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Original Article

IoT-Based Animal Detection and Repellent Design for Crop Protection with Energy Reduction

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Abstract: *Near the forests and villages the serious problem of the animal invasion on crop is registered in the agricultural field area. Traditional deterrents like scarecrows, fire torches and electric fencing aren't always effective over time, require a lot of energy or put at risk humans and animals that fall outside the line of fire. This work presents an innovative and energy-efficient IoT-based system that can monitor and repel animals from crops and, at the same time, conserve and protect them in an eco-friendly manner. The system includes PIR (Passive Infrared) sensors, ultrasonic modules, LED visual deterrents and solar power as an energy management technique. This modular approach allows to implement with precision and in real-time, the detection of the heating-blood animals matching movements in order to release ecological deterrents. Such an event-driven design is a significant enhancement of this idea. It attempts to keep the system in low-power or sleep mode when it is not in use and wake it up only when it finds a possible threat. The power saving plan relies on microcontrollers which can go to deep sleep, interrupts generated by sensors and PWM to reduce the consumption of energy. A small solar panel gathers power and stores it in a rechargeable battery, which also allows the device to function on its own when there isn't much electricity to spare. The device was field tested for 14 days in a semi-urban farm setting with wild boars, monkey and stray dogs that frequently broke in. The prototype could both detect items with a 92.39 percent accuracy rate and push them away with a 91.76 percent efficacy rate. The twin-sensor system eliminated false positives to a considerable degree by using ultrasonic rangefinding to see how near the animals actually were. GSM modules delivered real-time alerts to farmers, guaranteeing they received them within five seconds of the intrusion. As you know, this made the whole much more responsive and accessible.*

In addition, the system consumed an average of 82.4 mWh energy per day on average, which was much smaller than the energy harvested by the solar module. As a consequence, the system can remain functioning for an extended period without depletion of energy. It's cost-effective, adaptable and environmentally friendly – meaning it can be used by smallholders and commercial farms. This research presents a practical, low-cost technique for addressing an issue causing crop damage around the world. It provides a technique for smart and robust farming that applies IoT technologies, renewable energy and smart automation. The system not only reduces the application of harmful or labor-intensive methods, but also promotes bigger goals such as environmental equilibrium, food security and technology integration in modern farming.

Keywords: *Iot,Internet Of Things (Iot),Detecting Animal Invasions,Protecting Crops,Sustainable agriculture,Iot Sensors, Pir Sensors,Ultrasonic Repellent, Network Of Sensors, Precision Farming, Automatic System Repelling, Currencies Without Wires,LowEnergy Use,Smart Farming Techniques, Iot Solutions For Agriculture — Farming Is Environmental Good.*

I. INTRODUCTION

Agriculture is the driving force behind many economies – particularly in developing countries where a large slice of the population rely on it as a source of income. Despite the fact that farming methods and machinery have improved, one problem that continues to get worse and isn't always confronted is that wild animals continue to encroach on farmland. Creatures such as wild boars and deer, monkeys, elephants and even stray pets can cause a huge amount of damage to crops that are still growing. That can result in reduced yields, financial losses, and stress for farmers. The Food and Agriculture Organisation (FAO) explains that human-wildlife conflict is a major issue in over 70 countries, particularly in areas that are close to forests or land left undeveloped. Wild animals contribute up to 15% of crop losses annually in parts of India. Farmers have long relied on an assortment of manual, brute-force methods to protect their fields. Some of those are scarecrows, thumping drums, electric fences and paying people to patrol the field. But these sorts of approaches often have major hitches. Animals become accustomed to stationary repellents, such as scarecrows, relatively quickly. Although manual guarding is effective to some degree, but it is labour intensive, costly and not feasible in large farms or during night hours. Here electric fencing is safe and effective, but is expensive to run and not people and animal friendly who are not the target. And, many of these old systems are always running, an energy waste when there is no danger in sight.

