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Eco-Friendly Crop Protection Using Solar Powered Sound Sensors

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Abstract: Crop loss due to wild animals and birds remains a persistent challenge for farmers, especially in rural and semi-rural areas. Traditional methods such as scarecrows, fencing, and chemical deterrents often prove either ineffective in the long term or environmentally harmful. This research presents an eco-friendly and sustainable approach to crop protection using solar-powered sound sensors. The proposed system utilizes non-conventional solar energy to power sound-emitting devices triggered by motion or sound detection. When an intruder—such as a bird or animal—is detected in the field, the device emits high-frequency or predator-like sounds that naturally repel them without causing harm. This technology reduces dependence on electricity and chemical repellents, offering a cost-effective solution for farmers. Field tests showed a notable reduction in crop damage while maintaining ecological balance. The design is simple, requires minimal maintenance, and can be adapted to different crop environments. This study illustrates that integrating solar energy with sound-based deterrence is a viable strategy for modern, sustainable agriculture.

Keywords— Crop protection,smart agriculture,Automated crop security,Smart farming system,Sustainable pest management

I. INTRODUCTION

Agriculture plays a pivotal role in ensuring food security, supporting rural economies, and sustaining livelihoods, especially in developing nations like India. However, agricultural crops are susceptible to damage from birds and pests, leading to significant losses in yield and revenue for farmers worldwide. Traditional scarecrow methods, such as static figures or noise-making devices, often prove ineffective in deterring persistent pests. Additionally, reliance on non-renewable energy sources for scarecrow operation can be costly and environmentally detrimental. Therefore there arises a need for an innovative solution that combines renewable energy and advanced sensing technology to create a more efficient and sustainable scarecrow system. As the demand for eco-friendly and sustainable agricultural practices grows, there is a need for smart and cost-effective alternatives. Recent technological advances have introduced promising tools that merge electronics and renewable energy with agriculture. Among these, sound-based animal deterrents have emerged as a humane and effective method for crop protection. When integrated with solar power systems, these devices become not only environmentally friendly but also self-sustaining, making them highly suitable for remote or off-grid locations.

The proposed system in this research uses solar-powered sound sensors that detect the movement or sound of intruding animals and respond with pre-recorded deterrent sounds, such as predator calls or distress noises. This method does not harm the animals or the environment and can be customized based on the specific threat and crop type. By using clean energy to power the system, the solution eliminates the dependency on external electricity and ensures low operational costs.

This study aims to design, implement, and analyze a low-cost, sustainable crop protection system that addresses the shortcomings of existing methods. The research includes field testing to evaluate its effectiveness, ease of deployment, and scalability. The outcomes of this work contribute to the development of modern, eco-conscious agriculture that benefits both farmers and ecosystems features such as skin tone, face shape, eye structure, and lip contours using image processing techniques. Based on these attributes, a curated set of rules—developed in consultation

II. Literature Review

A growing body of research supports the transition toward automated and solar-powered crop protection systems that are both efficient and eco-friendly. Traditional methods such as static scarecrows or chemical repellents are increasingly being replaced by smart systems that use sensors, sound, and renewable energy to ensure constant field surveillance and deterrence.

Arajpure et al. (2022) proposed a smart agricultural scarecrow equipped with movable arms, 360° rotating cameras, and alarming devices. The system provides round-the-clock protection against birds, animals, and theft. Unlike traditional scarecrows, this automated version uses sensor-based input to initiate deterrent actions, increasing effectiveness and reducing manual labor in crop security.

Nagaraju et al. (2019) focused on using ultrasonic sound waves generated by a solar-powered device to repel birds from specific crop zones. Their device operates silently for humans but emits variable high-frequency sound waves that create an inhospitable environment for birds. This method is particularly valuable as it avoids chemical repellents and operates autonomously in the field using solar energy.

