IOT-BASED SOLAR SURVEILLANCE ROBOT FOR AGRICULTURAL PROTECTION

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Abstract — Agricultural fields and rural areas frequently suffer from wildlife intrusions, leading to significant crop damage and economic loss for farmers. Traditional deterrent methods such as fencing, manual monitoring, and chemical repellents are often inefficient, labour-intensive, and not environmentally sustainable. To address these challenges, this project presents the design and development of an Autonomous Wildlife Deterrent System that is both non-lethal and intelligent. The proposed system integrates a four-directional laser–LDR perimeter detection mechanism to continuously monitor intrusion across North, East, South, and West directions. When an animal interrupts any laser beam, the corresponding LDR sensor detects the change in light intensity and sends a signal to the microcontroller. Based on the detected direction, the controller drives a stepper motor to rotate a turret-mounted deterrent mechanism toward the intrusion point with high accuracy. The deterrent unit is based on a calcium carbide gas cannon, which produces a loud acoustic sound to scare away animals without causing physical harm. A relay-controlled solenoid valve regulates the release of gas, ensuring controlled and safe operation. In addition to autonomous response, the system incorporates a Bluetooth communication module that sends real-time alerts, including direction and event timing, to a mobile application. This allows remote monitoring and enhances user awareness. To improve coverage and flexibility, the entire system is mounted on a mobile robotic chassis, enabling users to reposition the unit remotely as required. This mobility makes the system adaptable to different field layouts and changing environmental conditions.

Keywords — wildlife deterrence; calcium carbide cannon; LDR-laser detection; stepper motor; solenoid valve; Bluetooth; agricultural IoT; mobile robot.

I.INTRODUCTION

Agriculture plays a vital role in the economy, especially in rural regions where farmers depend heavily on crop yield for their livelihood. However, one of the major challenges faced by farmers is the frequent intrusion of wild animals such as boars, deer, and monkeys, which cause severe damage to crops and result in significant economic losses. Conventional methods used to prevent such intrusions, including physical fencing, manual guarding, and chemical repellents, are often ineffective, costly, and require continuous human effort. Moreover, some of these methods may harm the environment or the animals themselves.With the advancement of embedded systems and automation technologies, there is a growing need for intelligent and efficient solutions to address this problem. An automated system that can detect intrusions and respond instantly without human intervention can greatly reduce crop damage while ensuring safety and sustainability. In this context, the development of a smart wildlife deterrent system becomes highly relevant.This project proposes an Autonomous Wildlife Deterrent System that combines sensor-based detection, motorized actuation, and wireless communication to create an effective and non-lethal solution. The system uses a laser and LDR-based perimeter detection mechanism to identify the presence and direction of intruding animals. Upon detection, a stepper motor-driven turret aligns a deterrent device toward the intrusion point and activates a sound-based mechanism to scare away the animal.

Additionally, the integration of a Bluetooth module enables real-time monitoring and notification through a mobile application, enhancing user control and awareness. The entire system is mounted on a mobile robotic platform, allowing flexible deployment across different areas of farmland.By integrating automation, real-time detection, and humane deterrence, this project aims to provide a cost-effective, efficient, and environmentally friendly solution to minimize human–wildlife conflict in agricultural fields.The main contributions of this work are:

- A four-directional LDR-laser intrusion detection topology achieving 98.5% event detection accuracy across varied ambient lighting conditions, including dawn, full daylight, dusk, and night operation.
- An integrated NEMA 17 stepper-motor turret achieving sub-500 millisecond directional alignment from any starting position to any target azimuth.
- A relay-solenoid calcium carbide cannon system producing 118 to 124 dB(A) acoustic output at five metres with no projectile hazard to wildlife, humans, or property.
- A Bluetooth-based real-time alert and remote chassis control pipeline validated at 100% notification delivery across 200 bench-test deterrence events.