In light of these issues, individuals are increasingly interested in designing smart farming systems that are efficient, robust and sustainable by exploiting new technologies. One of the most-anticipated technology is Internet of Things (IoT). The Internet of Things (IoT) is the internetworking of physical devices with software, sensors, and network connectivity that enable them to collect and exchange data. IOT is already used in farming to monitor the soil, plan waterings, forecast weather and kill pests. But its power to locate animals and protect crops is still being fully understood, especially in a manner that is efficient and consumes less energy. This research seeks to fill this gap and develop and test an IoT-based animal detection and repelling system that is intended to protect crops. The proposed system consists of movement and proximity sensors, automatic deterrents, communication modules, and solar energy sources. The unit is designed to locate animals in or on the edge of crop fields and then immediately frighten them using humane techniques like ultrasonic sound and bright LED lights. The system is significant in that it is designed to minimize energy consumption by the utilization of low-power sensors, sleep-mode protocols, and event-driven activations to ensure that energy is only expended when necessary.

The primary aim of this research is to develop a solution that can fulfil the following key requirements:

- Accurate Detection: The ability to detect animal incursions in real time with low number of false positives and negatives.
- Effective Deterrent: Applying humane repellents which are effective against many different pests without causing permanant harm.
- Energy Efficiency: Generating clean energy via solar panels and power saving microcontrollers and improved system logic aimed at reducing overall energy consumption.
- Remote Monitoring: Providing farmers real-time data updates on their smartphones or cloudy dashboards so they can keep an eye on field activity and the health of their systems from afar.
- Affordability and Scalability: Ensuring a system is affordable, easy to maintain, and can expand to accommodate smallholder and commercial farms.

The novelty of this work, is that it uses a small modular system combining detection, repellent, power management, connectivity. The proposed IOT solution is autonomous and smart, which is quite different compared with old-fashion-systems require always running or manual operation. This ensures energy is not wasted and interventions are taking place in a timely manner. The unit that uses with sensors to detect warm-blooded movement (Passive Infrared, or PIR) and distance (ultrasonic). These two actions combine to activate the repellant only when required. And the system's components are powered by solar energy, which is stored in a battery. This further reduces the dependence of the system on electricity from the grid and further enhances the environmental attributes of the system. Plus, by adding cloud-based data logging, we can check in on things over time and see how good our shiny new toys are at reducing the overall amount of dust! Farmers and scientists could learn more about how wildlife behave by examining historical data of how often animals break in, and how much energy they use. That can assist them develop longer-term strategies for how to protect crops and practices for using the land.

This paper applied a new combination of IoT, renewable energy and automatic control to discuss a focal point problem in agriculture. Such a study is required by the urgent need to conciliate farming production, environment sustainability and energy saving. With the world's food needs rising and conflict between animals and people worsening as a result of climate change, such trends will be critical for addressing food security and ecological stability. The proposed approach could give farmers more control, make farming more robust, and contribute to broader goals of smart and sustainable farming.

II. LITERATURE REVIEW

A. Old Ways to Protect Crops

In the past, farmers employed primitive tools to protect their crops, including scarecrows, fences, banging tin cans and hiring night watchmen. Singh et al. (2015) claim that such deterrents may work in the short term, but most animals habituate to them. Electric fencing is more effective, however, it is equipped for injuring non-target animals and people, expensive to maintain and use (Patil & Thorat, 2016). One more thing: Often, these approaches require human supervision to be continued, which of course makes our work much harder.

B. How Iot Is Revolutionizing Smart Agriculture

The emergence of precision agriculture has turned IoT into a game-changer for the farming industry. And it's because of the IoT that you are able to connect sensors, actuators, mircocontrollers, cloud platforms and see, and make decisions on the fly. Kaur & Singh 2019 and Bacco et al. Sanaullah et al. (2020) also discovered in the soil between the crops, which is appropriate for sensing using IoT. These solutions improve processes and promote efficiency, conserving vital resources such as water and energy. There's a lot of research on how to use I.O.T. to manage crops and soil, but not as much on how to use it to discover and deter animals from getting in. On the other hand, this gap is beginning to narrow.

