



# Optimizing Synergistic Combinations of Adaptive IoT-based Animal Repellent Systems for Sustainable Agriculture in Rajasthan, India

Niloofar Abed<sup>1</sup>, Ramu Murugan<sup>2</sup>, Sudheesh Manalil<sup>3</sup>

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## ABSTRACT

**Background:** Protecting crops from various threats, including vermin, pests, animals and rodents, is essential for sustaining agriculture. In India, especially in regions like Rajasthan, animal attacks result in significant crop losses, up to 40%. This section underscores the importance of safeguarding crops against these threats.

**Methods:** According to our sustainable agriculture assessment and cognition of the primary issue of the community that was conducted across multiple rural sites within the Sawai Madhupur district of Rajasthan from 2020 to 2023. This paper employs a comparative method to conduct a comprehensive review of animal-repellent systems, along with delving into interdisciplinary research in related fields to identify key factors influencing their effectiveness and proposes a novel holistic farm protection solution system.

**Result:** The proposed system offers robust crop protection while aiding environmental conservation and preserving local wildlife in Rajasthan, India. This paper underscores the importance of adopting IoT-based technologies for sustainable agriculture. It is a valuable resource for researchers, agronomists and various agriculture stakeholders to implement these advancements. This system holds promise for enhancing crop security, minimizing resource waste and ensuring food chain stability for generations to come.

**Key words:** Animal detection, Animal replant system, Crop protection, IoT, SDG, Solar.

## INTRODUCTION

The Indian agricultural sector, which engages around 58% of the population, with over 70% residing in rural areas (Kapur *et al.*, 2020), contributes significantly to the national economy, accounting for 38% of the Indian Gross Domestic Product (GDP). However, this sector is highly vulnerable to the unpredictability of monsoons and rainy seasons (Yusman *et al.*, 2018). In the fiscal year 2019-2020, the gross value added (GVA) of agriculture was 17.8% (Department of Agriculture *et al.*, 2021). A critical issue in Indian agriculture is crop losses due to animal, insect and rodent attacks, with an average of 36% of agricultural products falling prey to wild animals, particularly in farms near forests (Rao *et al.*, 2015). Climate change further compounds these challenges, jeopardizing the natural resources available to farmers. Protecting agricultural products is crucial, not only for the financial interests of farmers but also for sustaining the human-animal nutrition cycle. Traditional methods like scarecrows, pesticides and mechanical traps have drawbacks, demanding substantial labor, posing risks to the ecosystem and potentially causing severe environmental repercussions, including water and soil contamination. In response, interdisciplinary solutions rooted in biological research have emerged as effective alternatives, aligning with national initiatives such as the "Green India" Program and promoting sustainable agriculture and habitat practices (Angom *et al.*, 2021). Researchers have explored sensory mechanisms, including repulsive odors stimulating the olfactory senses of rodents (Schlötelburg *et al.*, 2019) and

<sup>1</sup>Amrita School for Sustainable Futures, Amrita Vishwa Vidyapeetham, Amritapuri-690 525, Kerala, India.

<sup>2</sup>Department of Mechanical Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Coimbatore-641 112, Tamil Nadu, India.

<sup>3</sup>Amrita School of Agricultural Sciences, Amrita Vishwa Vidyapeetham, Coimbatore-642 109, Tamil Nadu, India.

**Corresponding Author:** Ramu Murugan, Department of Mechanical Engineering, Amrita School of Engineering Amrita Vishwa Vidyapeetham, Coimbatore-641 112, Tamil Nadu, India.  
Email: m\_ramu@cb.amrita.edu

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sound-based approaches capitalizing on pests' and rodents' heightened sensitivity (Rashid *et al.*, 2017).

