PIR-Activated Solar-Powered Variable Ultrasonic Rodent Repellent for Rice Barn

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Abstrak*—Rodent disturbance in traditional rice barns is a post-harvest problem in remote rural villages because stored rice is vulnerable to damage, contamination, and quality degradation. Previous ultrasonic pest-control studies focused on outdoor rice-field environments, whereas rodent control during post-harvest storage in rice barns remains underexplored. This research aims to develop and evaluate a PIR-activated solar-powered variable ultrasonic rodent repellent prototype for rice barn applications. The study employed a Research and Development approach consisting of hardware design, system design, and device evaluation. The prototype integrates Arduino Uno, PIR sensor, ultrasonic speaker, LCD, solar panel, solar charge controller, and 12 V battery. The PIR sensor detects movement and activates ultrasonic output within the 20–100 kHz range. Variable ultrasonic frequency was applied to minimize rodent habituation and identify frequency ranges producing stronger behavioral responses. Testing included solar panel performance, component voltage, PIR sensor distance, and visual observation of rodent behavior. The solar panel produced stable 30 W output, and all components operated effectively at required voltages. The PIR sensor detected movement within 1–3 m, suitable for traditional rice barn areas of 3 × 4 m. Ultrasonic testing identified two sensitivity points within 30–70 kHz, with the strongest response at 70–79 kHz. The prototype is feasible as a non-chemical, energy-independent solution for traditional rice barns.

Keywords: ***Ultrasonic frequency, IoT, PIR Sensor, Rodent pests, Rice barn***

I. Introduction

Rodent infestation is one of the major problems in post-harvest rice barn management, especially in rural areas where harvested rice is stored for long-term household consumption or local distribution. During the post-harvest period, rice in barns is not only vulnerable to physical damage caused by rodents, but also to contamination from urine, feces, fur, and dead rodent remains. This condition can reduce rice quality, create sanitation problems, and increase the risk of further deterioration inside the rice barn. Recent post-harvest studies emphasize that grain protection after harvest is a critical stage in food security because harvested rice must be protected from biological threats such as insects, rodents, and microorganisms [1]. Rodent disturbance in post-harvest grain systems also contributes to quantitative losses and quality degradation, making rodent control important for maintaining the hygiene and quality of rice stored in rural barns [2].

Conventional rodent control in rice barns commonly uses poison bait, traps, or chemical repellents. Although these methods are easy to apply, they still have several weaknesses. Poison bait may cause rodents to die inside the rice barn, producing odor and sanitation problems, while chemical-based control requires repeated operational costs and may create environmental risks. Recent environmental studies show that pesticide residues can spread widely in the environment and raise concerns regarding their persistence and degradability [3]. Chemical pest-control dependence can also negatively affect non-target organisms, indicating the need for safer and more environmentally friendly rodent-control methods in small-scale rural rice barns [4].

Ultrasonic technology has become one of the alternative non-chemical approaches for rodent control in rice barns. Ultrasonic waves are high-frequency sound waves above the normal human hearing range, but they can still affect rodents because their auditory system is sensitive to high-frequency signals. Rodents are known to respond to ultrasonic frequencies in certain behavioral contexts, including communication, alarm response, discomfort, and avoidance behavior. Therefore, ultrasonic exposure has the potential to disturb rodent activity and reduce their presence in rice barns without using toxic substances. Recent research has shown that variable ultrasonic frequency can be used as a safer alternative for rodent repellence compared with chemical-based methods, especially for protecting agricultural environments from rodent disturbance [5].

However, several previous ultrasonic repellent systems still use static or fixed-frequency sound. This approach can reduce effectiveness when rodents become accustomed to a repeated acoustic pattern. In pest-control applications, repeated exposure to the same stimulus may cause habituation, where the animal response decreases over time. Recent acoustic pest-control research highlights that monotonous deterrent signals may lose effectiveness because pests can adapt to repeated sounds [6]. Therefore, variable ultrasonic frequency is important because it produces changing frequency patterns that are more difficult for rodents to ignore. A variable-frequency approach is expected to maintain discomfort and reduce the possibility of habituation during long-term use in rice barns.