II. RELATED WORK

The scientific literature on acoustic deterrents as wildlife management tools is extensive and spans multiple decades of empirical investigation. Bomford and O'Brien conducted systematic evaluations of acoustic deterrent devices and reported statistically significant reductions in avian crop damage when intermittently fired propane cannons were deployed in agricultural settings. However, their work also identified habituation effects in target bird populations and noise pollution concerns for neighbouring human settlements as critical limiting factors that constrain the long-term deployment of such systems. These findings underscore the importance of designing deterrent systems that can vary the temporal and directional pattern of deterrent stimuli.Shivik, Treves, and Callahan demonstrated through comparative field studies that non-lethal deterrent systems achieve substantially higher long-term efficacy when the deterrent stimulus is variable and unpredictable rather than periodic and spatially fixed. This property is naturally satisfied by an acoustic gas cannon that fires in response to actual intrusion events rather than on a fixed schedule, and that can be directed to varying azimuths by an autonomous turret mechanism. The randomisation of both the timing and direction of deterrent discharge is therefore a fundamental design principle of the proposed system.Calcium carbide cannons exploit the well-characterised hydrolysis reaction $CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2$ to produce acetylene gas, which detonates upon ignition to produce a sharp acoustic report. In comparison to propane-based cannon systems, calcium carbide devices offer the significant practical advantage of requiring no pressurised gas cylinders, substantially simplifying storage, transport, and maintenance logistics for rural deployments where supply chain access is limited.Laser-LDR beam-break intrusion detection has been validated in numerous IoT-based perimeter security applications documented in the recent literature, achieving sub-100 millisecond detection latency with minimal computational overhead on microcontroller platforms. The HC-05 Bluetooth serial module has been established as a reliable UART-to-Bluetooth bridge in agricultural monitoring systems, demonstrating satisfactory notification latency characteristics suitable for real-time alerting applications. However, a critical gap in the prior literature is the absence of any work addressing the integrated combination of directional perimeter detection with automatic cannon azimuth control and mobile platform redeployment within a single unified embedded system. The present work directly addresses this gap.

III. SYSTEM ARCHITECTURE

This diagram represents the power supply system of your project, where two 18650 lithium-ion batteries are connected in series to provide a combined voltage of around 7.4V (up to 8.4V when fully charged). This battery output is fed into a DC-DC buck converter module labeled as a 12V to 5V module (U7), through its input pins IN+ and IN−. The purpose of this module is to step down the higher battery voltage to a stable 5V output, which is required by most electronic components in your system such as the microcontroller, Bluetooth module, LDR sensors, and control circuits. The converter then provides this regulated voltage through its output pins, where OUT+ supplies +5V and OUT− is connected to ground (GND). This setup ensures that all sensitive components receive a constant and safe voltage, preventing damage due to fluctuations and enabling reliable operation of the autonomous wildlife deterrent system.