Information and Communication Technology (ICT), particularly IoT-based systems, has revolutionized Indian agriculture, enhancing productivity and environmental protection (Rajput *et al.*, 2021). These systems use optical, thermal, or ultrasonic sensors to detect intruders, with applications ranging from fruit condition detection to facial recognition. However, regional variations in fauna necessitate system optimization for effective operation (Kumar *et al.*, 2019). While current repellent systems

primarily target specific intruder types, there is a growing demand for versatile, fully automatic devices capable of repelling multiple species with high accuracy (Atalla *et al.*, 2023). IoT-based animal repellent systems have gained prominence in sustainable agriculture, offering safe and eco-friendly crop protection solutions, including real-time monitoring and data analytics to optimize performance (Dhanaraju *et al.*, 2022). To create adaptable animal-repellent devices tailored to specific environmental conditions, the development of custom datasets encompassing the unique behaviors of native animals is crucial. This article reviews research across various fields of animal repellents and proposes the primary design of efficient IoT-based devices for repelling agricultural intruders.

## MATERIALS AND METHODS

The research was conducted in Rajasthan from 2020 to 2023, that supervised by Amrita Vishwa Vidyapeetham University. This study analyzes research from 2014 to 2023 on pest and animal-repellent technologies for safeguarding Indian agricultural products. Unlike traditional methods, it considers intruder traits and environmental factors for broader field protection. The repellent system includes four components: 1) Animal Detector and Identifier; 2) Control System and Embedded Board; 3) Repellent Actuators and 4) Power Source, focusing on integration. Innovative solutions are proposed by leveraging achievements from related fields. Object detection studies, especially deep learning algorithms for animal detection, were extensively reviewed. IoT technologies were explored for efficient monitoring and control. The hearing sensitivity of various animal species was considered to influence behavior. Fig 1 illustrates the animal-repellent system's methodology, offering sustainable crop preservation via a quadruple-farm protection mechanism. The systematic approach involves step-by-step evaluations of diverse research findings, resulting in a novel compilation of interconnected components.

## RESULTS AND DISCUSSION

This section independently discusses the findings of each repellent system based on the four divisions outlined in the methodology.

### Animal detector and identifier

Two main detection approaches have emerged from research. The first method involves a single detector activating a controller or actuator upon animal detection, typically using ultrasonic, infrared, or resistance sensors. The second method uses sensors to trigger central components, such as activating an identification system camera for subsequent image processing. Within deep learning research on object detection, two main architectural categories were identified: one-stage and two-stage algorithms. The one-stage category includes well-known members like YOLO (You Only Look Once), Single Shot Detector (SSD), Detect Net and Squeeze Det. The two-stage

category encompasses Region-based Convolutional Neural Network (R-CNN), Faster R-CNN, Feature Pyramid Network (FPN) and Region-based Fully Convolutional Network (R-FCN) (Du *et al.*, 2020). One-stage detectors prioritize high inference speeds, while two-stage detectors excel in localization and recognition accuracy. The investigation explored standard algorithms and descriptors widely recognized in machine learning and computer vision, such as Histogram of Oriented Gradients (HOG), Scale-Invariant Feature Transform (SIFT), Speeded Up Robust Features (SURF) and Oriented FAST and Rotated BRIEF (ORB), for object identification. The choice of a specific approach depends on the research objectives, conditions and characteristics of the study subject. Research findings underscore the effectiveness of the YOLO architecture for real-time animal detection, particularly in scenarios where animals are not small or densely embedded in the background (Abed and Murugan, 2023). Various studies employed resistance sensors, passive infrared (PIR) sensors and ultrasonic sensors for detection purposes. For example, resistance sensors combined with fencing wire detected animal presence by closing an open circuit upon contact (Deshpande, 2016). PIR sensors detected infrared radiation emitted by external objects, successfully identifying various objects using an HC-SR501 sensor (Priyadarshini *et al.*, 2015). Ultrasonic sensors enabled distance-based detection, triggering cameras when animals approached within 3 meters of the farm. After processing images with ORB and MATLAB, it was easier to identify specific animals based on their unique features, with an impressive 82.5% success rate (Sharma *et al.*, 2017). Similarly, other studies employed the HARR cascade classifier descriptor, resulting in a detection accuracy of 78.1% (Sharma and Shah, 2017). Motion detection via ultrasonic sensors was enhanced with GPS technology, enabling real-time location tracking of animals through IoT and the Ubidots application (Manoharan *et al.*, 2020). In some instances, PIR sensors were coupled with cameras to detect motion, capture still images and record videos, providing immediate notifications (Bavane *et al.*, 2018; Pooja and Bagali, 2016). To facilitate video uploads to cloud platforms like Dropbox, Bash scripting was employed in certain cases, ensuring data persistence and accessibility. Additionally, the integration of RFID labels helped distinguish between authorized and unauthorized users, enhancing security (Ross *et al.*, 2020). Nevertheless, the system exhibited misclassifications, raising concerns about its practical efficiency in dynamic environments. While fuzzy logic and convolutional neural networks achieved high accuracy in animal identification, they rely on computer system support or cloud storage, which may not be universally accessible (Mohammed and Hussain, 2021).