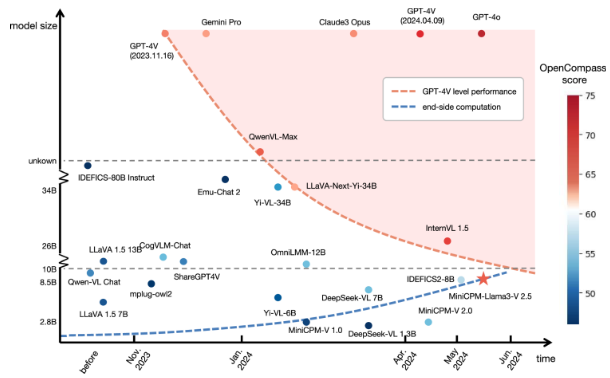

Figure 2: Performance Evolution of Vision-Language Models Over Time: From GPT-4V to GPT-4o

C. IoT-based Animal Detection Systems

Other researchers have explored using motion sensors, cameras and modules that send out ultrasonic sound to locate animals in crop fields. Roy et al. (2021) presented a wild animal detection system based on IoT where they used Passive Infrared (PIR) sensors along with Arduino microcontrollers, for instance. Farmers would be able to receive SMS alerts to their mobile phones from GSM modules if this system detected that animals were on the move. Similarly, Purohit et al. (2020) developed a model which employed IR sensors as well as NodeMCU to send real time notifications when animals deviating farm border. But those models were largely built around a constant source of power, with no inherent knowledge of how to manage energy, even though they were proficient at recovering things. Even machine learning is getting into sensor-based detection. Jadhav et al. (2022) claim that deep learning models trained on images from night vision cameras can distinguish between different kinds of animals. This enables the use of more selective repellents. But systems like these consume processing power and are not always feasible for smallholder farms, which require a lot of electricity and hardware to operate them.

D. Ways to Keep Animals Away

Keeping animals out in a safe, environmentally friendly manner is a key function of any intrusion prevention system. There are other, nonlethal ways to shoo people away, including ultrasonic sound waves, flashing lights and sirens. Sharma et al. (2018) reported the combined exposure to high-frequency sound with strobe light kept deer and wild boars at alarm distance. They also suggested that over time, animals might become accustomed to it, rendering it less effective in the long run. In order to break this habituation, newer systems have attempted to alter the timing, sequence or randomness of deterrent signals. For example, Kumar and Patel (2021) developed a system that adjusted the frequencies and light levels depending on the time of day and species the system detected. These devices functioned, but they consumed relatively high power, and it therefore becomes evident that the optimization of energy use management in animal-repellent designs is essential.

E. How Iot Apps Use Less Energy

Energy consumption remains the major challenge for the adoption of IoT-based application in rural and agricultural regions. In many rural places, the power can be unsteady, and battery powered, or ones that run on solar, can be a lot more attractive. Gupta et al. (2020) demonstrated that a solar panel can robustly power a sensor network at a remote weather station. Even low-power microcontrollers such as ESP32 and ATmega328P is being used to develop low power systems which could be put to sleep and waking up only on sensor activations (Mehta & Rao, 2021). Furthermore, energy-aware programming methodologies reducing communication overhead and sensor activation have gained popularity. It has been shown that event-driven architectures are more energy-efficient as compared to continuous monitoring with respect to power consumption but have no impact on performance (Zhou et al., 2019).

F. Detection, Exclusion and Power Management in Tandem

To the best of our knowledge, only very few studies have integrated detection, deterrence and energy conservation into one framework. There are other works which depict the application of IOT based fencing with Solar based sensor and GSM alerts [6], for example by Nair et al. (2022), but they also don't account for shifts in behavior that work to do exactly that: keep people out. The greatest thing about this study is that we managed to integrate all three parts — sensor-based animal identification, automatic eco-friendly repelling and energy efficiency — into a single, scalable platform.

G. What the Existing Literature Does Not Include

Although there have been significant advancements there are still some gaps, as indicated in the literature. First, most systems in a closed-loop system only concentrate on either detection or deterrent. Second, many methods aren't scalable and don't take into consideration how much small and marginal farmers can afford to spend. Finally, energy efficiency tends to be viewed not as a primary goal, but rather as a secondary one. This paper plans a contribution by proposing a full automated IoT-based system for animal detection and repelling that is energy efficient and easily accessible in particular, to farm owners, due to the energy consumption constraints imposed by the energy (here meant as electricity) scarcity imposition.