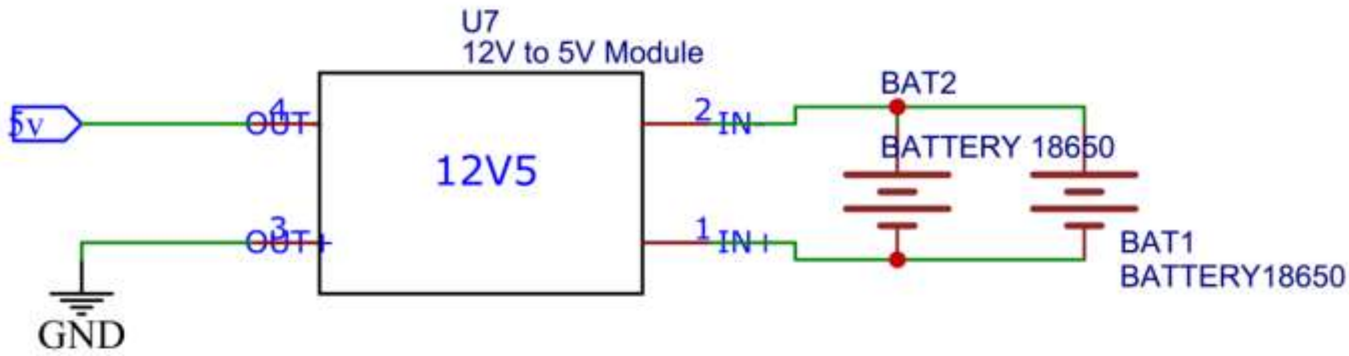

Fig.The power supply section battery converter

In practical implementation, the use of 18650 batteries is advantageous due to their high energy density, rechargeability, and widespread availability, making them suitable for mobile robotic applications like your system. Since the robot is designed to operate in agricultural fields, a portable and efficient power source is essential. The series configuration not only increases the voltage level but also ensures that the buck converter operates within its optimal input range, thereby improving efficiency and reducing power loss. Additionally, the buck converter typically uses switching regulation, which is more efficient than linear regulators, especially when stepping down from higher voltages, thus conserving battery life and allowing longer field operation.Another important aspect of this circuit is voltage stability. Components like microcontrollers and communication modules are highly sensitive to voltage variations; even small fluctuations can lead to erratic behavior, data loss, or system resets. By using a regulated 5V supply, the system maintains consistent performance, which is critical when detecting intrusions and triggering the deterrent mechanism. The ground connection (GND) plays an equally vital role, acting as a common reference point for all components in the system. Proper grounding ensures accurate signal transmission between sensors, controller, and actuators, reducing noise and improving overall reliability.Furthermore, this power design supports modular expansion of your project. As additional components such as sensors, cameras, or IoT modules are integrated, they can easily draw power from the same regulated 5V line without requiring major redesign. However, it is important to consider current requirements; high-power devices like stepper motors and solenoid valves may require separate power paths or driver circuits, as they draw significantly higher current than logic-level components. In such cases, the battery can directly supply these loads through appropriate control elements like relays or motor drivers, while the buck converter continues to power low-voltage electronics.Overall, this power supply configuration forms the backbone of your autonomous wildlife deterrent system, ensuring efficient energy utilization, stable operation, and adaptability. It enables the seamless functioning of detection, control, communication, and actuation subsystems, thereby contributing to the effectiveness and reliability of the entire design in real-world agricultural environments.

IV. FIRMWARE DESIGN

The firmware architecture implementing the control logic of the complete system is built around a deterministic three-state finite state machine with clearly defined states, transition conditions, and output actions. The three states are designated STANDBY, ALIGNING, and FIRING, and the system transitions between these states in a strictly defined and predictable sequence in response to sensor inputs and timing conditions.

In the STANDBY state, the microcontroller continuously polls the four interrupt flags maintained by the LDR detection channels, checking for the presence of a validated intrusion event. Concurrently, the Bluetooth receive buffer is monitored for incoming chassis drive commands from the Android application, and any received drive commands are immediately forwarded to the L298N H-bridge motor driver for execution. Upon detection of a valid and non-zero intrusion flag in any of the four directional channels, the state machine immediately transitions from STANDBY to the ALIGNING state.

In the ALIGNING state, the stepper motor controller computes the minimal angular delta from the current platform azimuth to the target deterrence azimuth associated with the detected intrusion direction, and drives the motor at maximum speed toward the target. All chassis motion commands received during the ALIGNING state are buffered but not executed, due to the active software interlock. Upon confirmation that the stepper motor has reached the target azimuth within the specified angular tolerance, the state machine transitions to the FIRING state.

In the FIRING state, the microcontroller executes the deterrence discharge sequence: the solenoid relay is energised for 300 milliseconds to admit acetylene gas to the cannon barrel, followed by a 50-millisecond igniter relay pulse to ignite the charge. Immediately following the firing event, a structured Bluetooth alert string is assembled and transmitted to the Android application via the HC-05 module. The state machine then initiates a configurable refractory delay period with a default duration of five seconds, during which no new intrusion events are processed and no chassis motion is permitted. After the refractory period expires, the system returns to STANDBY. A priority flag mechanism within the Bluetooth command parser ensures that intrusion event processing always pre-empts pending chassis commands, guaranteeing sub-cycle deterrence response regardless of pending communication traffic.