### Control system and embedded board

The control system serves as the brain of the setup, overseeing the interaction of devices and sensors for seamless integration of data collection, processing and communication, enabling real-time monitoring and control.

Versatile microcontroller units (MCUs) like Raspberry Pi, Arduino boards and ESP32 are often used as central control hubs, facilitating integration with various sensors and cameras. Communication between components occurs through various means, including GSM modems operating within a 2 G signal, using SIMCOM SIM300 SIM cards for message transmission and remote object management (Deshpande, 2016; Rekha *et al.*, 2017a). A Tri-band GSM/GPRS modem is commonly employed, with default frequencies set at EGSM 900 MHz and DCS 1800 MHz. Researchers have developed Android applications to collect real-time data from the farm, enhancing the precision of Wireless Sensor Network (WSN) systems for evaluating sensor deployment requirements (Rekha *et al.*, 2017b). The Raspberry Pi board has played a crucial role in centralizing system components, providing automatic notifications to farmers *via* SIM900A modules and employing advanced image and video detection algorithms to distinguish between human and animal intruders (Bavane *et al.*, 2018; Pooja and Bagali, 2016). Furthermore, certain designs have been executed with a broader integration of sensors to enhance the effectiveness of smart farm management (Durga *et al.*, 2017). Fig 2 and 3 visually represent the block diagram

encompassing the sample systems, illustrating different design connections and components.

### Repellent actuators

Repellent systems typically incorporate one or more of the following elements to deter intruders: I. Sonic Buzzer; II. Ultrasonic Buzzer; III. Flashlight; IV. Odor spray; V. Firecracker; VI. Smoker; VII. Manual. The efficacy of hearing-based mechanisms in repellents hinges on their design and calibration within the auditory range. Auditory perception is influenced by the spectrum of unpleasant frequencies, which varies depending on the biological characteristics of each organism. Humans can perceive frequencies from 20 Hz to 20 kHz, with the hearing threshold set at 0 dB as the reference level. Ultrasound includes sounds beyond 20 kHz, detectable by certain species. Creatures exhibit hearing abilities across the sonic, ultrasonic and infrasonic ranges, with some capable of perceiving sounds in all three domains. Table 1 compiles data from various studies on the hearing ranges of different animals (Heffner *et al.*, 2020a; Heffner *et al.*, 2020b; Jakobsen *et al.*, 2021; Menda *et al.*, 2019; Morley *et al.*, 2014; Trevino *et al.*, 2019).

