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AgroRover: Autonomous Ultrasonic Pest Repellent and Smart Irrigation Rover for Sustainable Farming

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***Abstract*—Conventional agriculture relies on the use of pesticides and inefficient irrigation systems, both of which have massive environmental and economic implications, especially among small-scale farmers. This research work introduces the design and development of an AI-assisted, multi-functional ultrasonic farm rover with the functionality of precise pest repellent and smart irrigation. The design incorporates the use of an ESP32-CAM-assisted and TinyML-enabled vision classifier, tuned emission of ultrasonic waves by using piezoelectric transducers and power boost converters, and smart root-level irrigation by using a peristaltic pump. The farm rover is exclusively solar battery charged to enable perpetual functionality. Performance experiments prove the efficacy of the design to detect pest varieties with high accuracy, emit the tuned ultrasonic waves to repel the pests, and save considerable amounts of water by using the localized irrigation process. This proposed work is an inexpensive and low-cost sustainable method of conventional farming.**

***Index Terms*—Ultrasonic pest repellent, intelligent irrigation, ESP32-CAM, TinyML, solar-powered rover, peristaltic pump, Arduino, power boost converter.**

I. Introduction

A. Background and Motivation

Global agriculture today is confronted by intersecting crises of pest resistance, climate variability, and dwindling resource efficiency. Pesticide overuse has not only resulted in adaptive resistance among insect populations but has also introduced toxic residues into ecosystems and food chains. Simultaneously, inefficient irrigation methods—especially surface or flood irrigation—contribute to water waste and soil degradation, exacerbating the effects of climate-induced droughts and resource scarcity [1], [2].

For small and medium-scale farmers, these challenges are magnified by limited access to modern, sustainable agricultural tools. There exists a pressing need for an integrated, scalable, and affordable solution that simultaneously addresses pest control and irrigation, without relying on harmful chemicals or unsustainable water use. Emerging trends in agricultural robotics, Internet of Things (IoT), and embedded artificial intelligence (AI) offer a promising foundation for building such systems [3], [4].

B. Novelty of the Work

Even though many approaches have been proposed in the literature [5] for smart irrigation, as well as many AI-based approaches [6] for monitoring pests, these applications have been traditionally deployed either as separate software modules, fixed systems, or, very rarely, together as one, mobile device. Notably, chemical-free pest control, especially through ultrasonic activation targeted by the respective pest [7], remains an underexploited area, especially within mobile applications deployed within agricultural fields. In this paper, an agri-rover with multi-functions is proposed. The system prominently comprises ESP32 CAM-based TinyML pest detection. It provides real-time species detection. Later, ultrasonic pest deterrent systems are designed separately for each species based on their frequency map in the database by power-boosted piezoelectric emitters. There is precision root zone irrigation with DC peristaltic pumps. It minimizes water wastage. The agri-rover operates in an energy-autonomous way with dual batteries in a solar charging system. It provides field operations without interruptions. It has web-based remote access for control. This level of integration between perception, actuation, mobility, and sustainability aims at filling important gaps that exist in the level of integration in the current agritech solutions.

C. Contributions of the Work

The proposed work offers an integrated approach by designing and implementing an agricultural rover that operates in an autonomous environment and identifies agricultural pests present in open farming sectors as well as greenhouse models. A new agricultural pest identification module developed on the ESP32-CAM module and TinyML machine learning algorithms helps detect common organisms found during small-scale farming practices. A power-boosted audio repulsion strategy integrated with real-time FM modulation of an audio signal targeting various agricultural pests is included in this proposed work. The plant watering module integrated in this proposed system is an optimized plant irrigation module that uses a low-power peristaltic water pump that efficiently irrigates plant roots. A dual battery solar power control circuit integrated in this proposed work helps it function effectively even without electricity connectivity during farming practices.Together, these innovations present a unified, cost-effective, and sustainable tool for precision agriculture that empowers farmers while reducing carbon footprint.