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Vikas et al. (2018) developed a low-cost, intelligent surveillance system designed to protect farmland from wild animal intrusion. Their smart embedded system includes sensors and real-time alerts, helping farmers monitor and secure fields effectively. The design emphasizes energy efficiency, making it ideal for rural agricultural settings.

Eleleem et al. (2014) addressed the ecological and behavioral complexities of rodent and bird control. They emphasized the importance of seasonal behavior, pest species composition, and local conditions in determining effective deterrent strategies. Their study also highlighted the use of specialized baits and rodenticides but acknowledged the need for safer, more sustainable alternatives.

Uzma et al. (2021) introduced a low-cost bird repellent that uses predator sounds as an acoustic deterrent. Powered by solar energy, the device is designed to protect high-value crops. The study highlighted that the effectiveness of this method depends on factors such as sound volume, quality, frequency, and repetition, indicating that a well-configured acoustic profile is key to successful deterrence.

Rajesh et al. (2015) studied the design and testing of a solar-powered audible bird scarer and concluded that optimized sound frequency and deployment strategies significantly improved effectiveness. Their research supports the potential of sound-based deterrent systems when engineered with the right acoustic parameters and field placement.

Collectively, these studies reveal a trend towards sensor-integrated, sound-triggered, solar-powered crop protection systems. They validate the use of motion detection, predator sounds, and ultrasonic waves as effective non-lethal deterrents. The proposed research builds upon this foundation by combining motion sensors and solar-powered acoustic devices to create a scalable, eco-friendly system capable of deterring both birds and animals while reducing reliance on chemicals and manual interventions.

III. METHODOLOGY

The proposed system is designed to protect crops from birds and wild animals using a sound-based deterrent mechanism powered by solar energy. The system operates autonomously using motion detection sensors and emits high-frequency or predator-mimicking sounds to repel intruders without causing harm. This section outlines the architecture, components, working principle, and implementation approach.

System Requirement

The system comprises the following major components:

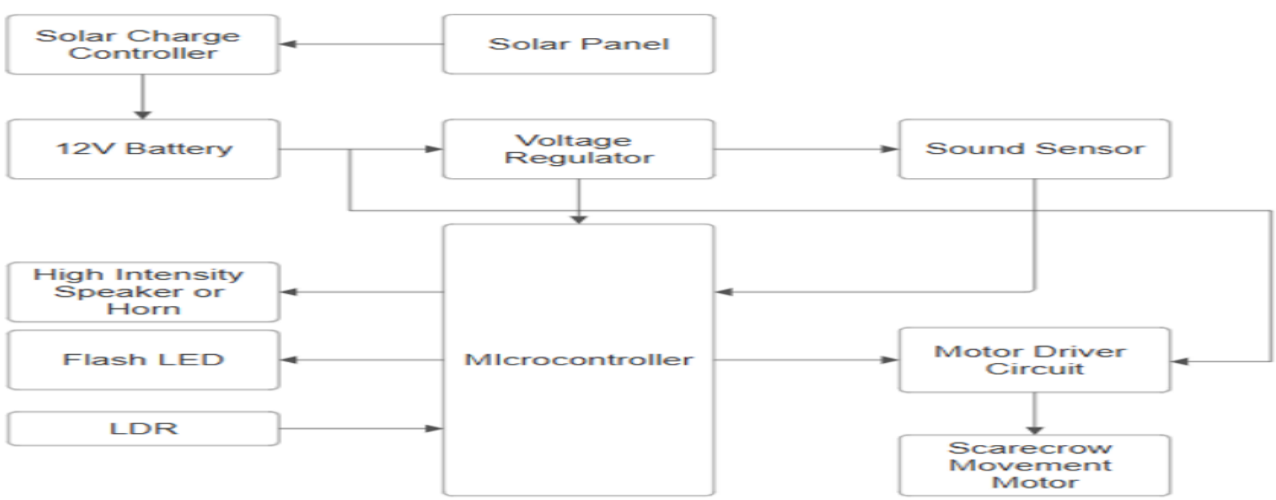

Fig.1 Block Diagram

A. Arduino

Arduino is an open-source electronics platform that combines both hardware and software to enable the development of interactive systems. It was initiated as a community-driven project that has grown into a widely adopted solution for designing microcontroller-based devices capable of sensing and interacting with the physical environment. The platform is especially known for its ease of use, making it accessible to beginners as well as professionals in embedded systems and automation.