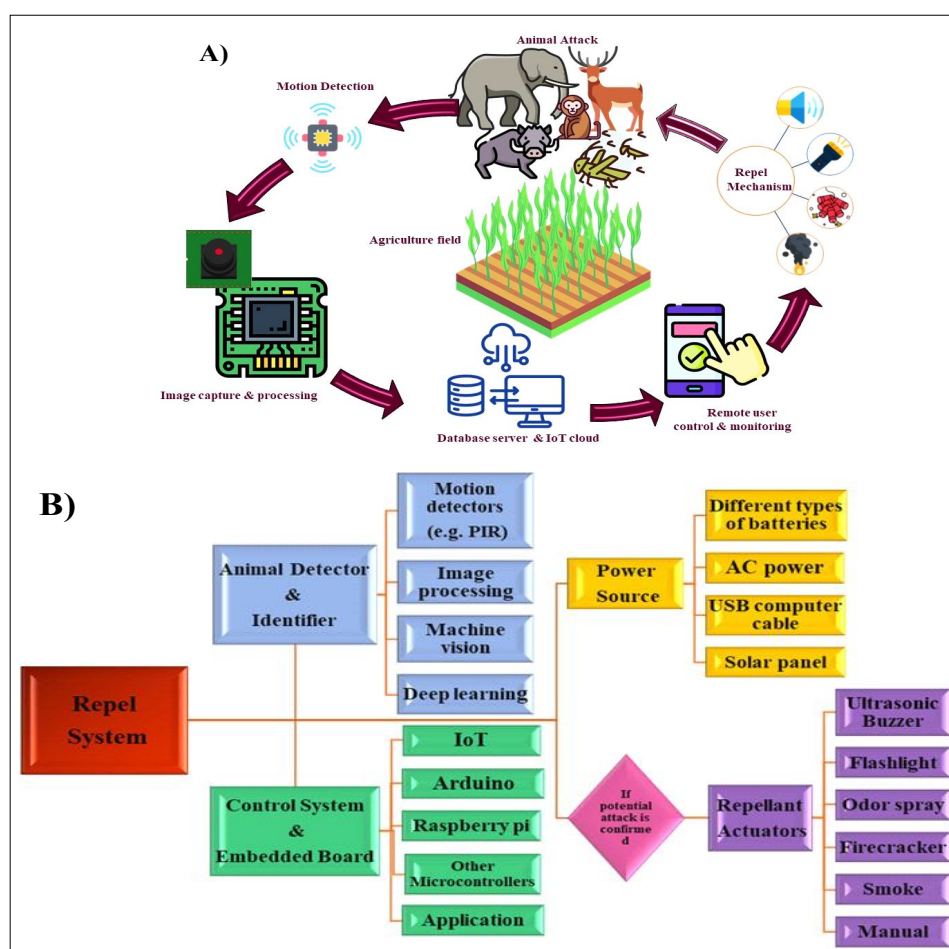


Fig 1: A) Schematic of crop repell system, B) Repel system flowchart.

Repellents that utilize unpleasant frequencies often manipulate the amplitude of sonic and ultrasound waves. For instance, some systems employ a sonic buzzer (Deshpande, 2016; Sharma *et al.*, 2017). Another system, presented by Yusman *et al.* (2018), by emits ultrasound in the 25 to 40 kHz range it successfully repels civets, cows, goats and monkeys. However, its limited detection range of 5 meters falls short of real farm applications. Studies have identified the frequency range of 25 kHz to 65 kHz as effective for repelling most pests, with specific frequencies between 38 kHz and 44 kHz for deterring (Saini *et al.*, 2016). However, a recurring issue with ultrasonic-repellent devices is that pests can adapt to the frequency over time, rendering them ineffective. To address this, ultrasonic pest-repellent devices, as conceived automatically switch frequencies every 30 seconds, preventing pests from adapting to the ultrasonic waves. Emitting modulated frequencies ranging

from 25 kHz to 65 kHz, these devices induce distress and discomfort in pests. However, they necessitate advanced calibration and monitoring, limiting their widespread applicability (Nair *et al.*, 2017). An alternative approach to repelling rodents involves the use of scents and plant products to stimulate their olfactory sense instead of rodenticides, offering a different means of repelling pests. Experiments with common voles (*Microtus arvalis*) involved T-maze trials to assess their aversive responses to various odors for repelling these rodents (Schlötelburg *et al.*, 2019).

Certain researchers integrated repellent systems into their designs, combining a buzzer, rotten egg sprays, electronic safe-firecrackers and focused light based on light intensity to deter animals from agricultural areas (Pooja and Bagali, 2016).

### Power supply

Power sources for the devices in the reviewed studies vary based on factors like capacity, portability, indoor/outdoor use and complexity. These power options include: I. Various battery types; II. AC power; III. USB computer cables; IV. Solar panels.

