Design and Development of Solar-powered Ultrasonic Bat Deterrent System for Sustainable Fruit Farming

T. Vidushi Anjana[1], R.P.R.K. Amarasinghe[2] and W.M. Deepika Priyadarshani[1]

[1] Department of Biosystems and Biotechnology, Sri Lanka Technology Campus, Meepe, Sri Lanka
[2] Department of Agriculture Technology, Sri Lanka Technology Campus, Meepe, Sri Lanka
Vidushianjana0@gmail.com

Abstract. Industrial fruit farming is generally done in a huge open field, which offers a large area for plants to grow. These orchards are maintained with high precision and with the timely application of fertilizers and pesticides to ensure higher crop yield. But across the globe, mostly in countries which are situated in tropical and subtropical regions (such as India, Sri Lanka, Brazil, etc.), fruit orchards that cultivate fruits such as Mango, Guava, Banana, Lychee, and fig attract frugivorous bats in harvest time. These bats consume the fruits and cause significant harvest loss [1]. Although harvest loss due to bats is a major problem, farmers cannot eliminate these pests because they are an endangered species and help agricultural activities such as pollination [2]. Therefore, farmers need an effective method to prevent bats from entering fruit orchards without harming them. This Design project focuses on designing a bat deterrent system that is expected to turn on automatically at night and emit an ultrasonic acoustic field that both echolocating and non-echolocating bats are sensitive to.

Keywords: Echolocation, Frugivore, Ultrasonic Frequency

1 Introduction

Agricultural production plays a critical role in supporting global food security and driving economies, particularly in countries heavily reliant on agricultural exports such as Sri Lanka. It is declared in the article "Critical analysis of the status of fruit crop industry in Sri Lanka" that Sri Lanka was able to produce nearly 33,000 metric tons of harvest from fruit farms and export 90% of the harvest to, the Middle East and the Maldives while earning an income of US$35.7 million [3]. However, pest management remains one of the most significant challenges for farmers worldwide, affecting both yield quality and quantity. Among these pests, fruit bats have emerged as a notable concern for commercial mango orchards. Known for their nocturnal activity and high mobility, fruit bats damage mango crops by feeding on ripe fruits, leading to considerable economic losses for farmers. Traditional methods for mitigating this damage, such as netting, chemical repellents, or manual monitoring, are often labor-intensive, costly, and environmentally unsustainable. Frugivore bats pose a significant challenge to crop production in fruit farms. While bats are ecologically beneficial due to their roles in seed dispersal and pollination, their consumption of fruit in orchards can result in considerable financial losses. Research conducted by the University of Colombo has revealed that a bat can consume 12-48 Kg of fruits [1], [4], [5]. According to research conducted in India Karnatak area, apart from damaging fruits, extensive feeding of fruit bats on tender twigs of Robusta coffee leads to drying of fruit-bearing branches, which leads to crop loss from 5.9%-9.48%. They found that fruit bats consume nearly 50,000kg of litchis per annum, and the damage continues to increase at a rate of 10% annually [6].

Fig.1. Damaged fruit from a Banana orchard of a small-scale farmer in Ragama

According to the survey I conducted, many Sri Lankan orchards, from small-scale to industrial level fruit orchards, have faced this problem (Fig. 1), and most of them were unable to find a solution. Farmers have lost minimum of Rs. 30,000 worth of harvest per season.

