Development of a Solar-Powered Frequency Generation System for Ultrasonic Repellent Applications

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Abstract: Pests and trespassing animals remain dominant sources of agricultural loss and health hazards in rural and urban areas. Conventional control schemes, such as chemical pesticides and physical barriers are mostly ineffective, environmentally dangerous, and economically ineffectual. This paper shows the design and development of a solar-powered ultrasonic repellent system that can identify and chase away various types of pests and animals with ultrasonic frequencies. The system includes microcontroller (ATmega328P), voltage regulator (LM7805). The system has both manual and remote-controlled modes and has the design that is compact, weather-proof, low-maintenance for agricultural and residential uses. Performance testing revealed stable output with ±5% accuracy and efficient repelling action against mosquitoes, rodents, cockroaches, bats, etc. A comparative life cycle cost study showed that the system to be running at a fraction of the cost of chemical-alternatives, providing a greener and more sustainable solution for long-term pest management. The multi-frequency, green system shows great promise in facilitation of productive agriculture, public health, and environmental sustainability.

Index terms: **Ultrasonic repellent, microcontroller, solar-powered system.**

I. INTRODUCTION

Agricultural production and public health are under serious attack from pests, insects, and animal intrusion. Mosquitoes spread diseases like dengue, malaria, and chikungunya, whereas rats, snakes, foxes, and birds damage standing crops and stored products, inflicting huge economic losses [4]. The loss is especially crucial in rural and semi-urban areas, where access to conventional pest control technology is poor and use of traditional means is extensive.

Traditional pest management methods like chemical repellents, pesticides, hand traps, and barriers (e.g., fencing) are not ideal. Chemical pesticides are excessively applied, which pollutes soil and water, destroys ecosystems, and leads to human health problems like respiratory disease and skin diseases. Pests also develop a resistance to chemicals over time, lowering long-term efficiency [15]. Hand traps need constant surveillance, while fencing is costly and offers incomplete protection [3]. These inadequacies clearly necessitate the existence of sustainable, automated, and low-maintenance systems that would thrive well against versatile pest attacks with no negative side effects.

Electronic Pest Control (EPC) gadgets that employ ultrasonic frequencies have become promising prospects. Ultrasonic signals of around 20–80 kHz are not audible to humans but inconvenience pests by disrupting their communication, navigation, and habitat choice. These devices are odorless, non-toxic, and harmless to humans and domestic pets. Unlike chemicals, ultrasonic gadgets do not deposit toxic residues within the environment and can be reused continuously for years with little maintenance.

Research in this area has shown promising outcomes. Investigations by Yusuf and Sanusi suggested low-cost ultrasonic mosquito repellents at 20–30 kHz frequencies [6], which proved to decrease the activity of mosquitoes in targeted areas. But these setups were meant for a single pest only. Abdulrahman et al. designed a microcontroller-based repellent with LM380 amplification and 30–50 kHz frequency to repel multiple pests. Although efficient, fixed-frequency designs lost performance over time as pests adapted to them. [7] Silakari et al. presented an IoT-controlled repeller with an ATmega328P microcontroller and Timer 4047 frequency generator, featuring automated and manual operating modes, GSM notification, and solar power interface. Their findings confirmed the potential of renewable-powered repellents but emphasized the necessity for sweeping frequencies for effective performance across species.

Repelling Frequency Range	Animals
20kHz-65kHz	Rat
40kHz-60kHz	Mosquito
35kHz-40kHz	Cockroach
20kHz-40kHz	Snake

Table 1 - Frequency range for multiple organisms

New developments have emphasized adjustable ultrasonic frequencies [13], energy-efficient technologies, and wireless control system integration. Multi-frequency or sweeping-frequency solutions minimize the chances of pests tuning into a single frequency, and microcontroller-based systems enhance precision and dependability [1]. Solar-powered technology promotes deployment in off-grid areas, lessening reliance on traditional power supplies and minimizing operating expense [3][9]. The synergy of frequency agility, renewable power, and automated detection is the state-of-the-art in ultrasonic pest control systems [10].