Several recent studies have developed ultrasonic and smart pest-control systems, but most of them are still focused on open-field agricultural environments or general pest-control applications. For example, adaptive ultrasonic pest-control systems have been proposed for rice-field rat management [7]. Solar-powered pest-control systems have also been developed for agricultural pest-control applications using microcontrollers, sensors, and renewable energy sources [8]. However, the condition of a rice barn is different from an open field. A rice barn is generally a semi-enclosed rural structure where walls, rice piles, sacks, wooden materials, and narrow spaces may influence ultrasonic propagation and rodent movement. Therefore, ultrasonic rodent control for rice barns requires a design that is suitable for rural barn conditions, not only for open agricultural land.

Another important issue is energy efficiency. If the ultrasonic device operates continuously, it may consume unnecessary electrical power even when no rodent is present. This becomes a problem in rural rice barns where access to stable electricity may be limited. The use of a PIR sensor allows the system to detect rodent movement and activate the ultrasonic output only when movement is detected. In addition, the integration of solar panels, a solar charge controller, and battery storage supports autonomous operation, making the device more suitable for rice barns located in rural or off-grid areas. Previous studies on solar-powered pest-control devices have shown that renewable energy can support automatic agricultural pest-control systems and reduce dependence on conventional electricity sources [9].

Based on the previous studies, the research gap lies in the limited implementation of variable-frequency ultrasonic rodent expulsion specifically for rice barns in rural areas. Existing studies generally discuss ultrasonic repellents, field-based pest control, or solar-powered agricultural devices separately. However, there is still limited research that integrates variable ultrasonic frequency, PIR-based automatic activation, and solar-powered operation into one system designed for rodent expulsion in rural rice barns. Therefore, the novelty of this research is the implementation of a variable-frequency ultrasonic rodent expulsion system in the 20–100 kHz range, supported by PIR motion detection and independent solar power, for application in rice barns. This research aims to design and implement a variable-frequency ultrasonic system for rodent expulsion in rural rice barns. The proposed system uses Arduino Uno as the main controller, a PIR sensor to detect rodent movement, an ultrasonic speaker to emit variable frequencies, and a solar-power subsystem consisting of a solar panel, solar charge controller, and battery. The importance of this research lies in providing a non-chemical, energy-efficient, reusable, and environmentally friendly solution to reduce rodent disturbance in rice barns. The expected contribution of this research is a practical prototype that can support sustainable post-harvest rice protection, especially for small-scale rice barns in rural areas.

II. METHOD

This research method uses a Research and Development (R&D) approach designed to develop a rodent pest repellent device for rice barns. The research was carried out through three main stages, namely tool design, system design, and device evaluation. The tool design stage focused on determining and arranging the main hardware components, including the Arduino Uno, PIR sensor, speaker, LCD, solar panel, solar charge controller, and 12 V battery. The system design stage described the overall working mechanism and wiring connection of the device, starting from the solar power supply system, motion detection process, Arduino-based signal processing, and ultrasonic output activation. Furthermore, the device evaluation stage was conducted to test the performance of the system and ensure that each component, especially the PIR sensor and ultrasonic speaker, could operate according to its designed function. This method was selected because the research is oriented toward developing a device that can detect the presence of rodents and provide a response in the form of ultrasonic sound as an effort to repel pests. To clarify the research stages, the following flowchart illustrates the overall working system of the device. The flowchart of the device working system can be seen in Figure 1.