1.1 Bat Echolocation Mechanism and Ecology

Bats are flying mammals that forage at night and help in pollination. There are two types of bats according to their diet, such as insectivore bats and frugivore bats. Frugivore bats consume fruits, while the diet of insectivore bats consists of insects. While some of the frugivore bats use visual and olfactory senses to find fruits, most of them use rudimentary echolocation to locate food. Echolocation is a biosonar system that is used by some animal species to navigate and locate food. From frugivore bat species Rousettus leschenaultia, Cynopterus brachyotis and Rousettus aegyptiacus use echolocation to forage, while Pteropus gigantus, Cynopterus sphinx use olfactory and visual senses (non-echolocating) to capture their food. Apart from this bat species, the main frugivore bat varieties that have been found in Sri Lanka are Pteropus giganteus and Rousettus leschenaulti [1], [7]. From those bat species, Rousettus leschenaulti or Indian False Vampire Bat, is a bat species commonly found in Sri Lanka and known to be one of the most widespread bat species in the country that could be found in all six bioclimatic zones. Additionally, this bat species has the highest individual count in our country. Compared to the echolocating mechanism of insectivore bats (which is a laryngeal echolocation), the echolocation mechanism of frugivore bats is weaker, as it is a rudimentary form of sonar. Both echolocating and non-echolocating bats are found to be sensitive to the ultrasonic sound frequency range [8], [9], [10], [11].

As shown in Fig. 2(a) and (b), *Rousettus aegyptiacus*, for instance, produces click-like signals with durations of 0.6–1ms and peak frequencies ranging from 12 to 70 kHz [10]. Despite the simplicity of their echolocation systems, these bats demonstrate effective obstacle avoidance, raising intriguing questions about the underlying mechanisms. The echolocation calls of *R. aegyptiacus* and *R. leschenaultia* are less intense and shorter in duration compared to insectivore bats that use [11]. This poses challenges for detecting returning echoes, particularly in cluttered environments.

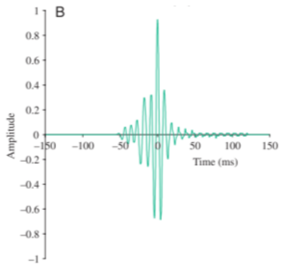


Fig. 2(a)

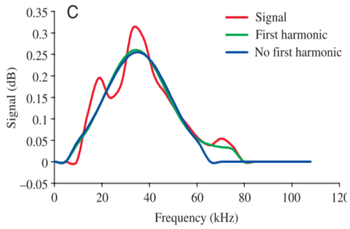


Fig. 2(b)

Fig. 2. (**a)** shows the time duration of a click; **2(b)** shows the peak frequency range of a bat echolocation click of a bat from genus *Rousettus (R. aegyptiacus)* [10]

Apart from the mentioned echolocation ultrasonic frequency ranges, it is stated that *Rousettus leschenaulti* uses echolocation frequency between 19 to 35 kHz, which contains both single and double clicks [12].

According to [8], [9] the non-echolocating bats, such as *Eidolon helvum* and *Cynopterus brachyotis* the hearing range of the bats are relatively flat (±4 dB) between 3 kHz and 45 kHz, with energy above background level up to 100 kHz.

In a study conducted to research a possible bat repellent mechanism using ultrasonic clicks produced by the Peacock Butterfly, it is found that the ultrasonic clicks of the peacock butterfly, which are very similar to the bat's echolocation clicks, can startle inexperienced bats, but after repeated exposure, the bat did not react. This shows that exposure to the same frequency for a long time can lead to habituation [13].

1.2 Current methods that are followed to prevent those challenges

Efforts to address the challenges posed by bats in agricultural settings have spanned a range of strategies, each with varying levels of success and limitations (Table 1). These strategies include visual deterrents, netting, chemical repellents, and ultrasonic devices.

Visual deterrents such as reflective materials, scarecrows, and predator decoys are among the simplest and most cost-effective methods employed by farmers. The premise is to create a visual stimulus that mimics a threat, thereby discouraging bats from approaching orchards. However, bats are intelligent animals capable of learning and adapting to their environment. Studies have shown that while visual deterrents may be effective initially, their efficacy diminishes over time as bats habituate to the stimuli, but research conducted in 1984 has found that using floodlights to deter bats can be successful 90% time [14]. And in research conducted in 2023 also found that the damage from bats could be minimized using LED lights [6]. But this might not be 100% effective because some bat species rely on echolocation rather than relying on vision for navigating and foraging.