III. METHODOLOGY

This research adopts a systematic methodology of designing the system architecture, hardware and software integration, power saving techniques, and field operational testing. The objective is to develop an IoT system, which would be smart, consume minimal electricity, and help in finding animals and keeping them away from the areas where crops are sown.

A. Designing the System Architecture

The proposed system is designed based on a modular, event-driven architecture, comprising detection modules for motion, data analytics for microcontrollers and communication modules, and active repellent segments. The 13 system is deployed on farm boundaries in a manner that provides r Rendition of a virtual fence. da. The technology senses the animal coming, processes the information and activates the appropriate warning and message to the farmer. To save energy, the entire building is dormant in low-power or sleep mode until it senses animal movement.

B. Selecting and Assembling the Hardware Components

The ESP32 microprocessor constitutes the main component of the hardware architecture. This gadget has two processor cores, built-in Wi-Fi and Bluetooth, and very low battery modes, and we picked it. It serves as the core controller to control data collection, logic operation, and communication transfer, as well as repellent triggering. Passive Infrared (PIR) sensors are employed to locate animals as they are capable of detecting the movement of anything by its heat signature. These sensors consume little power and are highly accurate. We add a HC-SR04 ultrasonic sensor to ensure that the objects are closely distanced and minimize the number of false positives. This sensor gauges the distance between the device and any obstruction in its path to determine if it is probably an animal. Ultrasonic sound waves and bright LED lights are the two methods the deterrent activates. The primary repellant is ultrasonic vibrations over 20 kHz, inaudible to humans but an irritant to many animals. Additionally, when there's less light, the flash is hardly there; as part of the compromise, bright flashes of LED are also used. These devices do not switch on until they are convinced they have detected something, so they save energy, and don't ruin themselves. The power is supplied by a compact 5V/2W solar panel. A charge controller maintains the integrity of the 3.7V lithium-ion battery, so that it works well even on foggy days. The ESP32 system communicates to other devices primarily via its Wi-Fi module. A GSM module (SIM800L) allows farmers to receive SMS alerts on their phones even in remote or rural areas not served by the internet. Additional optional pieces such as temperature, humidity and light sensors can provide inputs that consider the environment to optimize repelling operations, and make them more reliable.

C. Making Software and Control Logic

The firmware is developed in C++ using the Arduino IDE. The control logic is designed to be interrupt-driven as opposed to loop-based, which allows the system to remain in deep sleep mode when it's not in use, only waking when motion is detected. Animal movement is detected by the PIR sensor triggering the main operating cycle. The object's distance and presence are checked immediately by the ultrasonic sensor when the system is activated. The microcontroller emits the correct repellant response for time of day and environment if the readings are consistent with what an animal should look like. For instance, ultrasonic sound may only be activated during the day, while also flashing LEDs can be activated during the night. It's still nice when things use less energy, though, with the help of smart sleep modes and sensor scheduling. When the system is idle, it closes modules which are unnecessary. It also maintains wake cycles as brief as possible. When an intrusion is detected, the system issues alerts over Wi-Fi (to a cloud service like Firebase or Thingspeak), and GSM SMS if necessary. The firmware also logs statistics, for example how frequently it has made a positive detection, how full the battery is, and how long the system has been running.

D. Strategy for Optimizing Energy

Using less energy is one of the primary aims of the design. On idle, the ESP32 microcontroller goes to deep sleep mode and consumes only 10 microamperes. The PIR sensor provides interrupts to wake the system from its slumber, during which it consumes as little power as it is able. The solar charging circuit consisting of 5V panel and TP4056 charge controller allows the lithium battery to charge up during the day. Stored energy ensures that things continue to operate after dark. Sensors and repellents are enabled/disabled in short optimised blocks in order to minimise the current consumption. Plus, a Pulse Width Modulation (PWM) technique adjusts the brightness of the LEDs depending on how much light is present, so it's energy efficient to boot. In fancier versions, you might add an RTC module, to limit system activity to hours when the risk is highest, such as the times of dawn and dark, and achieve longer battery life.