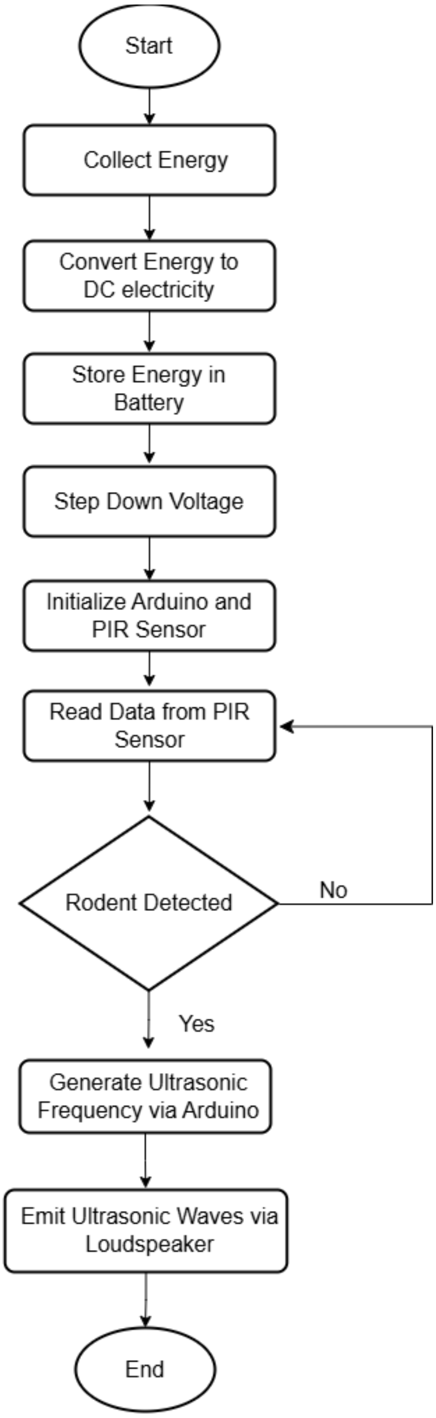


Figure 1. Flowchart of the Device Work System

A. Hardware Design

The hardware design stage in this research was carried out to develop a rodent repellent device that can operate automatically in a rice barn environment. The system is designed using Arduino Uno as the main controller, a PIR sensor as a motion detector, an ultrasonic speaker as the output component, and an LCD as a display unit. The device works by detecting rodent movement around the rice barn through the PIR sensor. The PIR sensor detects changes in infrared radiation caused by moving warm bodies (rodents) within its field of view. The Fresnel lens focuses infrared signals onto the pyroelectric sensor, triggering an output when the detected signal exceeds a predefined threshold. When movement is detected, the Arduino Uno processes the sensor signal and activates the ultrasonic speaker to emit variable ultrasonic frequencies in the range of 20–100 kHz. The use of variable frequency is intended to reduce the possibility of rodent habituation to a single sound pattern. In addition, the device is supported by a solar power system consisting of a solar panel, solar charge controller, and 12 V battery, so that the system can operate independently in rural rice barn areas with limited access to electricity. The hardware structure is arranged in a compact prototype so that all components can be placed safely and functionally during field implementation. The hardware design of the proposed rodent repellent device can be seen in Figure 2.

Figure 2. System Hardware Design

B. System Design

The overall system design of the rat pest repeller device developed in this study consists of several key components that work collaboratively to detect and repel rats effectively and efficiently.

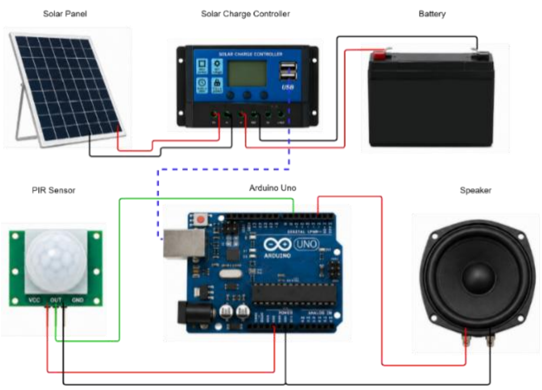
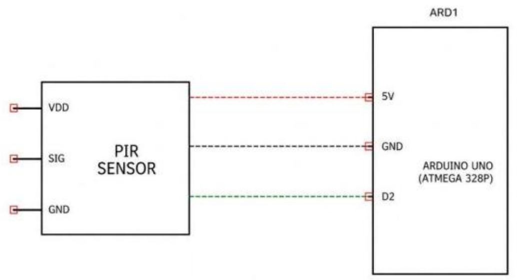


Figure 3. System Assembely Design

Besides the main circuit, the system is also divided into several schematic sections to make it easier to understand. The schematics of the Arduino Uno, solar panel, and PIR



sensor are shown in Figure 3, Figure 4, and Figure 5, respectively.