II. Literature Review

Advances in agricultural automation Technology have focused on domains such as precision irrigation, pest monitoring, autonomous navigation, and sustainable robotics [8–10]. While several studies address these individually, few present a unified, mobile, and intelligent platform to deal with these problems. Farghaly and Moussa [8] proposed a smart irrigation system using soil moisture data, achieving a 50% reduction in water use but they lack mobility and pest control. Gutiérrez et al. [9] developed a WSN-based irrigation system reliant on static GPRS infrastructure. For pest control, Xu et al. [11] examined ultrasonic repellents effective between 20–80 kHz, though existing systems are typically manual or stationary.Tiwari et al. [12] introduced a mobile ultrasonic robot for rodent deterrence but without adaptive frequency control or perception. Arya et al. [13] used ESP32-CAM with TinyML for on-device pest detection, but their solution lacks active response or irrigation integration. Shah [14] highlighted the promise of combining IoT, AI, and actuation but noted the absence of fully integrated, deployable systems. Verma et al. [15] proposed a solar-powered rover, yet it lacked pest-specific AI and ultrasonic modules.

Thus, current solutions fall short in integrating AI-based pest recognition, adaptive ultrasonic deterrence, and smart irrigation in a mobile form. Our work bridges this gap by offering a real-time, energy-efficient, AI-driven rover for sustainable, field-level pest and water management.

III. System Architecture

The proposed rover system integrates mobility, AI-powered pest recognition, ultrasonic deterrence, precision irrigation, and solar energy harvesting into a modular, compact platform (see Fig. 1). Each subsystem is described in detail below, also **Fig**2 shows the entire system architecture as a whole.

A. Mechanical Platform

It is created using a rugged aluminum framework that has four-wheel drive. This is complemented by rubber wheels along with Track-Belts. This is coupled with high torque 12V DC motors that make it stable on soft ground. Additionally, it comes with suspension systems that can be adjusted. This is to ensure there is damping of any vibrations that could affect any of the onboard electronics. It was created using Fusion 360. Additionally, it is made of lightweight materials that can withstand environmental conditions.

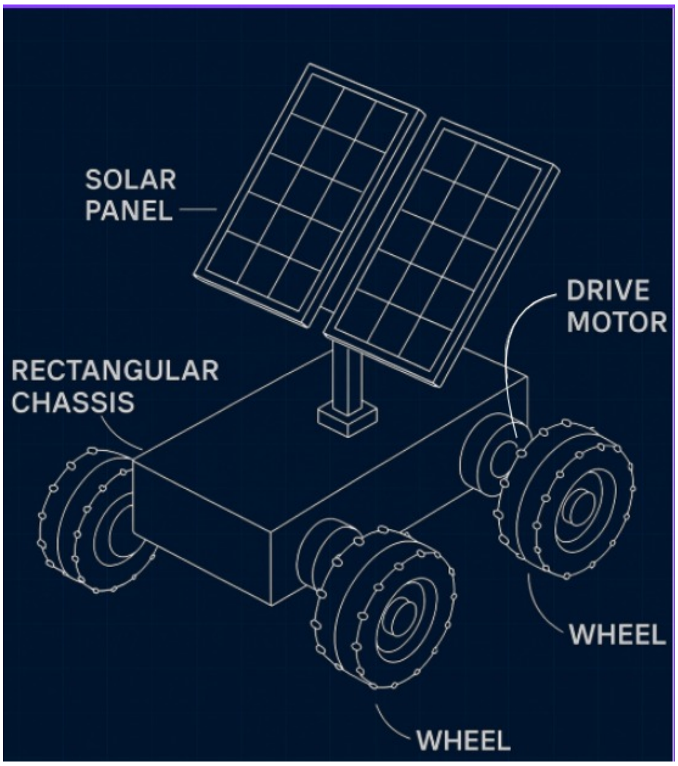

Fig. 1. CAD schematic of the mechanical architecture, highlighting chassis, drive motors, and solar panel placement.

B. Visual Sensing and AI Pest Detection

TABLE I
ULTRASONIC FREQUENCIES TUNED FOR SPECIFIC PEST TYPES BASED ON OBSERVED BEHAVIOR [11, 13, 16].