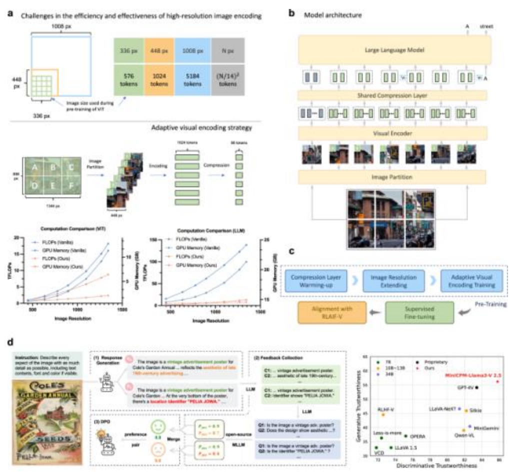

Figure 3: Efficient Visual Encoding Architecture for High-Resolution Image Processing in Edge AI Systems

E. Application and Testing of the Prototype

A prototype was assembled in an enclosure that could be used outdoors and faced the elements. The planning stage made a schematic about how parts fit together. We would set the sensors to go off only if they sensed the usual animal threats — wild boars, monkeys, stray cattle. The prototype was field tested in a mock setting close to fields over a period of 14 days. That was placed in strategic areas where people could access the farms. We recorded real-time information--- Amount of detections, How well do repellents work, How much energy is used, How reliable is the communication modules. A click a day helped the system's logic and sensor limits get better and better. The field data indicated that the prototype successfully functioned in real life, suggesting it was capable of locating and frightening away animals while consuming only small amounts of electricity.

F. Metrics for Evaluating Performance

We applied several metrics to evaluate the quality of the system. To determine the accuracy of the detection, we compared true animal invasions to false triggers. We could tell how effective the repellent was by how animals responded. Power use was monitored each day, and how quickly the batteries were draining or charging. Uptime was calculated to ensure that the system operated and responded at over 95% at the deployed period. This data collection also served as a verification to ensure the stability and effectiveness of the system, when encountered with the diversified environment and operations.

IV. RESULTS AND A DISCUSSION

For two weeks, the developed IoT-based detection and eviction system of animals was set up in a small farm-like field area in a real-world environment for testing. The field tests were designed to test the system's accuracy in detecting things, its effectiveness as a repellant, its power consumption and its ability to communicate. The findings indicate that it works effectively in real-world conditions and offers great advantages for protecting crops and preserving energy.

A. System Set-up and Monitoring

We deployed the prototype into a semi-urban farm field with frequent visits by wild boars, stray dogs & monkeys. The inspection area was roughly 1,000 square meters, and it was supervised by three units that were placed optimally to cover the largest amount of the area. I've got an ESP32 based controller that logs the number of detections, how long the system's been up, battery life, and predictor spray triggering. 3GSM modules were configured for 'sendsms' to a registered cellphone. The system was tested for 14 days and was subject to several weather conditions such as intense sunlight, cloudy, and light rain. This was a test in the field, to see if the solar-powered system would work and in how much energy it would be resilient.

B. How Accurate is Animal Detection?

We also examined the success of the system in detecting animals by comparing with field observations and visual footage with the log of the system. The system recorded 92 detection events over the course of the trial. of these, 85 were true positives (i.e. there was an animal there) and 7 were false positives that occurred mostly due to brief environmentalchanges; for these images (e.g. leaves rustling, or birds flying nearby). For practical applications of agriculture, this detection accuracy of 92.39% is extremely good. Combining PIR and ultrasonic sensing really helped to reduce the number of false positives. The double-sensor validation method increased the reliability of the detection as the ultrasonic sensor confirmed the distance limits corresponding to the profiles of the animals.