Figure 4. Schematic diagram of solar panel

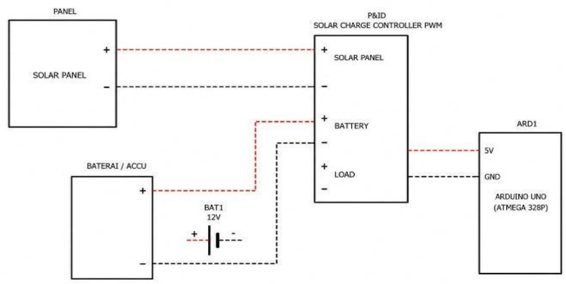


Figure 5. Schematic diagram of PIR sensor

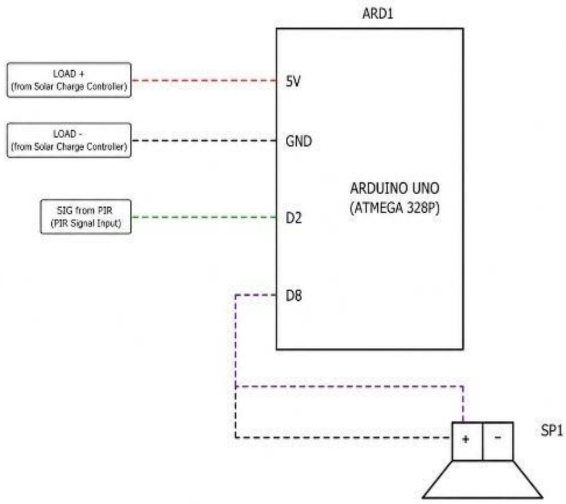


Figure 6. Schematic diagram of Arduino uno

The wiring connection design was arranged to ensure that each component in the proposed rodent repellent system could operate according to its function. The solar panel is connected to the solar charge controller as the main energy input, while the battery is connected as the energy storage unit. The load output of the solar charge controller is then used to supply power to the Arduino Uno. Furthermore, the PIR sensor is connected to the Arduino Uno through the 5V, GND, and digital input pin D2, while the speaker is connected to digital pin D8 as the ultrasonic output. The detailed pin connections of the system are shown in Table 1.

Table 1. System Wiring Connections

Pin/Terminal	Connection	Description
Solar Panel (+)	SCC Solar (+)	Positive input from solar panel
Solar Panel (-)	SCC Solar (-)	Negative input from solar panel
Battery (+)	SCC Battery (+)	Positive connection to 12V battery
Battery (-)	SCC Battery (-)	Negative connection to 12 V battery
USB SCC	USB B Connector Arduino	Power supply to Arduino Uno
Arduino 5V	PIR VCC	Power supply to PIR sensor
Arduino GND	PIR GND	Ground for PIR sensor
Arduino D2	PIR OUT/SIG	Motion detection input
Arduino D8	Speaker (+)	Ultrasonic output signal
Arduino GND	Speaker (-)	Ground for speaker

Table 1 shows the electrical connection of the proposed system. The solar panel and battery are connected to the Solar Charge Controller (SCC), which regulates battery charging and distributes power to the load. The USB port of the SCC supplies the Arduino Uno with a regulated 5 V output. This 5 V output is obtained from the 12 V battery voltage through an internal step-down converter. Therefore, the SCC USB port can safely power the Arduino Uno, while the Arduino distributes 5 V and GND to the PIR sensor, receives the motion signal through pin D2, and controls the ultrasonic speaker through pin D8.

The ideal relationship between input and output voltage in a step-down converter is expressed as follows:

$$V_{out} = D \times V_{in} \tag{3}$$

Where,
V_{out} = converter output voltage (V)
V_{in} = converter input voltage (V)
D = duty cycle of the switching converter