An Arduino board can process a variety of input signals—such as data from sensors, the press of a button, or even internet-based instructions—and convert them into corresponding outputs, such as activating a motor, illuminating an LED, or triggering an online response. One of the most commonly used models is the Arduino Uno, which is built around the ATmega328 microcontroller. It

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features 14 digital input/output pins (including 6 PWM-enabled pins), 6 analog input pins, a 16 MHz quartz crystal oscillator, USB connectivity, a DC power jack, an ICSP (In-Circuit Serial Programming) header, and a reset button.

The Arduino ecosystem supports the development of numerous DIY electronics and automation projects. Multiple versions of Arduino boards are produced by different manufacturers, each utilizing various types of microcontrollers, allowing flexibility in terms of project requirements and performance capabilities.

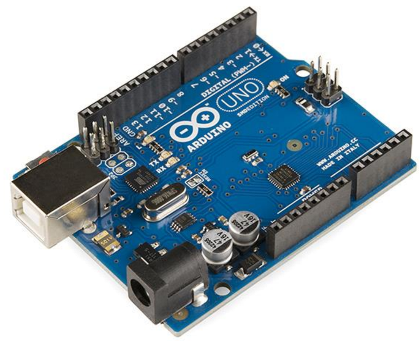
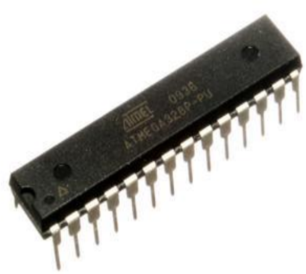


Fig.2. Arduino

B. ATmega328

It is a high-performance, single-chip microcontroller developed by Atmel as part of the AVR mega family. It is an 8-bit RISC-based microcontroller that combines efficiency with robust functionality. This device features 32 KB of in-system programmable (ISP) flash memory with support for read-while-write operations, 2 KB of SRAM, and 1 KB of EEPROM, providing versatile memory resources for embedded applications.The microcontroller includes 23 general-purpose input/output (GPIO) pins, 32 working registers, and three programmable timers/counters with various compare modes. It also supports both internal and external interrupts, as well as integrated communication interfaces such as a USART, SPI, and a 2-wire serial interface (I²C compatible). Additionally, it is equipped with a 6-channel 10-bit analog-to-digital converter (ADC)—extendable to 8 channels in TQFP and



QFN/MLF packages—making it suitable for analog signal processing.

Power efficiency is a key feature, as the ATmega328 supports five software-configurable power-saving modes and operates within a voltage range of 1.8 to 5.5 volts. Its design enables instruction throughput of up to 1 MIPS per MHz, making it ideal for time-critical operations in real-time systems.The microcontroller also offers robust non-volatile memory options, with endurance ratings of approximately 10,000 write/erase cycles for flash memory and 100,000 cycles for EEPROM. Data retention spans up to 100 years at 25°C or 20 years at 85°C, ensuring long-term reliability. Additional features include a programmable watchdog timer with its own internal oscillator, an optional boot code section with separate lock bits for secure in-system programming, and hardware-level read-while-write support to facilitate seamless memory operations.