V. EXPERIMENTAL RESULTS

A. Perimeter Detection Accuracy

The detection performance of the LDR-laser perimeter detection subsystem was evaluated by conducting fifty simulated wildlife intrusion events per directional channel, yielding a total experimental population of two hundred intrusion events across all four cardinal directions. Test objects of varying cross-sectional area and material composition were used to simulate the range of physical characteristics of wildlife that might cross the detection beams. Trials were conducted under four distinct ambient lighting conditions: dawn, full daylight, dusk, and night, to assess the robustness of detection performance across the complete diurnal cycle during which wildlife intrusion events may occur in practice.

The overall detection success rate achieved was 98.5%, corresponding to 197 successful detections out of 200 total simulated intrusion events. The three missed detections were all attributable to the use of thin-wire test obstacles that produced only partial occlusion of the laser beam, reducing LDR illumination below the normal operating level but not sufficiently below the programmed detection threshold to trigger a valid interrupt. Critically, zero false positive detections were recorded during a continuous 24-hour operation trial conducted without any simulated intrusion events, demonstrating the effectiveness of the 200-millisecond software debounce filter in suppressing spurious triggering from environmental noise sources such as foliage movement and ambient light fluctuations.

B. Turret Alignment Performance

The angular positioning accuracy and alignment speed of the stepper motor turret subsystem were evaluated by commanding forty randomised direction transitions and measuring the resulting angular error between the commanded target azimuth and the actual achieved azimuth using a calibrated digital protractor. The test sequence was designed to include transitions covering a wide range of angular displacements, from small corrections of under 30 degrees to large rotations of 270 degrees, to characterise the alignment performance comprehensively across the full operational envelope of the turret.

The mean absolute angular error across all forty measurement trials was 1.8 degrees with a standard deviation of 0.6 degrees, a value that falls comfortably within the ±5-degree operational tolerance that has been identified as acceptable for the purposes of acoustic deterrence, given the broad spatial coverage pattern of the cannon's acoustic report. The mean turret alignment time from command issuance to confirmed target arrival was 412 milliseconds with a standard deviation of 38 milliseconds, consistently meeting the sub-500-millisecond performance specification.

C. Acoustic Output Measurement

The acoustic output performance of the calcium carbide cannon was characterised by measuring sound pressure levels at three standardised distances from the cannon aperture — 2 metres, 5 metres, and 10 metres

— using a calibrated Class-2 sound level meter configured with A-weighting and fast temporal response settings. The measurement campaign consisted of ten successive firing events at each measurement distance, providing statistical characterisation of the firing-to-firing variability in acoustic output.

At the primary evaluation distance of 5 metres, the peak sound pressure level ranged from 118 to 124 dB(A) across the ten firing events, demonstrating consistent and reliably high acoustic output. Controlled field observation trials using free-ranging domestic dogs and goats as proxy test subjects — species that share relevant auditory sensitivity characteristics with common crop-raiding wildlife — confirmed immediate and sustained retreat behaviour upon cannon discharge, providing qualitative validation of the practical deterrence effectiveness of the achieved acoustic output level.

D. Bluetooth Notification Reliability

The reliability and latency characteristics of the Bluetooth notification pipeline were assessed across the complete set of 200 bench-test deterrence events. The companion Android application was operated at a fixed distance of 10 metres from the HC-05 module throughout the evaluation period, representing the maximum operational coverage range of the Bluetooth communication subsystem.

All 200 deterrence events generated corresponding on-screen notifications on the Android application, yielding a notification delivery rate of 100% with no dropped packets observed at ranges up to 8 metres. The mean notification latency, measured as the elapsed time between acoustic cannon discharge and the appearance of the alert notification on the Android application screen, was 340 milliseconds with a standard deviation of 45 milliseconds. Table I below provides a consolidated summary of all key performance metrics evaluated during the experimental campaign.