C. Evaluation

Evaluation in this research was conducted to assess the performance of the rodent repellent system, particularly the PIR sensor's ability to detect movement and trigger the ultrasonic speaker. This stage verified whether the prototype operated according to its intended function by testing the PIR sensor at several distances and observing whether the Arduino Uno could process the input signal and activate the ultrasonic output properly. The detection response was evaluated based on the presence or absence of an output signal when rodent movement occurred within the sensor coverage area. The results were used to determine the effective detection range of the PIR sensor and the reliability of the system in producing an automatic ultrasonic response. This evaluation also ensured that the interaction between the sensor, controller, and output device worked consistently as an integrated system. Therefore, the obtained results became the basis for assessing the feasibility of the prototype for rice barn applications.The error value and accuracy of the PIR sensor detection were calculated using equations (1) and (2).

$$error = \frac{y - x}{y} \times 100\% \tag{1}$$

$$accuracy = \frac{x}{y} \times 100\% \tag{2}$$

Where,
x = number of successful detections obtained from the PIR sensor test
y = total number of tests conducted

The error value indicates the percentage of failed detections, while the accuracy value shows the percentage of successful detections during the evaluation process. The evaluation results were used to determine the effectiveness of the PIR sensor in detecting rodent movement and to ensure that the ultrasonic speaker could be activated automatically when movement was detected. Therefore, this evaluation provides a basis for assessing whether the proposed system is suitable for automatic rodent detection and ultrasonic activation in rice barn applications.

III. Result and Discussion

The testing in this research was conducted to evaluate the performance of the designed variable-frequency ultrasonic rodent repellent system. The evaluation focused on four main aspects: the performance of the power supply system, the voltage characteristics of the main components, the detection capability of the PIR sensor, and the overall performance of the prototype. The power supply test was carried out to determine whether the solar panel, solar charge controller, and battery could support the operation of the system. Meanwhile, component voltage testing was conducted to verify that each component received an appropriate and stable voltage during operation. The PIR sensor test was performed to observe the sensor response in detecting movement at several distances, while the overall system performance test was used to ensure that the prototype could detect movement and activate the ultrasonic output automatically.

The system testing was carried out through several stages, namely:

1. Testing of the system power supply
2. Testing of the component voltage
3. Testing of the PIR sensor
4. Testing of the overall system performance

The results of each test were analyzed to determine whether the proposed prototype could operate according to its designed function. The discussion covers the stability of the power supply, the suitability of the measured voltage values, the detection performance of the PIR sensor, and the ability of the system to generate ultrasonic output automatically when movement is detected. Therefore, this section provides an overview of the feasibility of the developed prototype as a variable-frequency ultrasonic rodent repellent system for rice barn applications.

A. Testing of the System Power Supply

The performance evaluation of the solar panel was conducted under an integrated system condition, in which the solar panel was connected to the solar charge controller (SCC), battery, and all supporting devices. Therefore, the test results represent the solar panel performance under actual operational conditions.

Table 2. Solar Panel Performance Under Real Conditions

Time (WIB)	Voltage (V)	Current (A)	Pout (W)
10.00	16.0	1,8	30
10.30	16.0	1,8	30
11.00	17.0	1,7	30
11.30	18.0	1,6	30
12.00	18.0	1,6	30
12.30	18.0	1,6	30
13.00	18.0	1,6	30
13.30	18.0	1,6	30
14.00	18.0	1,6	30
14.30	18.0	1,6	30
15.00	18.0	1,6	30
15.30	18.0	1,6	30
16.00	16.0	1,8	30
16.30	16.0	1,8	30

The performance evaluation of the solar panel power supply system was conducted on Monday, 18 May 2026, from 10:00 to 16:30 WIB, with data recorded at 30-minute intervals. Electrical parameters comprising output voltage (V), current (A), and output power (W) were measured directly using a digital multimeter connected to the solar panel output terminals, so that the obtained data represented the actual operational conditions in the outdoor environment. Based on the data presented in Table 2, a voltage variation pattern correlated with changes in solar irradiance intensity throughout the day was identified. At the initial measurement at 10:00 WIB, the voltage was recorded at 16.0 V with a current of 1.8 A. The voltage increased gradually in line with the rising solar irradiance intensity, reaching a peak value of 17.0 V at 11:00 WIB. Subsequently, the voltage stabilized at a maximum value of 18.0 V from 11:30 to 15:00 WIB, which represented the most optimal solar irradiance period during midday. In the afternoon, a decrease in voltage began to be observed at 15:30 WIB and returned to 16.0 V at 16:30 WIB, consistent with the reduction in solar light intensity. Overall, the output power (Pout) of the solar panel remained consistently at 30 W throughout the entire testing period, indicating that the system operated stably and in accordance with the established technical specifications.