C. Sound Sensor

sound sensor comprises a microphone element at its core, capturing sound waves and converting them into electrical signals. This element typically includes a diaphragm and a coil or piezoelectric material, where sound-induced vibrations generate voltage changes. These weak signals undergo amplification and conditioning within the sensor's signal processing circuitry to enhance their quality and prepare them for further processing. An analog-to-digital converter (ADC) then converts these analog signals into digital format for compatibility with digital systems like microcontrollers or computers. Additionally, some sound sensors feature

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sensitivity adjustments to fine-tune their response to varying sound levels or frequencies, making them adaptable for diverse applications. The output from a sound sensor can take various forms, including analog voltage levels or digital signals like Pulse Width Modulation (PWM), facilitating easy integration with different electronic devices. These sensors find wide utility across industries and applications, from sound detection and analysis in environmental monitoring or security systems to voice recognition in smart devices and musical instruments. Their ability to detect and process sound waves makes them invaluable for tasks ranging from detecting anomalies or alarms to enabling sophisticated audio-based interactions in modern technological environments

Fig.4.. Sound Sensor

D. Voice Module

The ISD1820 is a compact and easy-to-use voice recording and playback module, ideal for adding simple audio functionality to electronic projects. It features an onboard microphone and allows users to record audio messages of up to 10–20 seconds using non-volatile flash memory. The recording is initiated by pressing and holding the REC button, while playback can be triggered using either the PLAYE (edge-triggered) or PLAYL (level-triggered) buttons. The module retains the recorded audio even after power is removed, making it suitable for standalone voice applications.Designed for low-power operation, the ISD1820 module can be powered by a 3V to 5V DC supply and includes a small amplifier to directly drive an 8-ohm speaker. It also features an LED indicator to show recording status and offers options for looped playback via external microcontroller control, such as with an Arduino. Due to its simple interface and functionality, the ISD1820 is commonly used in talking toys, security systems, voice alerts, and various DIY electronics projects that require voice prompts or playback capabilities.

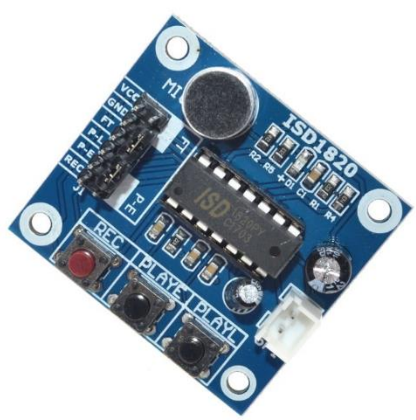

Fig.5 Voice Module ISD1820

E. Motor Driver

The L298N motor driver is a popular dual H-bridge motor driver module used to control the speed and direction of DC motors and stepper motors in robotics and automation projects. It is based on the L298N IC, which can control two independent DC motors or one stepper motor, making it ideal for applications that require bidirectional motor control.The module can operate motors with voltages between 5V and 35V, and it can handle up to 2A current per channel. It includes an onboard 5V voltage regulator, which can be enabled or disabled with a jumper. This allows the module to power low-voltage components or microcontrollers directly if

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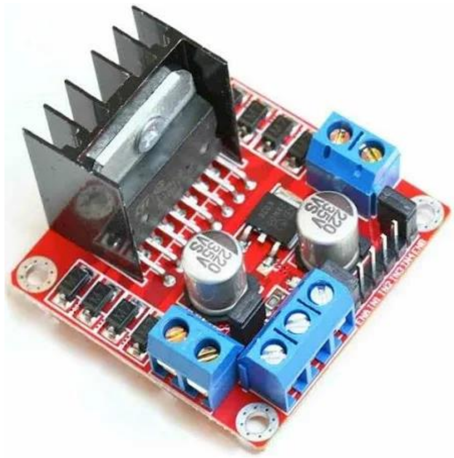
needed.Each motor connected to the L298N module can be controlled in both directions using two input pins (IN1 and IN2 for motor A, IN3 and IN4 for motor B). The speed of each motor can be controlled using Pulse Width Modulation (PWM) via the EN (enable) pins. ENA and ENB control motor A and motor B respectively and can be connected to PWM outputs of a microcontroller.



F. Solar Panels

Solar panels, essential components of solar energy systems, harness sunlight to generate electricity through photovoltaic technology. Composed of interconnected solar cells made of semiconductor materials like silicon, these panels convert solar radiation into direct current (DC) electricity via the photovoltaic effect. Encased in tempered glass with protective encapsulation and a sturdy aluminium frame, solar panels withstand environmental factors while maximizing sunlight absorption.