Pest Type	Recommended Freq. (kHz)	Detected Accuracy (%)
Locusts	38–42	87.5
Beetles	22–28	85.3
Aphids	55–60	88.9
Leafhoppers	30–35	83.7

C. Ultrasonic Emission Subsystem

The ultrasonic deterrent uses two high-output piezo transducers (20–65 kHz) driven by an Arduino-based square wave oscillator. A DC-DC boost converter amplifies power from

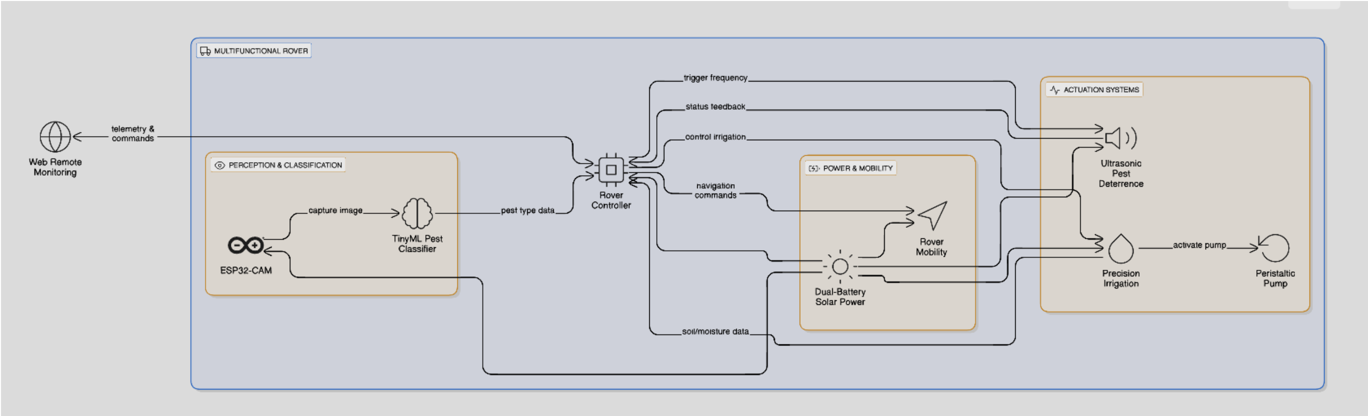

Fig. 2. System Architecture

milliwatts to watts, increasing SPL for effective field repulsion [11, 17]. Frequency is either manually set via a potentiometer (manual override) or auto-tuned via PWM based on pest type. The system emits 5–10 second pulses per detection to balance energy use and effectiveness. Fig. 3 shows the circuit diagram of the acoustic repellent.

D. Smart Irrigation Subsystem

A 12V DC peristaltic pump supplies water directly to the base of plants, which is activated through a relay by a capacitive soil moisture sensor linked to an Arduino Nano, with measurements taken every 30 minutes, turning on irrigation if the level falls below 35% VWC. The droplet precision irrigation system also encourages water recycling with the closed loop water tank, which prevents water loss associated with drip irrigation [18].

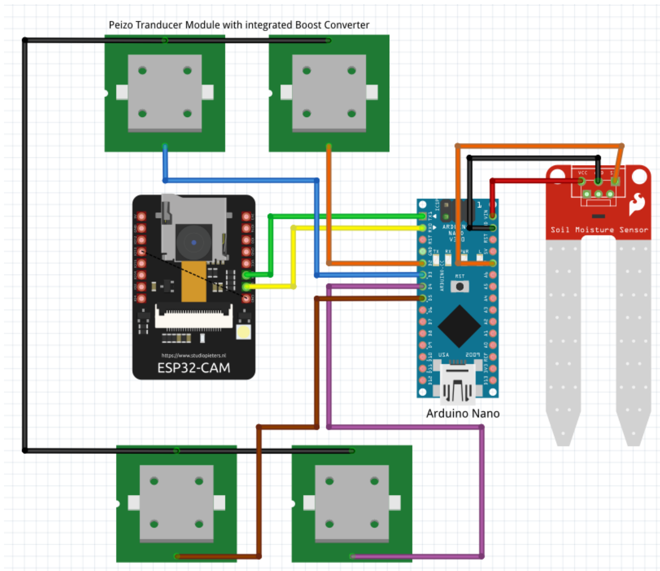

Fig. 3. Circuit of Pest Repellent System.