B. Component Voltage Testing

The voltage characteristic evaluation was carried out on all main components to verify the suitability of the electrical parameters with the system requirements. This test focused on observing the stability of the supply voltage and output voltage during device operation. Thus, it could be ensured that each component was able to operate reliably under various operational.

Table 3. Component Testing Result

Component	Voltage (V)	Result
Dry Battery	13.1	Operates Effectively
Arduino Uno	5	Operates Effectively
Sensor PIR	5	Operates Effectively
Speaker	5	Operates Effectively
Solar Charge Controller	5-12	Operates Effectively

Table 3 presents the voltage testing results of each main component integrated within the rat pest repeller system. The evaluation was conducted to verify that all components operated within their respective rated voltage specifications, ensuring system reliability and electrical compatibility. The dry battery served as the primary power source of the system, delivering a measured supply voltage of 13.1 V during testing, which slightly exceeds its nominal rating. This condition is considered normal, as a fully charged lead-acid or dry battery typically produces a voltage above its nominal value, and the component was confirmed to operate effectively under this condition. The Arduino Uno microcontroller, PIR sensor, and speaker each operated at a regulated voltage of 5 V, all of which were verified to function effectively within their designated voltage range. The Solar Charge Controller (SCC) was recorded with a dual output voltage range of 5–12 V. This dual output characteristic is attributed to its role in managing two distinct power distribution lines within the system: the 5 V output is designated to supply the Arduino Uno microcontroller and its associated peripheral components, while the 12 V output is directed to charge and maintain the dry battery. This configuration ensures that each component receives a stable and appropriate voltage level, thereby preventing electrical damage and optimizing the overall energy management of the system.

Overall, all five components demonstrated effective performance under their respective voltage conditions, confirming that the electrical design of the system is well-suited to support continuous and reliable operation of the rat pest repeller device.

C. PIR Sensor Testing

The testing of the PIR sensor was conducted to evaluate the sensor's ability to detect rodent movement in the field. During the testing process, the PIR sensor was integrated with the Arduino microcontroller, where the generated signal was then transmitted to the ultrasonic speaker as the device used to repel rodents. A series of tests was carried out by varying the detection distance from 1 to 5 meters. Based on the obtained data, the PIR sensor showed its best detection performance within the distance range of 1 to 4 meters. Meanwhile, at a distance of 5 meters, the sensor's ability to detect movement decreased significantly. This condition depends on the viewing angle and the inherent sensitivity of the PIR sensor, where the farther the object is from the sensor, the weaker the received infrared radiation intensity becomes, so it no longer exceeds the required detection threshold to generate a valid output signal.

Table 4. PIR Sensor Testing Result

Distance between PIR Sensor and Rodent	Description
1 Meter	Detected
2 Meters	Detected
3 Meters	Detected
4 Meters	Not Detected
5 Meters	Not Detected

D. Testing of Ulrasonic Waves on Rodents

The ultrasonic wave testing was conducted to evaluate the behavioral responses of rodents when exposed to varying frequency ranges emitted by the speaker integrated within the repeller system. Each frequency range was applied for a duration of five minutes under controlled observation conditions, during which the rodents' physical and behavioral reactions were recorded visually. Table 5 presents the complete results of the ultrasonic wave effect test on rodents across multiple frequency ranges.