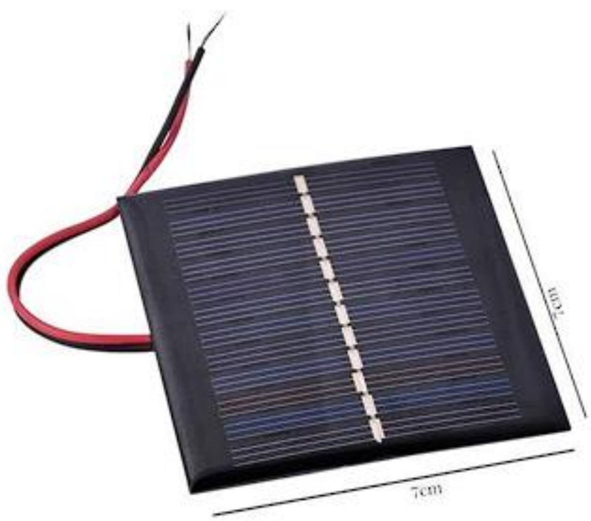


Fig.6 Solar Panel

G. Speakers

Speakers, fundamental components of audio systems, convert electrical signals into sound waves, enabling the reproduction of audio content. They consist of several key elements, including a cone-shaped diaphragm, voice coil, magnet assembly, and enclosure. When an electrical signal passes through the voice coil, it interacts with the magnetic field produced by the magnet assembly, causing the diaphragm to vibrate and produce sound waves. The size, design, and materials used in speakers influence their frequency response, power handling capacity, and overall audio quality.Enclosed within a housing or enclosure, speakers are designed to enhance sound projection, clarity, and bass response while minimizing distortion and resonance.

H.LCD

Technology could be applied to auxiliary components such as a control panel or monitoring system. For example, an LCD display integrated into the control panel could provide real-time feedback on the scarecrow's operational status, including battery charge levels, solar power generation metrics, and sound sensor readings. This visual interface would allow users to monitor the system's performance and make informed decisions regarding maintenance or adjustments based on the displayed information.

Principle

The operation of the proposed system is based on the detection of environmental sound cues, specifically those produced by birds and animals in or near agricultural fields. The system uses a sound sensor to capture these auditory signals and triggers a dual-response mechanism consisting of audio playback and physical movement to deter the intruders. The entire setup is powered by a solar energy system for sustainable and off-grid operation.The sound sensor continuously monitors the ambient noise in the environment. It is configured to detect specific frequency and intensity thresholds corresponding to bird calls, rustling, animal growls, or similar cues. When such a sound is detected, the sensor sends an analog signal to the Arduino microcontroller, which interprets the input.

Once the input exceeds the pre-set noise threshold, the microcontroller initiates two actions simultaneously:

Sound-Based Deterrence: The microcontroller triggers a sound playback module (e.g., DFPlayer Mini or equivalent) to output pre-recorded predator sounds or high-pitched noises through a connected speaker. These sounds are chosen for their effectiveness in scaring away specific types of pests and intruding animals. The playback typically lasts for 10 to 30 seconds and is loud enough to simulate real threats without causing harm.

Mechanical Motion via DC Motor: Simultaneously, the Arduino activates a DC motor connected to mechanical "arms" on the scarecrow-like model. When powered, the motor rotates a shaft or cam which causes the arms to swing or move side-to-side in a continuous motion. This mechanical movement provides a visual scare element, reinforcing the audio signal and increasing the chance of repelling the animal. The motor runs for a limited time (e.g., 15 seconds) controlled by the Arduino through a relay or motor driver circuit (e.g., L298N or L293D).

After the response cycle completes, the microcontroller enters a cooldown delay period to avoid excessive triggering, save power, and prevent habituation by the animals. The cooldown duration (e.g., 30–60 seconds) ensures efficient operation and allows the system to reset before reactivating.