This work extends these advancements with the design and implementation of a solar-powered, microcontroller-driven ultrasonic pest and animal repellent system. The system uses an ATmega328P microcontroller programmed through Arduino IDE, for accurate ultrasonic frequency generation and voltage regulation using LM7805 to ensure stable operation [16]. Adjustable frequency ranges are optimized for targeted organisms — mosquitoes (20–30 kHz), rats (30–50 kHz), cockroaches (35–40 kHz), and snakes or other small intruders (20–60 kHz general mode). The system can be in both automatic modes, in which pests are detected and repelled automatically, and manual mode, where users can control it using a switch panel or remotely through Wi-Fi connectivity.

Other features are a 16×2 LCD display for system status, battery level, and mode settings, as well as solid PCB integration for small size and weatherproofing. The unit is powered by a 20 W solar panel wired into a rechargeable battery for off-grid use and continuous operation. Critical components are MOSFET IRF3205 drivers for power efficiency, Zener diodes and capacitors for voltage regulation, and ultrasonic emitters with high-intensity output for use outdoors[5]. The system will be tested under both laboratory and field conditions to confirm performance parameters like frequency accuracy, efficiency of pest repelling, solar charging capacity, and power consumption. Comparative life-cycle costing with chemical repellents like DDT and Propoxur reflects long-term economic advantages, eco-friendliness, and reusability of the device developed.

Through combining renewable energy, microcontroller-based control, and smart frequency modulation, this research presents a scalable, environmentally friendly solution for pest and animal control in agricultural and residential settings. It is one of the moves toward sustainable agriculture, enhanced public health, and minimized ecological footprint of chemical pesticides worldwide.

II. METHODOLOGY

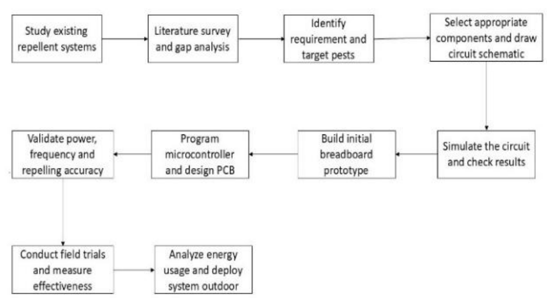

Fig.1-Methodology Block Diagram

2.2 COMPONENTS AND SPECIFICATIONS:

The system to be developed is based on producing ultrasonic frequency to drive them away. The methodology includes the hardware architecture, signal generation, power management, and test protocols. The system is modular and has three major functional blocks namely power supply unit, frequency generation unit, control unit.

A. System Overview The system structure incorporates the following main components:

Microcontroller Unit (MCU): ATmega328P-microcontroller act as the central control unit that control sensing, signal generation [10].

Frequency Generation Module: Built-in timer is utilized to produce accurate ultrasonic frequencies ranging from 10 kHz to 60 kHz. These are designed to ward off certain pests (e.g., mosquitoes: 20–30 kHz, rats: 30–50 kHz).

- Ultrasonic Emitter & Speaker: Translates electrical signals into ultrasonic waves pointed at the detected intruder [11].
- Solar Charging System: Drives the system from a solar panel coupled with voltage regulator (LM7805) and a rechargeable battery for off-grid usage.
- LCD Display and Manual Switches: Enables real-time status display and manual operation control.

B. Hardware Design and Integration-

- Power Supply Unit: A 20W solar panel recharges a 12V battery, which is stepped down using LM7805 voltage regulator to supply 5V output to microcontroller and peripheral devices. Zener diodes and capacitors are used to voltage stabilization.
- Ultrasonic Signal Generation: The timer in astable mode produces square wave outputs at pest-specific ultrasonic frequencies. Variable resistors and capacitors are used to set frequency. Speaker emits the ultrasonic sound.
- Microcontroller Control Unit: The ATmega328P control frequency selection, input/output operations, and peripheral communication. The microcontroller interprets sensor inputs, activates ultrasonic emission when detection and refreshes the LCD.
- LCD Display and User Interface: A 16x2 LCD is employed to display system status, present mode. Manual switches are available for the user to switch between auto and manual modes or choose various repelling frequencies.

C. Software and Control Logic: The system is coded with Arduino IDE. The algorithm has following steps:

- Initialize hardware components.
- In case of manual mode, enable user to operate repeller through switch.
- Loop back for constant monitoring.

