1	3
19/08/202	12:20:33	20	5	1	28	84	46	4	2
19/08/202	12:20:39	20	4	5	27	81	42	5	3

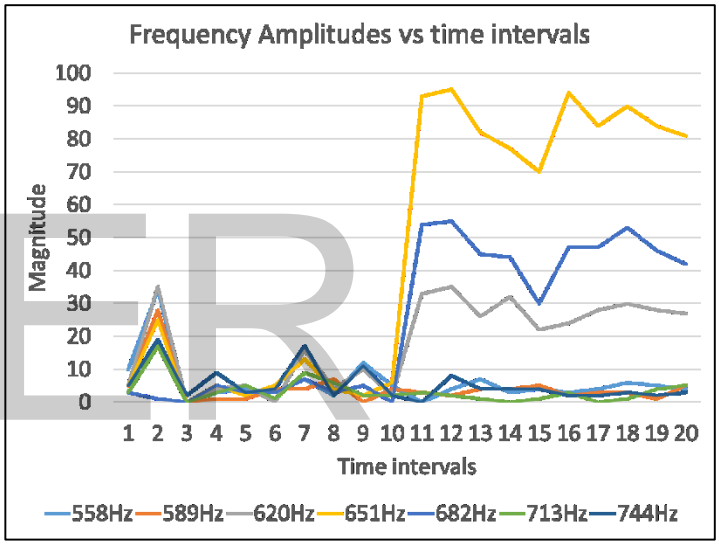

Figure 4. Graphical analysis of Table 1

TABLE 2
Experimental Data Collected using Mosquitoes

Date	Time	Temperat	403Hz	434Hz	465Hz	496Hz	527Hz	558Hz	589Hz	620Hz	651Hz
19/08/202	13:20:35	22	68	65	16	51	101	83	11	25	26
19/08/202	13:20:38	21	31	12	22	31	5	13	10	2	1
19/08/202	13:20:41	21	0	7	5	3	5	3	5	7	2
19/08/202	13:20:45	21	12	5	4	8	20	4	1	5	8
19/08/202	13:20:48	21	5	9	7	8	8	4	7	2	2
19/08/202	13:20:52	22	6	4	11	4	11	1	5	2	4
19/08/202	13:20:55	22	4	5	5	7	6	2	5	1	4
19/08/202	13:20:58	22	0	3	15	12	5	7	8	8	1
19/08/202	13:21:02	21	1	5	14	6	4	2	6	5	6
19/08/202	13:21:05	22	3	11	35	31	2	1	5	3	5
19/08/202	13:21:09	22	4	8	24	21	12	9	11	6	8
19/08/202	13:21:12	21	10	1	16	12	2	4	1	10	5
19/08/202	13:21:15	22	5	1	23	7	3	11	5	10	5
19/08/202	13:21:19	22	5	18	71	51	4	4	4	3	6
19/08/202	13:21:23	21	3	2	25	9	4	7	1	2	4
19/08/202	13:21:26	22	3	22	56	40	0	4	1	7	2
19/08/202	13:21:30	22	7	15	33	27	4	6	4	10	10
19/08/202	13:21:33	21	2	10	32	28	4	2	4	5	5
19/08/202	13:21:37	22	1	12	27	29	6	8	5	2	6
19/08/202	13:21:40	22	8	4	37	17	2	5	4	4	7
19/08/202	13:21:44	22	5	6	1	3	5	3	5	5	1
19/08/202	13:21:48	22	3	5	7	4	5	3	2	9	8
19/08/202	13:21:51	22	7	8	10	7	11	3	8	5	1
19/08/202	13:21:55	22	2	10	12	6	5	9	11	5	8
19/08/202	13:21:58	22	4	4	6	5	2	1	3	3	3
19/08/202	13:22:01	21	6	3	4	4	1	2	6	7	2
19/08/202	13:22:05	22	2	8	2	5	2	6	2	4	2

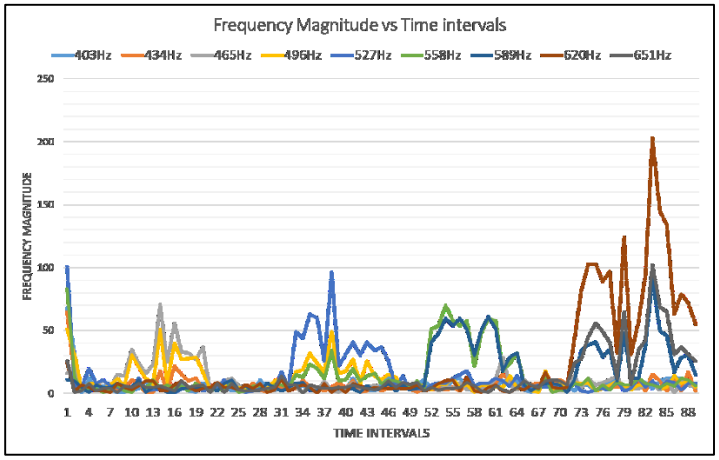

Figure 5. Graphical analysis of Table 2

Based on our experiment findings, it was established that: -

Amplitude of the source frequency increases with decrease with decrease in Doppler distance: -

Distance, s = speed of sound x time
= 331 m/s x periodic time (T)

Periodic time (T) = 1/f

Where f is the frequency f_s, which is related to magnitude x, which is recorded at time intervals as shown in the line graphs.

2. To trigger an action one use either the: -

- Amplitude setting or
- Distance equated from Doppler frequency f_s

It was concluded that the frewuncy magnitude of various insects, in this case mosquitoes, can be used to trigger control cirtiutry which can be interfaced with exixting insecticide spray mechanism so as to automate the entire process. This will ensure ccost effective ose of aerosols and the only spray when necessary initatiative, to control insect population both domestic and in puclic places.

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