In many cases, these devices rely on DC power, typically under 12 volts. For instance, Rashid *et al.* (2017) utilized a 10-watt solar panel alongside an LM317 voltage regulator to achieve the desired voltage; Fig 4 depicts the scheme of the project.

According to the design model for Ratspay, if four images are captured daily using AA lithium batteries with a capacity of around 3,000 mAh, it can operate for approximately six months. Alternatively, a single rechargeable LiPO cell can be used and recharged every six months for longer usage (Ross *et al.*, 2020). In an alternate setup, power was sourced from either an AC-to-DC converter or a battery, while some systems drew power from a computer *via* a USB cable (Yusman *et al.*, 2018). The system boasts advantages like flexibility in power

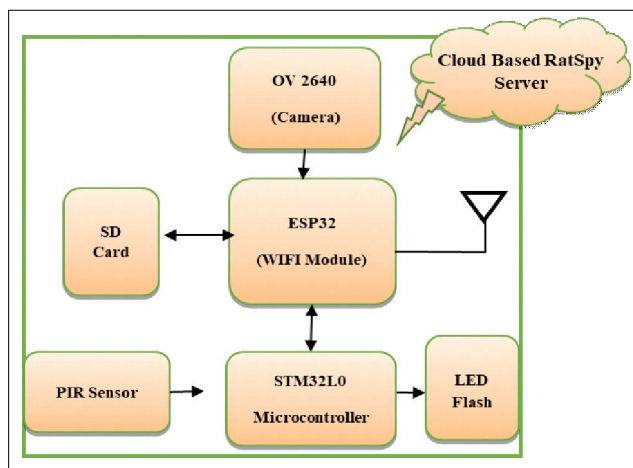


Fig 2: RatSpy system block diagram (Ross *et al.*, 2020).