D. Testing and Validation The system was tested under different conditions for:

- Frequency accuracy: Tested with digital oscilloscope.
- Power efficiency: Sampled solar charging and discharge cycles of battery. Testing will be undertaken both in lab conditions and in open-field conditions to determine actual performance.

III. IMPLEMENTATION

The proposed pest repellent system was implemented through the systematic integration of hardware and software modules, enabling repulsion, and display functions in real time. The goal was to create a compact, solar-powered, low-maintenance device capable of operating autonomously in agricultural or residential environments to protect against pests and animal trespassing.

1. Hardware Implementation:

- Microcontroller Integration: The central processing unit of the system was built using ATmega328P microcontroller programmed through Arduino IDE. For frequency generation in another prototype, a timer was used.

These controllers managed:

- Frequency control of ultrasonic signals
- Turning on repeller unit
- LCD status indication

2. Ultrasonic Frequency Generation: The inbuilt timer was employed in astable mode to produce a stable square wave in the ultrasonic frequency range of 10–60 kHz. The adjustable output frequency was established with the help of variable resistors in order to target specific pests (e.g., mosquitoes: 20–30 kHz, rodents: 30–50 kHz) [11]. The frequency signal was introduced to a MOSFET (IRF3205) that amplified the signal strength and powered the speaker to produce sound frequencies inaudible to human ear but annoying to pests.

3. Solar-Powered Energy System: The equipment was powered by a 20W solar panel charge-coupled to a ~14V rechargeable battery. A LM7805 voltage regulator ensured a reliable 5V supply to the

microcontroller. Zener diodes and capacitors provided a stable supply and noise reduction. The solar configuration supported uninterrupted off-grid operation, making the equipment extremely appropriate for rural and remote area deployments.

4. LCD and Manual Interface: A 16x2 LCD module showed real-time system status including:

- System ON
- Voltage
- Battery level

A manual switch panel was provided to facilitate:

- Automatic and manual mode switching
- Manual activation of repeller
- Frequency modes selection based on target organisms.

5. Software and Control Logic: The system was implemented on the Arduino IDE platform.

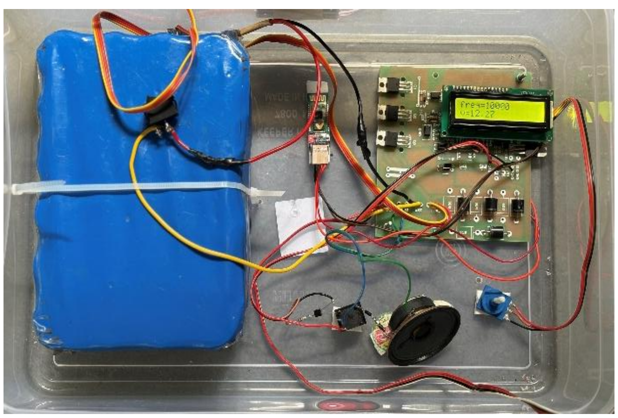

Fig.2-Iimplementation of hardware components and display status

The software workflow consists of:

- Initialization of timers, and modules.
- Turn on ultrasonic frequency generator and speaker.
- Show message on LCD.

In manual mode, enable user-initiated operation through switches. Monitoring loop to log and repeat. Interrupt routines and custom delay functions were used to provide timely signal generation and power efficiency in idle states.

Printed Circuit Board (PCB): Design a single-layer PCB of custom design was made to hold all components including:

- Microcontroller
- LCD and switches
- Power circuitry

The PCB layout was designed for small size, weather conditions, and simple mounting with the solar panel.

Field Deployment and Packaging: The last prototype was housed in a weather-sealed enclosure appropriate for outdoor use. The speaker and solar panel were mounted on the top panel, and input/output interfaces were moisture-sealed. The system will be deployed and tested in:

- A farm field to keep crops away from rats and birds.
- A home backyard to keep mosquitoes and small animals away.

The device worked properly under real-time world usage, with steady power supply from the solar panel and appropriate sensor-activated repelling actions.