Table 5. Rodent Responses to Ultrasonic Exposure

Test Number	Frequency (kiloHertz)	Effect on Rodents	Rodent Visual Observation	Remarks
1	20 - 29 kHz	Freezing behavior, indicated by a stiff and motionless body posture, accompanied by increased alertness.		The rodent appeared to perceive the condition as a potential threat, causing it to remain still and hide inside the nest or in the corner of the barn.
2	30 – 39 kHz	Restlessness, indicated by repeated movements and changes in body position.		The rodent began to move away from the test area. The uncomfortable and noisy condition caused the rodent to leave the barn area and search for a quieter place.
3	40 – 49 kHz	Balance disturbance, observed through unstable movement and difficulty maintaining body orientation.		The rodent showed severe disorientation, indicated by reduced motor coordination, circling behavior, or collision with the barn wall while attempting to find an exit.
4	50 - 59 kHz	Changes in social and communication behavior, observed through reduced interaction and irregular movement patterns.		The rodent showed signs of confusion, indicated by uncontrolled hyperactive movement or withdrawal behavior inside the barn.
5	60 – 69 kHz	Strong anxiety-like response, observed through rapid movement, avoidance behavior, and attempts to escape from the sound source.		The rodent showed trembling behavior and a defensive curling response in the deepest corner of the barn, possibly as an attempt to reduce exposure to the sound.
6	70 – 79 kHz	Discomfort response, observed through sudden movement, avoidance, or retreat from the sound source.		The rodent showed the strongest response at this frequency range, indicating a sensitive point of ultrasonic exposure. This response was observed through rapid running, panic-like jumping, and immediate escape behavior away from the sound source.
7	80 – 89 kHz	Reduced response at the upper range of rodents' hearing sensitivity.		The rodent showed a reduced response to the frequency exposure. Panic-like or discomfort responses decreased, while the rodent remained alert inside the barn.
8	90 – 100 kHz	Minimal or no observable response, indicating that the frequency may be beyond the effective hearing range of rodents.		The rodent showed little to no observable response to the frequency, indicating that the frequency may no longer be effectively perceived by the rodent.

Based on the ultrasonic wave testing results, eight trials were conducted using different frequency ranges from 20 kHz to 100 kHz, with each frequency tested for 5 minutes to observe the rodent's behavioral response. At 20–29 kHz, the rodent showed freezing behavior and increased alertness, while at 30–39 kHz it began to show restlessness and movement away from the test area, indicating the first sensitivity point. In the 40–69 kHz range, the observed responses became more varied, including balance disturbance, irregular movement patterns, anxiety-like behavior, avoidance, trembling, and defensive curling. The strongest response occurred at 70–79 kHz, where the rodent showed sudden movement, rapid running, panic-like jumping, and immediate escape behavior, indicating the second sensitivity point. Therefore, the test results show that there were two main sensitivity points within the 30–70 kHz frequency range, with the most effective response occurring near the upper part of this range. However, at 80–89 kHz the rodent's response began to decrease, and at 90–100 kHz little to no observable response was detected. Rodents are known to have a hearing range up to approximately 80-90 kHz, which explains the reduced response at frequencies above 80 kHz (Table 5, tests 7 and 8). This finding indicates that the frequency may no longer be effectively perceived by the rodent.

IV. CONSLUSION

This research successfully designed and evaluated a PIR-activated solar-powered variable ultrasonic rodent repellent prototype for traditional rice barn applications. Ultrasonic frequency variation was obtained through Arduino-based frequency control, where the output signal was programmed to generate different frequency ranges from 20 kHz to 100 kHz. The test results showed that the solar panel produced a stable output power of 30 W, while the main components operated effectively at their required voltage levels. The PIR sensor detected movement within 1–3 m, which is suitable for traditional rice barns in remote rural villages with an average compact area of approximately 3 × 4 m. Ultrasonic exposure testing showed that frequency variation influenced the observed behavioral and psychological-like responses of rodents, with frequencies within 30–70 kHz producing the most noticeable effects, including restlessness, avoidance behavior, anxiety-like response, trembling, and escape behavior, while the strongest response occurred at 70–79 kHz after 5 minutes of exposure. These results indicate that variable ultrasonic frequency can reduce the possibility of habituation and produce stronger deterrent effects than a single fixed-frequency output. The main advantage of the proposed prototype is its non-chemical, energy-independent, and automatic operation, making it suitable for rural rice barn environments. This prototype can be deployed as a standalone, maintenance-free rodent repellent for traditional rice barns in off-grid rural areas, reducing post-harvest losses without chemicals or electricity bills. However, this research is still limited to prototype testing and controlled rodent observation, so further field testing in actual rice barns is recommended to evaluate long-term effectiveness, environmental influence, and system durability under real post-harvest storage conditions.

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