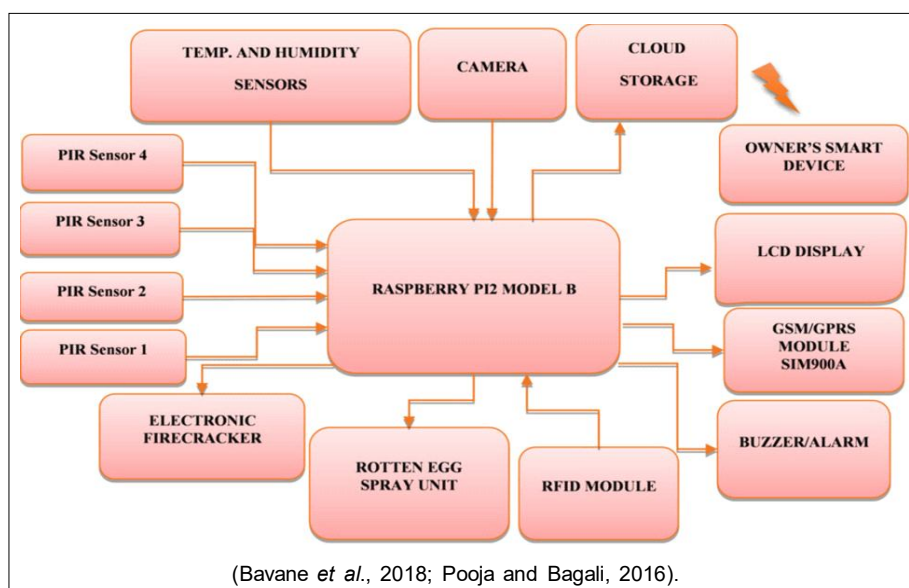


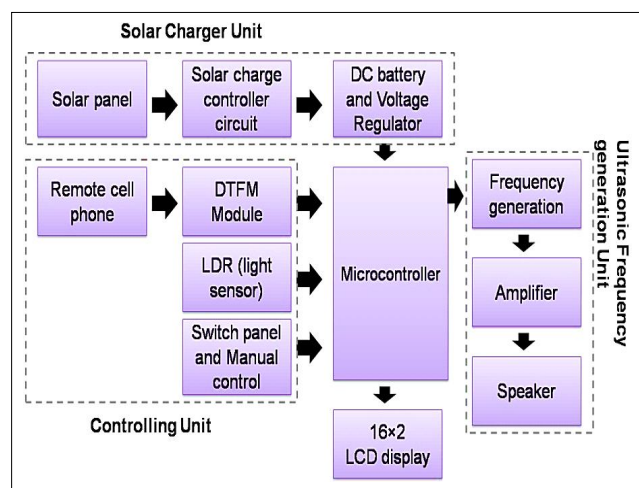
Fig 3: Scheme of repellent system by Raspberry pi core.



sources (Solar, AC mains, or batteries) and continuous monitoring; however, it is not without drawbacks. Challenges include the constant need for battery charging checks and

the complexity of large-scale deployments (Deshpande, 2016). Intelligent, clean energy-powered devices play a vital role in deterring intruders in agricultural fields, aligning with Sustainable Development Goals (SDGs) 7 and 15. Reducing pollution of any sort, especially industrial (Abed *et al.*, 2019) and agricultural, is an inevitable solution to preserve the land and create a platform for survival.

A review of major studies and projects highlights the critical importance of preventing damage from trespassing animals, driving investigations in various fields and utilizing diverse techniques. Numerous studies have focused on modifying and enhancing specific components of repellent devices, yielding valuable results. Additionally, unrelated research has provided constructive solutions to enhance existing designs. While most laboratory studies and prototypes have centered around pests or rodents, there is a scarcity of applied research on a farm scale. In summary, Table 2 provides a comparative overview of findings from distinct articles. Equipment selection for projects depends on factors such as invasive species, plant characteristics, environmental conditions, device cost, sensitivity to protection and coverage area.



**Fig 4:** The Solar-powered smart ultrasonic insect repellent as presented by Rashid *et al.* (2017).

**Table 1:** Frequency range for different species.

| Species          | Approximate frequency range (HZ) | Species                                   | Approximate frequency range (HZ) |
|------------------|----------------------------------|-------------------------------------------|----------------------------------|
| Monkey           | 34.8-45,000                      | Owl                                       | 200-12,000                       |
| Elephant         | 16-12,000                        | Chinchilla                                | 50-33,000                        |
| Blue bull        | 33-50,000                        | Raccoon                                   | 100-40,000                       |
| Cow              | 23-35,000                        | Ferret                                    | 16-44,000                        |
| Dog              | 67-45,000                        | Tree frog                                 | 50-4,000                         |
| Cat              | 45-64,000                        | Canary                                    | 250-8,000                        |
| Horse            | 55-33,500                        | Parakeet                                  | 200-8,500                        |
| Bat              | 2,000-110,000                    | Cockatiel                                 | 250-8,000                        |
| Japanese Macaque | 28-37,000                        | Hedgehog                                  | 250-45,000                       |
| Guinea Pig       | 54-50,000                        | Peacock                                   | 29-7,500                         |
| Kangaroo         | 50-62,000                        | Porpoise                                  | 75-150,000                       |
| Squirrel         | 113-49,000                       | Goldfish                                  | 20-3,000                         |
| Rabbit           | 360-42,000                       | Catfish                                   | 50-4,000                         |
| Pig              | 40-40,500                        | Tuna                                      | 50-1,100                         |
| Hamster          | 96-46,500                        | Sea Lion                                  | 200-50,000                       |
| Bullfrog         | 100-3,000                        | Beluga Whale                              | 1,000-123,000                    |
| Rat              | 200-76,000                       | Dolphin                                   | 150-150,000                      |
| Mouse            | 1,000-91,000                     | Orthoptera (Locust, grasshopper, cricket) | 1500-50,000                      |
| Sheep            | 100-30,000                       | Coleoptera (Beetles)                      | 20000-50,000                     |
| Goat             | 78-37,000                        | Neuroptera (Net-winged insects)           | 12,500-50,000                    |
| Pigeon           | Less than 7,000                  | Dictyoptera                               | 10000-50,000                     |
| Chicken          | 125-2,000                        | Hemiptera (True bugs)                     | 1000-24,000                      |
| Gerbil           | 100-60,000                       | Lepidoptera (Butterfly, moths)            | 1000-50,000                      |
| Wild boar        | 42-40,500                        | Diptera (Fly)                             | 100-50,000                       |
| Red Ear Turtle   | 50-1,000                         | Hymenoptera (Sawflies, wasps, ants, bees) | Less than 2,000                  |
| Opossum          | 500-64,000                       | Orthoptera (Locust, grasshopper, cricket) | 1500-50,000                      |
| Civet            | 16-44,000                        | Tiger                                     | 20-60,000                        |
| Honeycomb moth   | 50-300,000                       | Mosquito Aedes Aegypti                    | 150-600                          |