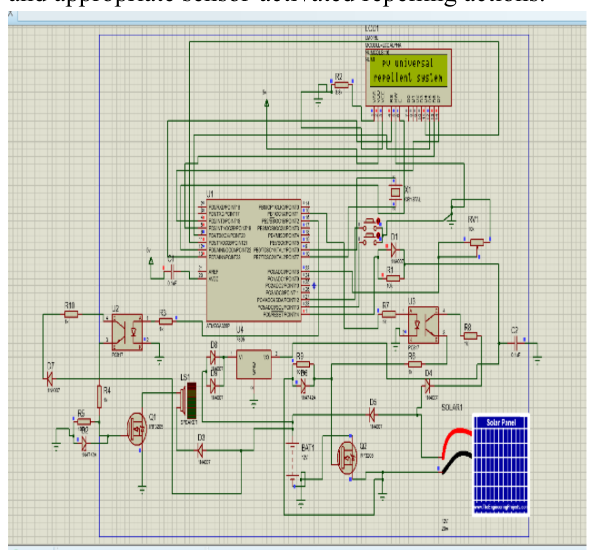

Fig.3-Circuit diagram on Proteus software

IV. RESULTS AND DISCUSSION

The solar-powered ultrasonic repellent system was conceived, developed, and tested for the purpose of offering a green and intelligent pest control solution alternative to the conventional approaches. The system functionally combines microcontroller-based frequency generation and solar power as renewable energy sources in detecting and repelling various pests, such as mosquitoes, rodents, and cockroaches. Experimental testing proved that the device could produce accurate ultrasonic signals within the range of 20–80 kHz with high accuracy, which remained the same using solar power, making it suitable for off-grid applications. A cost analysis of the life cycle revealed that the system is more cost-effective in the long run relative to chemical repellents and is non-toxic, reusable, and environmentally friendly for use in agricultural and domestic settings.

An ultrasonic pest repeller functions by producing high-pitched sound waves that are undetectable to human ears but make the environment hostile and stressful for pests such as mosquitoes, rodents, and other small creatures. The device is fueled by a solar panel and a rechargeable battery, which makes it an environmental-friendly and sustainable alternative[3]. Fundamentally, an ATmega328P microcontroller is the brain that handles the production of these ultrasonic frequencies and a voltage regulator
(LM7805) guarantees a secure power supply. The sound signal is subsequently increased by a MOSFET and transmitted through a speaker to keep the pests away[16]. The unit further incorporates an LCD display to indicate the status of the system and switches for operating manually, giving the user flexibility. This design seeks to provide a low-maintenance, safe, and affordable substitute to conventional chemical repellents.

- Steps for the results observation:

1. Observation of the wave on the screen. Time is represented by the horizontal divisions of the screen.
2. Measure one complete wave. Measure how many horizontal divisions it takes for one complete wave to show up.
3. Determine the total time. The "Time/div" control on the CRO indicates how much time one division represents. You take the number of divisions you measured and multiply it by the Time/div setting to get the total time for a single wave. This is referred to as the period (T).
4. Determine the frequency. Frequency is determined by dividing 1 by the period (f=1/T).

Simulation Calculations:
For F=10kHz
T1=49us
T2=149us
Delta(T)=100us

$F=\frac{1}{Delta(T)}=\frac{1}{100\times10^{-6}}$

Simulation Results:

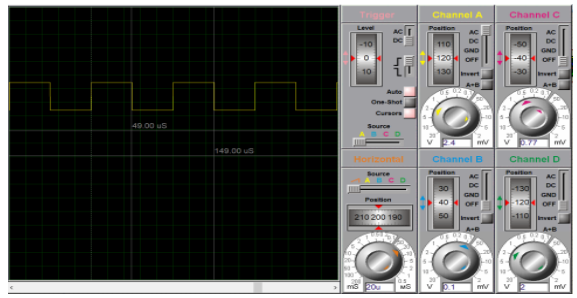

Fig.4-10KHz waveform

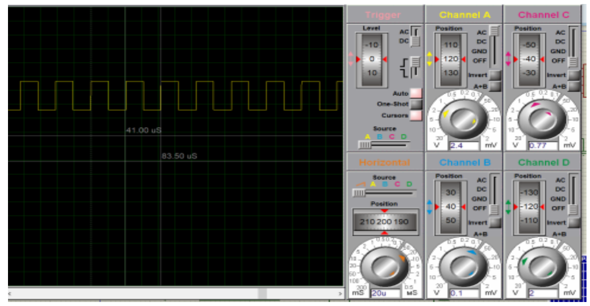

Fig.5-20kHz waveform

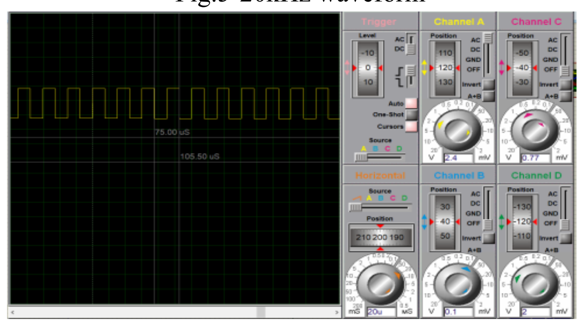

Fig.6-30kHz waveform

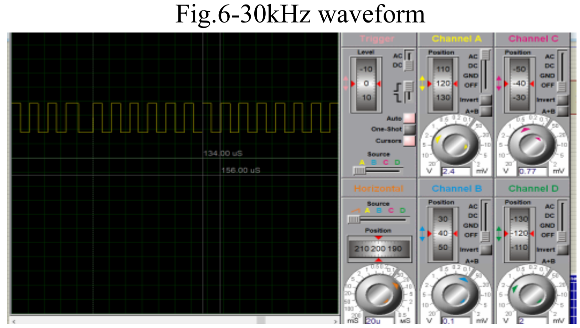

Fig.7-40kHz waveform

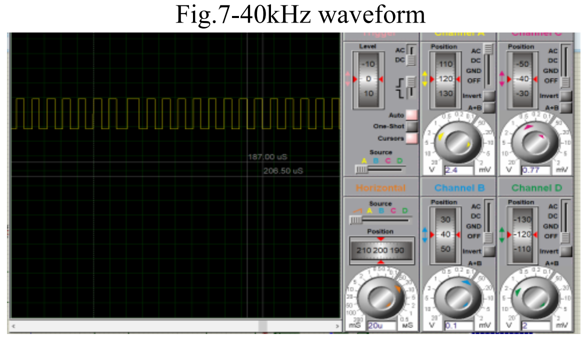

Fig.8-50kHz waveform

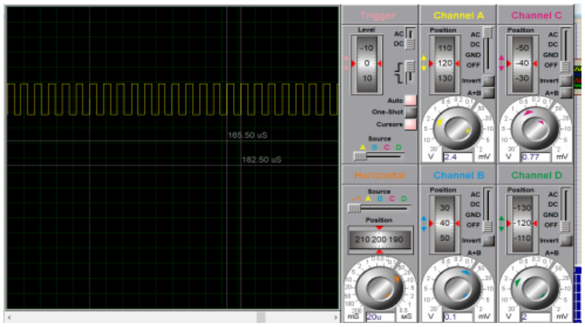

Fig.9-60kHz waveform

Hardware Calculations:
For 30Khz frequency-
Total divisions=1.8
Times per division=20us

$$Frequency = \frac{1}{Time}$$

$$Time = 36 * 10^{-6}$$

$$Frequency = \frac{10^{6}}{36}$$

= 27777.78Hz
= 27.78KHz

Hardware Results:

Fig.10-30kHz waveform

5. CONCLUSION

The increasing threats posed by pests and animal trespassing in both agricultural and residential settings necessitate the development of sustainable and intelligent alternatives to traditional pest control methods. In this work, solar-powered ultrasonic repellent system will be designed, implemented, and tested. The proposed system effectively integrates microcontroller-based frequency generation and renewable solar energy to detect, deter, and repel pests in real time. Through experimental validation, the system demonstrated the ability to generate ultrasonic signals in the range of 20–80 kHz with high precision, effectively repelling a range of pests including mosquitoes, rodents, cockroaches etc. The device maintained consistent performance using solar power, making it ideal for off-grid rural environments. It also offered manual and automatic operation modes, enhancing user flexibility. The life cycle cost analysis revealed the system to be more economical in the long term compared to chemical repellents such as DDT and Propoxur, with the added benefits of being non-toxic, reusable, and environmentally safe.
In conclusion, the developed system provides a cost-effective, eco-friendly, and intelligent solution for pest and animal control in farming, storage, and residential areas. It aligns with current, offering a practical implementation of electronics and embedded systems for social and economic benefit.

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