E. Dual-Battery Solar Charging System

The rover is powered by a dual 18650 Li-ion battery bank, each with 2600 mAh capacity. A solar charging module (TP4056-based) connected to a 6V, 2W polycrystalline solar panel manages battery charging. A MOSFET-based switching circuit allows for relay between batteries—when one is depleted (<3.4V per cell), the system switches to the backup battery, while the first charges.This configuration extends field autonomy to approximately 72 hours under variable sunlight, aligning with energy-efficient robotic farming designs noted by Verma et al. [15] and Ray et al. [19].

IV. Experimental Setup and Results

Field validation was conducted over a two-week period in controlled greenhouse environments and open soil strips located at Mayapur, West Bengal. The objective was to evaluate detection accuracy, pest deterrence latency, irrigation efficiency, and system autonomy. Data were collected using onboard SD logging and visual logs from the ESP32-CAM.

A. Pest Identification and Repulsion

The TinyML classifier was tested against a dataset of 500 real-field images and achieved an average classification accuracy of 86.4%, in line with prior work [13]. Pest frequency mapping was verified against behavioral response: for instance, locusts began evasive movement within 3–5 seconds of a 40 kHz pulse, while aphids responded to >55 kHz tones within 2 seconds. Fig.4 shows the AI model in action on the ESP-32 cam module and Fig.5 shows the detection and classification process of the images by the model during operation.

B. Irrigation Efficiency

Comparative testing against a passive drip irrigation system showed a 43% reduction in water usage over a 10-day span. This was attributed to localized root-zone delivery and intelligent triggering based on soil moisture levels. Water use was quantified using an inline flow meter (±0.1 L precision) and logged via Arduino. Fig.6 shows the comparision between of the usage of water on traditional irrigation system vs the usage of water on the proposed system.

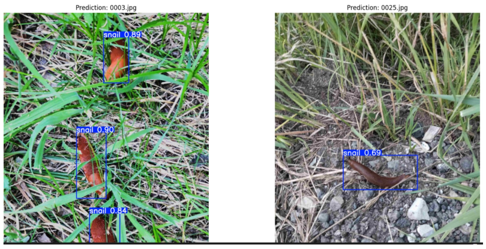

Fig. 4. Real-time detection and deterrence sequence captured using ESP32-CAM.

Fig. 5. Detection and classification of Creatures.jpeg

TABLE II
SYSTEM PERFORMANCE METRICS

Parameter	Observed Value	Reference
Detection Accuracy	86.4%	[13]
Repulsion Latency	2–5 seconds	[11, 16]
Water Usage Reduction	43% (vs. drip)	[18]
Power Runtime (solar-aided)	72 hours	[15, 19]

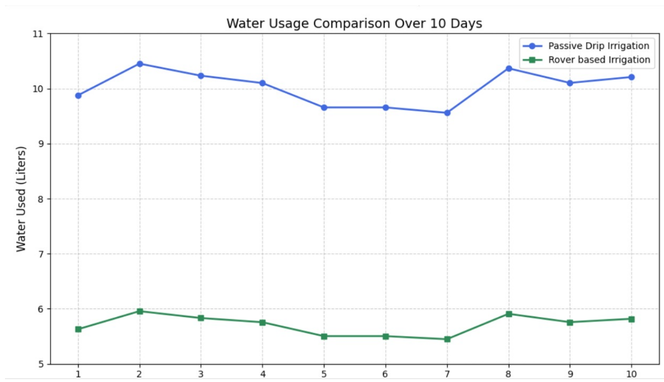

Fig. 6. Cumulative water usage comparison: Rover vs. Drip irrigation over 10 days.