**Table 2:** Comparison system segments in different researches.

| Section                           | Components                   | Details                                                                                                                                                                                                                                                                                                               | Target fields                                          |
|-----------------------------------|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|
| Animal detector and Identifier    | Motion sensors               | Fencing wire as a resistance sensor (Deshpande, 2016);<br>PIR sensor (Bavane <i>et al.</i> , 2018; Kumar <i>et al.</i> , 2019; Pooja and Bagali Mohmad Umair, 2016; Priyadarshini <i>et al.</i> , 2015;<br>Ultrasonic sensor (Manoharan <i>et al.</i> , 2020; Ross <i>et al.</i> , 2020; Sharma <i>et al.</i> , 2017) | Unsustainable<br>Indoor<br>Out-door                    |
|                                   | Camera and imageprocessing   | Camera (Bavane <i>et al.</i> , 2018; Pooja and Bagali Mohmad Umair, 2016; Sharma <i>et al.</i> , 2017; S. U. Sharma and Shah, 2017)                                                                                                                                                                                   |                                                        |
|                                   | Raspberry pi                 | Raspberry Pi2 Model B (Bavane <i>et al.</i> , 2018; Pooja and Bagali Mohmad Umair, 2016)                                                                                                                                                                                                                              | Complex tasks                                          |
|                                   | Arduino                      | Arduino Uno (Saini <i>et al.</i> , 2016; Sharma <i>et al.</i> , 2017; Yusman <i>et al.</i> , 2018)                                                                                                                                                                                                                    |                                                        |
|                                   | Other MCUs                   | STM32L0 and ESP32 (Ross <i>et al.</i> , 2020)                                                                                                                                                                                                                                                                         | Medium level project                                   |
| Control system and embedded board | IoT                          | DTMF and MT8870 and GMS mobile (Rashid <i>et al.</i> , 2017)<br>IoT (Atalla <i>et al.</i> , 2023; Manoharan <i>et al.</i> , 2020; Rekha <i>et al.</i> , 2017; Ross <i>et al.</i> , 2020)                                                                                                                              |                                                        |
|                                   | Sonic buzzer                 | Sonic buzzer (Deshpande, 2016; Sharma <i>et al.</i> , 2017)                                                                                                                                                                                                                                                           | Animal                                                 |
|                                   | Ultrasonic buzzer            | Variable frequency system (Nair <i>et al.</i> , 2017; Rashid <i>et al.</i> , 2017)<br>Fixed frequency (Saini <i>et al.</i> , 2016)                                                                                                                                                                                    | Insect (mosquito) Animal<br>(Monkey, Cow, Goat, Civet) |
|                                   | Flashlight                   | Stable range between 25 kh-40 kh (Yusman <i>et al.</i> , 2018)                                                                                                                                                                                                                                                        |                                                        |
|                                   | Odor function                | Flashlight (Deshpande, 2016)                                                                                                                                                                                                                                                                                          | Animal                                                 |
| Repellent actuators               | Firecracker                  | Rotten egg (Pooja and Bagali Mohmad Umair, 2016) carrot seed oil, black pepper oil, spruce needle oil, benzaldehyde (Schlötelburg <i>et al.</i> , 2019)<br>Electronic firecracker Safe fire crackers just for making harsh sound (Bavane <i>et al.</i> , 2018; Pooja and Bagali Mohmad Umair, 2016)                   | Animal (Wild boar) Rodent                              |
|                                   | Manual                       | Manual actuator (Ross <i>et al.</i> , 2020)                                                                                                                                                                                                                                                                           | Animal (Elephant)                                      |
|                                   | Different types of batteries | Lead acid battery 12v 4.5ah (Saini <i>et al.</i> , 2016)<br>Lipo cell 3,000 mAh(Ross <i>et al.</i> , 2020)                                                                                                                                                                                                            | Rodent, spider                                         |
|                                   | AC power                     | DC battery rechargeable (Rashid <i>et al.</i> , 2017)<br>AC and transformed to DC 12V -9V (Nair <i>et al.</i> , 2017) AC (Deshpande, 2016)                                                                                                                                                                            |                                                        |
|                                   | USBcharging Solar panel      | USB cable of computer (Yusman <i>et al.</i> , 2018)<br>Solar panel 10 Watt (Rashid <i>et al.</i> , 2017; Saini <i>et al.</i> , 2016)                                                                                                                                                                                  | Prototype<br>Exposure to adequate solar radiation      |