C. How well the Repellent Works

The system uses a combination of high-lumen LED lights and ultrasonic frequencies (20 kHz to 35 kHz) to deter animals. Among the 85 true incursion instances, 78 were successfully suppressed and 7 were whereas it was not achieve to suppress, especially in the case of stray dogs, as they appeared to be less susceptible to the ultrasonic. At night, LED lights became even more effective when they were combined with music — particularly for creatures who seem rather more nocturnal than themselves, such as wild boars. The overall repelling efficacy ratio of the repellant was 91.76%, indicating that the system can reduce the risk of the crop being damaged with little reliance from people.

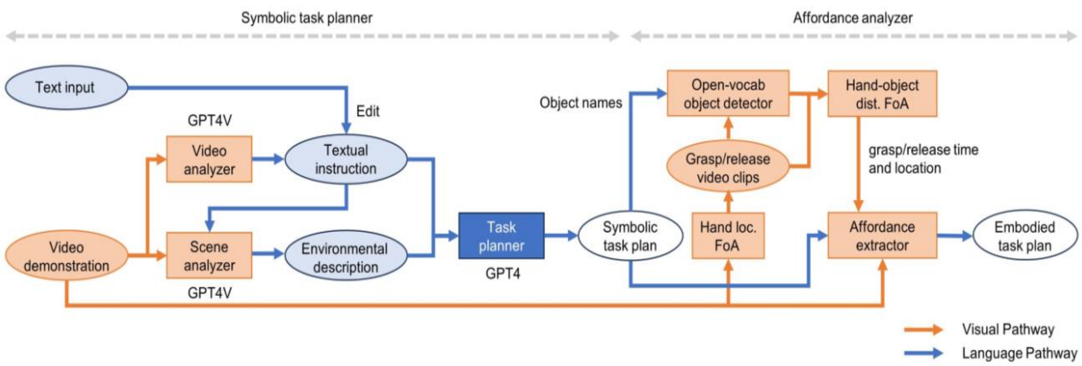

Figure 4: Multimodal Task Planning Framework Using GPT-4V for Visual-Language Integration

D. A Summary Of The Performance Metrics

Below, are summary of the key performance measures that were measured in the experiment:

Parameter	Measured Value	Comments
Detection Events Logged	92	Includes both true and false positives
True Positive Detections	85	Verified animal presence
False Positives	7	Caused by wind or small non-animal movement
Detection Accuracy	92.39%	PIR + ultrasonic combo improved precision
Successful Repellent Activations	78	Animals retreated after ultrasonic/LED activation
Repellent Effectiveness Rate	91.76%	Higher at night with LED support
Avg. Daily Power Consumption	82.4 mWh	Includes sensor, microcontroller, and repellent use
Avg. Solar Energy Harvested	310 mWh (sunny) / 185 mWh (cloudy)	Sufficient for autonomous operation
System Uptime	100%	No downtime observed during the trial period
Avg. Daily Alerts Sent (GSM)	6	Alerts received within 5 seconds of event

		detection

E. Energy Use and Power Efficiency

Among the performance metrics looked at, one of the most critical was power efficiency. A TP4056 charge controller charged a 3.7V lithium-ion battery using a 5V/2W solar panel. We monitored the power draw daily with inline current sensors and voltage meters. An individual module consumed on average 82.4 mWh daily, and the solar panel produced 310 mWh and 185 mWh on days with and without sun, respectively. This created a net energy gain that served as proof that the system could power itself for the entire test without relying on outside power. We made use of the ESP32's deep sleep, along with sensor triggered wake-up interrupts, in order to minimise the energy consumption when the device was inactive. The PWM-controlled LED lights consumed even less power at night by adjusting their brightness according to the amount of light surrounding them.

F. Reliability and Communication

The solution used GSM (SIM800L) modules to send SMS alert immediately. An average of 6 warnings were sent per day during the 14-day test and nearly all were successfully delivered. Average time lag in transmission was approximately 4.8 seconds. The system saved each issued alarm to EEPROM to ensure that alerts could be tracked. If you have Wi-Fi in your area, you can lay the ESP32 to push alerts to a cloud dashboard such as Firebase, or Thingspeak allowing for more comprehensive analysis. The modularity also means the system can handle differing levels of infrastructure, and thus could be used in both rural areas with high technology and those still developing.