Netting is a more robust approach, acting as a physical barrier that prevents bats from accessing crops. While netting can be highly effective in protecting specific areas, its implementation poses significant challenges. The cost of installing and maintaining nets over large agricultural areas can be prohibitive, particularly for small-scale farmers. Additionally, improperly installed nets can inadvertently trap and harm bats and other non-target wildlife, raising ethical and conservation concerns [15].

It is mentioned in [15], [16], [17] that the conflict between the fruit growing industry and frugivore bats is a problem in many countries such as Malaysia, Israel, South Africa, Cyprus and Australia, and the government has legalized bat culling as an easy alternative to using deterrents. This action has been criticized internationally and, a recent red list assessment of this Pteropus species reclassified it from Vulnerable to Endangered. Therefore, Bat culling is not an ethical or environmentally friendly way to reduce the damage [2].

Ultrasonic deterrents represent a more technologically advanced approach, leveraging bats' reliance on echolocation for navigation and foraging. These devices emit high-frequency sound waves intended to interfere with bats' echolocation abilities, deterring them from entering fruit orchard areas. However, existing ultrasonic deterrents have several limitations. Many devices are designed for general animal control and lack the precision needed to target bats specifically (for example: GH-502M Outdoor Bird Bats Deterrents Ultrasonic Dog Raccoon Pest Repeller with PIR Sensor, Ultrasonic Solar Powered or USB Charging Deterrent Animal Farm Insect Repeller). Furthermore, continuous noise emissions can lead to habituation, reducing their long-term effectiveness. In some cases, people also could hear the deterrent noise which makes the device less user-friendly, most of them are designed for indoor use. These shortcomings show the need for a more sophisticated system that adapts to the unique challenges of orchard environments.

Table 1. Pros and Cons of Current methods and proposed solution to repel bats.

Parameters	Netting	Light Deterrent	Existing Ultrasonic Bat deterrents	Proposed Ultrasonic Bat repellant system
Effectiveness	Moderate	Low	Low	High
Habituation	--	Yes	Yes	No
Eco-Friendly	Moderate	Yes	No	Yes
Durable	Moderate	No	No	Yes
Cost Effective	Yes	No	No	Moderate
Scalability	High	Low	Low	High

2 Methodology

A survey was conducted in the first phase of the research to get a clear idea about the amount of damage done by bats to the fruit orchards. In this phase, a Google form was designed with a questionnaire and was sent to fruit farmers around the island, and this survey was designed with both Sinhala and English language options so more people would be encouraged to fill the form.

As bats are nocturnal animals, they tend to attack fruit orchards at night. Some Frugivore bats use their olfactory and visual senses to detect foraging spaces, while others use echolocation for navigation and foraging. And it has been found that even the non-echolocating frugivore bats such as Eidolon helvum and Cynopterus brachyotis are sensitive to the ultrasonic sound frequencies [8], [9]. Therefore, two methods have been used to deter frugivore bats;

- Emitting Ultrasonic frequencies to disrupt the echolocation ability of frugivore bats
- Turning on an LED Light to disrupt the visual senses of bats.

The major frugivore bat species in Sri Lanka are *R. leschenaultia*, *Pteropus Gigantus*, and *Cynopterus sphynx*. These bats produce click-like signals with durations of 0.6–1ms and peak frequencies ranging from 20 to 50 kHz [10], [11]. Therefore, the ultrasonic wave frequency that bats are sensitive to, should also be in between 20 to 50 kHz and the 100 dB Sound Pressure level to which both echolocating and non-echolocating bats are sensitive. Ultrasonic Speakers in the Ultrasonic Ranging Module HC-SR04 [18] were taken to emit the repelling frequency. The specifications of the Ultrasonic speakers are mentioned in Table 2.

Table 2. Specifications of the Ultrasonic speakers [18].