**Table 3:** Proposed combination of animal repellent system.

| Section             | Components                                  | Remark                                                                    |
|---------------------|---------------------------------------------|---------------------------------------------------------------------------|
| Detection           | Detection motion: Ultra sonic sensor        | Adaptive by warm outdoor condition                                        |
|                     | Image processing Identifier algorithm: YOLO | A fast and accurate deep learning architecture                            |
| Control             | Raspberry pi                                | Highly capable to support several sensors, actuators and image processing |
|                     | IoT                                         | Enhancing the monitoring and managing                                     |
|                     | Sonic buzzer                                | Big and medium animals                                                    |
|                     | Ultrasonic buzzer                           | Small rodent and insects                                                  |
|                     | Flashlight                                  | Big and medium animals                                                    |
| Repellent actuators | Odor spray (Rotten egg)                     | Medium animals                                                            |
|                     | Safe fire cracker                           | Big and medium animals                                                    |
|                     | Smoker                                      | Big and medium animals                                                    |
|                     | Shaker                                      | Big and medium animals                                                    |
| Power supply        | Solar panel                                 | Appropriate sun rays and clean resource                                   |

This paper explores strategies for repelling unwanted animals from farms, emphasizing Rajasthan's unique farming conditions. Solar energy, batteries and direct current are essential power sources, with solar energy being practical in sunny regions, eliminating the need for frequent battery replacement. Arduino and Raspberry Pi boards are prominent choices for control segmentation. Arduino simplifies sensor interfacing, running on battery power with onboard storage, while Raspberry Pi, resembling a mini-computer, presents complexities when battery-powered and relies on SD card storage. Intelligent security technology aims to reduce human intervention while requiring human oversight. IoT-enabled systems facilitate remote device control and monitoring, offering insights into farm conditions and invasive species. This device aims to enhance crop protection, aligning with SDG indicator 2.4.1. To foster sustainable agriculture and resilience engineering, designing intelligent devices utilizing environmentally friendly renewable energy sources for intruder control is essential. Table 3 provides a device configuration for sustainable crop protection in Rajasthan, based on insights and specific requirements.

## CONCLUSION

In conclusion, this article introduces a smart crop protection system designed not only to protect crops but also to promote sustainable agriculture, ultimately benefiting farmers in various crop and horticultural practices. This proposed system has the potential to significantly reduce pesticide usage, mitigate harmful agricultural practices and ensure a safer food supply chain. Its adaptability to diverse agricultural scenarios enhances its effectiveness and its potential for further expansion as a remote intelligent farm management mechanism, incorporating deep learning and the Internet of Things, positions it as a valuable tool for optimizing soil, irrigation and livestock management across diverse regions.

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## Conflict of interest

There is no conflict of interest for this study.

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