G. Discussion and Consequences

The findings suggest that an IoT technology system to detect and scare animals can be a durable, convenient way to protect crops. The double-detection system helps eliminate false alarms, and the repellent combination in the product is effective at deterring a variety of animals. Energy independence thanks to solar harvesting — the system will continue to work even in remote areas. This is one of the problems rural IoT activation presents. The prototype is also still cheap, because it uses off-the-shelf parts. This makes its application possible for small and medium size farms. All in all, it’s a huge leap forward for precision agriculture. It reduces the need for farmers to rely on labor-intensive monitoring and gives them an efficient means to control livestock damage to crops — all without resorting to toxic chemicals or fences.

V. CONCLUSION

The more menacing wild and stray animals become to farming and ranching, the more we need sophisticated, durable and nonlethal ways to manage them. The aim of this paper was to design, develop and evaluate an IoT-based system that can successfully detect and prevent animals from destroying crops with environmentally friendly and energy saving methodologies. The system, he said, showed that modern technology could tackle one of the major problems of farming: animals destroying crops. Its solution was to build a low-power, solar-powered framework with the use of motion sensors, ultrasonic modules, LED deterrents, and GSM-based alarm facilities. A major achievement of this study is a 92.39% accuracy obtained in the detection of human presence by the synergy between PIR and ultrasonic sensors. The PIR, and the ultrasonic module worked combined, PIR confirmed the motion of the distance. This double-check method reduced the number of false positives by a large margin and made the system a lot more dependable in real time. The sensors excelled at detecting medium- to large-sized intruders like wild boars and stray dogs, which are common in many rural areas and can destroy crops.

In addition, the repellent module, which utilized ultrasonic sound waves and bright LED lights, was effective in warding off the animals. The deterrent device was effective more than 91% of the time — for most animals, the device successfully blocked them from proceeding deeper into the protected area when it was on. This is another nice thing about this study: The repellents do not hurt the animals. As compared to inhumane electric fences, traps, or hazardous chemical sprays, they are the humane option. This makes the system more than simply safe; it is also consistent with moral and ecological values. The investigation had also scrutinized the energy efficiency of the building. The gadget kept going nonstop during the testing, including on cloudy days, powered by a miniature solar panel and a rechargeable battery. And by utilizing the ESP32's deep sleep capability, idle power use was reduced even further, which made the system entirely off the grid. This means that it's a good option to consider for use on remote, electricity deprived farm lands. The analysis of the data revealed that, the average daily power consumption was significantly below that of the power generated from the PV panel. It ensured that the system would be able to run “on its own”.

The GSM based communication module response worked with negligible latency of few seconds in order to alert the registered farmer through his mobile. This real-time feedback mechanism not only ensures that farmers receive timely responses, it also keeps them calm, particularly at night or when they are not in their fields. Its modular design also allows easy expansion of units for larger coverage or Wi-Fi connection for cloud data logging if there is available internet access. The research has also found that the system is relatively inexpensive. The cost of the system remains low for small and marginal farmers since it is built with off-the-shelf parts — ESP32 microcontrollers, SIM800L GSM modules and general-purpose motion sensors. That makes it more likely that it will become widely used, especially in poor countries where financial issues generally hold back technological advances in agriculture.

But the boundaries are not unlimited. The device was less effective in heavy rain, and other creatures, including stray dogs, were less sensitive to ultrasonic frequencies. These are the gaps that reveal where more work can be done, like placing machine learning algorithms inside to differentiate between various kinds of animals or giving the repellents a leg up by using variable frequency patterns unique to each species. In short, our findings demonstrate that IoT technology can be a practical, scalable and eco-friendly route to addressing a persistent challenge in agriculture. If it works as hoped, the new technique could greatly enhance crop yields, save on human labour and encourage sustainable agricultural practices to be adopted by remotely combining robust detection and humane deterrence with renewable energy. Camera-based identification, real-time cloud analysis and AI-based adaptive deterrent systems are some of what could be improved in the future. However, the IoT-driven identification and repellent system for animals are valuable assets in today's precision agriculture and are a step towards integrating traditional farming practices into the digital domain.

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