Electrical Parameters	Description
Working Voltage	DC 5V
Working Current	15mA
Emitting Frequency	40 kHz
Maximum range	4m
Minimum range	2cm
Beam Angle (Half angle	15°

An LDR sensor is used to detect whether it is day or night, because bats are active only at night and therefore the system is designed to determine whether it is day or night and turn on automatically at night. Most Industrial Fruit Orchards are in dry zones, therefore using Solar panel 50W and Lead-acid rechargeable batteries for power supply is energy efficient (approximately 9 devices can be powered by using one rechargeable battery). The device is determined to be programmed using an Arduino Uno board.

The DC output of Solar Panel depends solely upon the sunlight it receives. The sun light varies with the time and different weather conditions. Therefore, as shown in Fig. 3, the DC output of the solar panel could vary with time [21].

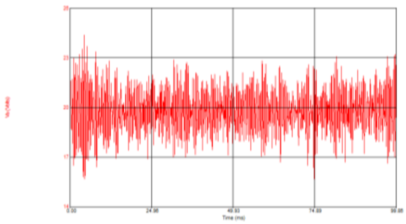


Fig. 3. DC Output of a Solar Panel [21]

To maintain a constant voltage output the PWM (Pulse width modulator) adjustment was implemented in the system of the device. In PWM, the controller changes the duty cycle of the pulses which it receives from the solar panel and modulates pulse width continuously and output constant voltage, enabling efficient harnessing of solar energy.

Generally, the process of a satellite dish is to collect broadband signals into the LNB. To reflect the highly directional ultrasonic sound waves in a broader area and to enhance coverage, a parabolic concave dish was implemented in the design [19]. The speaker was placed away from the focal point to defocus the sound waves to spread out to cover a broader area of tree branches [19]. The dish should be made from a material with a smooth yet hard surface to minimize sound energy loss (aligning with 1% absorption loss), and sound pressure level (SPL) while enhancing the reflectivity [20]. Polished aluminum was used to build the dish (Table 3).

Table 3. Summary of the components in the device and their functions.

Device Components	Function
Ultrasonic Speaker	To emit the Ultrasonic sound frequency
LDR Sensor	To detect Day and Night time
Amplifier	Adjust the frequency range
Pulse width modulator (PWM)	modulates pulse width continuously and output constant voltage
Parabolic dish	Enhance the coverage area by reflecting sound waves
Solar Panel	To generate electricity by solar power
Arduino Uno Board	To write the program

Two field trials were conducted in our garden where bats come to feast on over Banana harvest before installing the parabolic dish.

3 Discussion

The development of the Ultrasonic bat repellent device addresses a significant concern of Industrial fruit farmers, particularly in mango, rambutan and banana orchards, where bat infestations lead to substantial economic losses. The proposed solution uses the principles of acoustic interference and behavioral disruption by targeting the sensitivity of bats to ultrasonic sound waves.

According to the data gathered in the survey, it was found that over 20% financial loss happens per year due to the damage by bats (Fig. 4). The survey has shown that the industrial fruit farms have lost a minimum of Rs. 200,000 per year due to bat damage. An industrial fruit orchard in southern province had lost approximately 400 Tom EJC mango fruits during harvesting period in one day. Although farmers implemented different methods to prevent bats from entering the orchards, they failed and the maximum loss was found to be Rs. 150,000 per year in a Tom EJC mango orchard situated in Ampara.

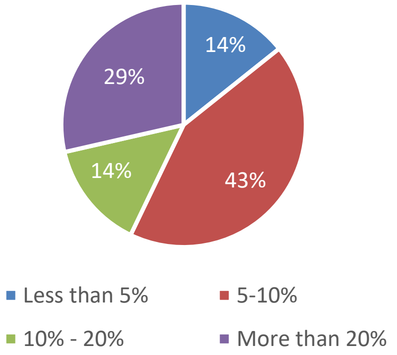


Fig. 4(a)