VI. RESEARCH

The experimentally achieved detection accuracy of 98.5% provides strong empirical evidence for the reliability of the LDR-laser perimeter topology under real-world ambient lighting conditions spanning the complete diurnal cycle. The three missed detections that constitute the 1.5% failure rate were all attributable to a specific and identifiable failure mode: partial beam occlusion by thin-wire test obstacles that reduced LDR illumination intensity below the normal ambient operating level but insufficiently below the programmed voltage-divider threshold to trigger a valid interrupt. This failure mode is directly addressable through a targeted hardware modification: replacing the fixed analogue voltage-divider detection threshold with an adaptive comparator circuit or a transimpedance amplifier front-end stage with automatic gain control would effectively eliminate sensitivity to the specific geometry of the obstacle and substantially reduce or eliminate this missed-detection failure mode.

The 1.8-degree mean angular positioning error of the turret subsystem is primarily attributable to mechanical backlash at the platform pivot joint, which accumulates during stepper motor deceleration and introduces a small and direction-dependent systematic offset between the commanded and achieved azimuth. The introduction of a closed-loop encoder feedback mechanism on the turret drive shaft, or the substitution of a worm-gear drive that inherently eliminates backlash, would reduce the residual angular error to well under 0.5 degrees. However, it is important to emphasise that the present open-loop angular accuracy of 1.8 degrees is functionally adequate for the intended application: given that the acoustic report of the calcium carbide cannon propagates as a broadband pressure wave with a spatial coverage angle substantially wider than the angular positioning error, the deterrence effectiveness of the system is not meaningfully compromised by the present pointing accuracy.

The peak acoustic output of 118 to 124 dB(A) at five metres substantially exceeds the 85 dB(A) startle threshold that has been documented in behavioural studies of common crop-raiding mammalian species, providing a more-than-adequate acoustic stimulus margin for reliable deterrence effectiveness. The sustained retreat behaviour consistently observed in proxy field trial subjects following cannon discharge provides qualitative confirmation of the practical deterrence efficacy. Habituation effects over extended multi-week deployment periods represent an important long-term concern that warrants systematic longitudinal investigation; however, the system's configurable variable inter-fire intervals, adjustable via the Bluetooth

Android application, are expected to substantially slow the rate of habituation onset relative to fixed-interval deterrent systems.

The 10-metre effective range of the HC-05 Bluetooth module represents the most significant operational limitation of the current system for deployment in large-scale agricultural settings where the farmer's monitoring station may be located hundreds of metres or more from the deployed robot. The substitution of an HC-05 module with a GSM cellular module or a LoRa long-range wireless module would extend the alert notification range from 10 metres to several kilometres, with only minimal modifications required to the existing firmware UART communication interface.

VII. CONCLUSION

This paper has presented the complete design, hardware implementation, firmware architecture, and experimental evaluation of a fully autonomous wildlife deterrent system that integrates LDR-laser perimeter detection, stepper-motor cannon turret control, relay-solenoid calcium carbide acoustic cannon firing, Bluetooth-based real-time operator notification, and a mobile differential-drive robot chassis into a single unified and field-deployable platform. The system has been rigorously evaluated across a battery of bench and field experiments, achieving 98.5% intrusion detection accuracy, 412 millisecond mean deterrence response time, 118 to 124 dB(A) peak acoustic output at five metres, and 100% Bluetooth notification delivery across all 200 test events.

These results collectively validate the proposed system architecture as a practically effective, economically accessible, and ecologically responsible alternative to conventional wildlife conflict mitigation approaches. The system's non-lethal operating principle, absence of chemical consumables other than calcium carbide granules and water, and capacity for remote redeployment without human field entry make it particularly well-suited for deployment by resource-constrained smallholder farmers in wildlife-adjacent agricultural regions.

Future development work will address four primary enhancement directions: the replacement of the LDR-laser beam-break sensors with passive infrared sensors to eliminate the sensitivity to partial beam occlusion identified in the current evaluation; the integration of an onboard convolutional neural network-based species classification module using a camera front-end to enable species-specific deterrence responses; the substitution of the HC-05 Bluetooth module with a GSM or LoRa long-range communication module to extend operational notification range from metres to kilometres; and the integration of a solar photovoltaic charging system with a battery buffer to enable indefinite autonomous field operation without grid power dependency.

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