The entire system is powered by a solar panel connected to a rechargeable battery, which provides sustainable energy for both daytime and nighttime operation. A voltage regulator ensures that the DC motor and other components receive stable power without fluctuations. Since the system only activates when a sound event is detected, it is both energy-efficient and minimally invasive to the surrounding environment.

This approach combines real-time sound detection, non-lethal deterrence through audio, and visual disruption using mechanical movement, making it an effective and eco-conscious solution for protecting crops from animals and birds.

Implementation

The proposed system was successfully developed and deployed on a small-scale agricultural plot to evaluate its real-world effectiveness in protecting crops from birds and wild animals. The design emphasizes autonomous operation, low cost, ease of deployment, and reliance on renewable energy. The system primarily uses a sound sensor to detect the presence of animals based on auditory cues such as bird calls or rustling noises. When such sounds are detected above a defined threshold, the system responds by activating a speaker to emit predator sounds and simultaneously triggering a DC motor that swings the scarecrow's arms to visually repel intruders.

The hardware setup consists of several key components including an Arduino UNO microcontroller, a microphone-based sound sensor module, a DC motor connected to lightweight arms, an L298N motor driver, a 12V solar panel, and a rechargeable lead-acid battery to store solar energy. The system also includes a voltage regulator to ensure stable power distribution and a relay module for safe switching of the motor. The entire assembly is mounted on a weather-resistant platform with the solar panel positioned at an elevated angle to maximize sunlight exposure. The sound sensor and speaker are installed at crop height to ensure accurate detection and effective sound propagation.

The control logic was programmed using the Arduino IDE. The microcontroller continuously monitors ambient noise via the sound sensor. When the input surpasses a set decibel level, indicating a potential threat, the microcontroller activates the speaker and the DC motor simultaneously. The speaker plays pre-recorded animal repellent sounds, while the motor swings the scarecrow's arms for a short period. A built-in delay prevents the system from activating too frequently, conserving energy and reducing the chance of animals becoming habituated to the deterrent.

The prototype was deployed in a 300 square meter test area and observed for a period of 15 days. During this time, the system demonstrated consistent responsiveness to animal sounds, successfully deterring multiple intrusions. Comparisons with an unprotected control plot showed a noticeable reduction in crop disturbances. The solar-powered setup proved sufficient to run the system day and night with minimal maintenance. Safety features such as overcharge protection for the battery and current-limiting fuses in the motor circuit were included to prevent hardware damage. Overall, the system was found to be energy-efficient, cost-effective, and practical for rural farmers, supporting sustainable agricultural practices with minimal environmental impact.

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IV. Conclusion

Protecting crops from birds and wild animals continues to be a persistent challenge for farmers, especially in regions with limited access to modern infrastructure. The system developed in this project offers a simple yet effective solution by combining sound-based animal detection with solar-powered deterrent mechanisms. By using a sound sensor to pick up animal-related noises and responding through both audio signals and physical motion, the model provides a dual-layered defense that increases the chances of scaring intruders away without causing harm.

One of the major strengths of the proposed model lies in its ability to operate independently of the power grid. The use of a solar panel ensures that the system remains functional throughout the day and night, even in areas where electricity supply is irregular or unavailable. This makes it especially useful for small and medium-scale farmers who require reliable, low-maintenance protection for their crops. The choice of a DC motor for arm movement also contributes to keeping the design cost-effective and mechanically straightforward.

Field deployment showed promising results in reducing crop interference from animals and birds. The system responded appropriately to environmental sounds and successfully triggered deterrent actions, indicating that the concept is practical and ready for further refinement. Looking ahead, this approach could be expanded with features like mobile notifications, automatic logging of activity, or even AI-based sound classification to distinguish between different types of threats. In conclusion, the integration of renewable energy and reactive design in this system demonstrates a meaningful step toward more sustainable and accessible crop protection technologies.

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