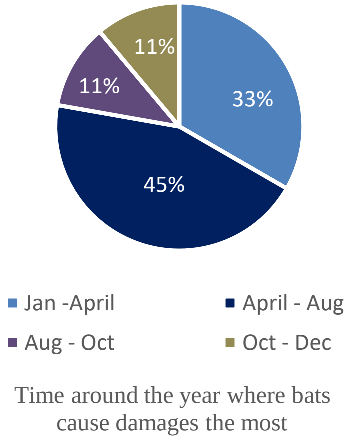


Fig. 4(b)

Fig. 4. (a) financial loss caused by bats according to the survey; (b) Time around the year where bats cause damages the most

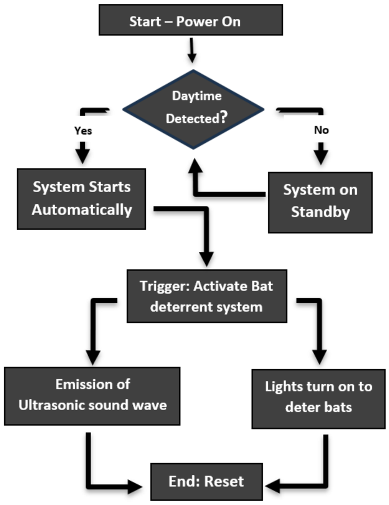
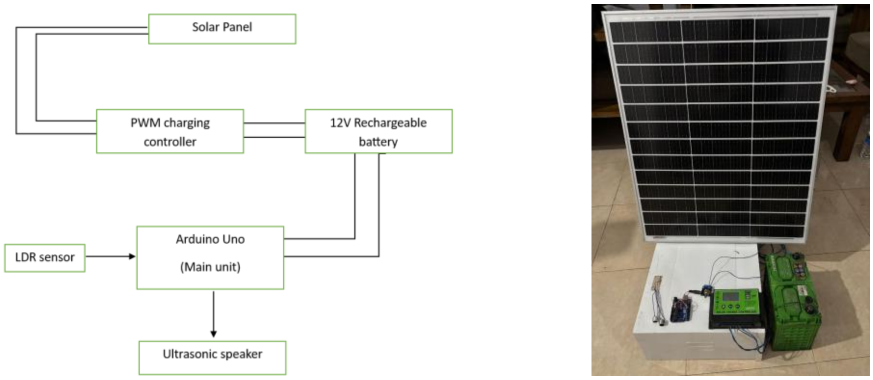


Fig. 5. Flow chart which represents process of Ultrasonic Bat Deterrent System

The farmers have taken steps towards protecting their harvest by implementing different methods to reduce damage done by bats, such as using netting, sound deterrents, light traps, and even cutting down the trees in which bats reside. In the survey most of them have voted their methods to be useless, and a least have voted it them to be somewhat accurate. There was no fruit farm in the survey that had not been attacked by bats.

Fig. 5 shows the process of the Ultrasonic Bat repellant device. Both echolocating and non-echolocating fruit bats were found to be sensitive to ultrasonic sound frequencies between 20 kHz to 50 kHz. The device aims to repel fruit bats by emitting sound waves in that specific frequency range. The frequency emitted by the device can be adjusted using an amplifier to avoid habituation.

The circuit of the ultrasonic bat repellent device shown in Fig. 6 has been developed.



(a) (b)

Fig. 6. (a)Block diagram of the components; (b) Circuit of Ultrasonic Bat Deterrent System.

4 Conclusions

The solar-powered ultrasonic bat repellent device has been designed as a potential sustainable, eco-friendly solution to deter bats from fruit orchards using ultrasonic sound waves with a frequency between 20-40 kHz 2ith 100dB SPL. While the theoretical framework and design components have been carefully developed.

The device has been tested a few times in field conditions. Upcoming experiments will focus on evaluating its effectiveness, range, and environmental impact. Based on the status of the research, the device was effective in 2 conducted trials. However, more researches are required to study and cover the echolocating and non-echolocating bats in Sri Lanka, and more trials should be done in different fields to check the effectiveness of the device.

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