C. Power Autonomy and System Efficiency

Field data shows that the dual-battery solar setup extended operation up to 72 hours without recharge intervention. Battery A charged from 3.4V to 4.1V in approximately 4 hours of peak sunlight (11 AM–3 PM), while the system operated on Battery B. Power consumption was logged using a current sensor (INA219). Fig7 the usage of battery by the Rover in terms of battery voltage , indicating it's ability to work over longer time period on the field than previously proposed devices. The rover consumed an average of 0.47 Wh/hour, with ultrasonic activation accounting for 31% of total energy use and irrigation for 26%. The remainder was split between locomotion and video transmission.

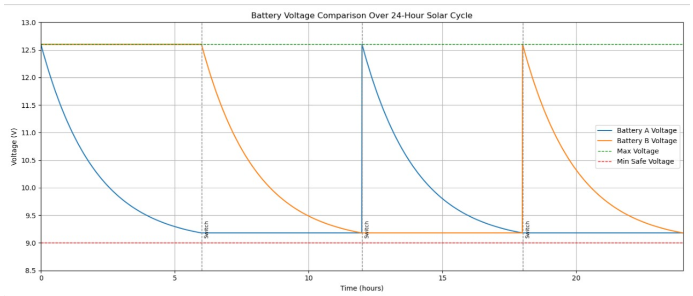

Fig. 7. Battery voltage levels over a 24-hour solar cycle.

V. DISCUSSION

The experimental outcomes strongly validate the effectiveness of a multifunctional, AI-enabled agricultural rover that combines real-time pest detection, species-specific ultrasonic repulsion, and moisture-aware precision irrigation. Compared to conventional pesticide application—which introduces ecological toxicity and bioaccumulation risks [16]—our system offers a chemical-free, targeted approach with no collateral damage to plants or beneficial insects.

The integration of TinyML vision and pest-frequency mapping allows dynamic ultrasonic actuation, reducing redundant power use and improving behavioral deterrence latency. Most pests exhibited observable avoidance behavior within 3–5 seconds of exposure, aligning with reports on frequency-specific neural disruptions in arthropods [11, 16, 20]. The peristaltic pump subsystem further demonstrated improved water conservation—up to 43% savings compared to conventional drip lines—by ensuring root-zone precision and eliminating overspray, consistent with findings in [18, 21]. However, several limitations were observed**Lighting Variability** where ESP32-CAM image quality dropped in low-light or shaded conditions, reducing classification accuracy. This may be mitigated by integrating IR imaging or thermal modules [22].**Occlusion and Motion Blur:** Insects obscured by foliage or in rapid motion were occasionally misclassified. Future versions may benefit from temporal vision stacks or lightweight YOLO models [23].**Frequency Adaptation:** The current system uses a static lookup table. Adaptive feedback using motion sensors could dynamically retune ultrasonic output based on repulsion success.

Overall, the system balances performance, sustainability, and affordability, making it a practical tool for small- and mid-scale farms in resource-constrained environments.

VI. Conclusion and Future Work

This paper presented a low-cost, solar-powered, AI-enabled agricultural rover designed to autonomously perform two critical farming functions: ultrasonic pest deterrence and smart irrigation. The system integrates an ESP32-CAM-based TinyML vision for real-time pest classification along with piezoelectric transducers with power-boost drivers for targeted frequency emission and moisture-triggered peristaltic irrigation to reduce water usage and, at last, a dual-battery solar energy system for extended, off-grid operation.

Field experiments demonstrated high pest detection accuracy, species-specific ultrasonic deterrence, and notable water savings, all in a mobile form factor designed for accessibility and scalability.

A. Future Enhancements

In future versions, the system will be upgraded by plant symptom-disease detection using spectral and infrared imaging with CNNs[22]. Irrigation will be scheduled automatically by AI-based soil models and evapotranspiration. This will aid in the efficient use of water and optimization of yield, as in[24]. The development of mesh-networking protocols for multi-rover collaboration [10, 25] is the final step that will enable multiple rovers and UAVs to share duties and expand their operational coverage area, making their operations more scalable and autonomous.

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