Scopus

Journal of Vibration Engineering

ISSN:1004-4523

Registered

- SCOPUS
- DIGITAL OBJECT IDENTIFIER (DOI)
- GOOGLE SCHOLAR
- IMPACT FACTOR 6.1

Our Website
www.jove.science

IoT Enabled Animal Detection and Adaptive Sound Repellent System for Sustainable Crop Protection

Dr. R. Vasanthi
Assistant Professor
Department of Agricultural Engineering
Kalaignarkarunanidhi Institute of Technology

A. Girinath
Under Graduate student
Department of Agricultural Engineering
Kalaignarkarunanidhi Institute of Technology

M. Madhumitha
Under Graduate student
Department of Agricultural Engineering
Kalaignarkarunanidhi Institute of Technology

S.A. Prithika
Under Graduate student
Department of Agricultural Engineering
Kalaignarkarunanidhi Institute of Technology

***Abstract* - Responsible farmers are constantly faced with significant financial losses through wild animals that are able to easily get introduced into their agricultural fields which can usually be found close to forests and urban landscapes. We have designed an intelligent Sensor-driven Animal Movement Detection and Adaptive Sound Repellent System (STD-MS) to address this concern. The STD-MS utilizes microwave radar sensors that will detect movement in conjunction to a microcontroller which outputs sounds of different frequencies through speakers. The sounds chosen for the animal will be pitch and loudness adjusted specific to the size and/or behavior of the animal, thus mitigating the chance of habituation. The purpose of this project is to develop an IoT based system for animal detection as well as adaptive sound repellent system for environmentally sustainable crop protection. The system will use microwave radar sensors and microcontrollers to detect animal movement in near real-time within the agricultural fields with wireless IoT monitoring and data logging benefits.**

***Keywords*: Smart agriculture, Animal detection, Motion Sensors, Sound repellent, Crop protection.**

I. Introduction

The agricultural industry is the pillar of the world economy and assists with the challenge of increasing food availability, especially to support the growing population. However, farmers regularly face significant challenges as crops are damaged by wild animals such as boar, deer, monkeys and elephants. The consequences can be devastating in terms of yield loss and cost for the farmer, even more so in developing countries. Many of the conventional deterrent methods, including fencing, scarecrows, human guarding and chemical deterrents have limitations either as low efficacy, high cost or environmental impacts. This type of method is clearly not sustainable in the long-term as it either relies heavily on the ongoing input of a human component or is a fixed method of defense. Technology is developing rapidly and with the advancement of IoT (internet of things) new intelligent and automated solutions are emerging as environmentally friendly alternatives that supports agricultural practices. IoT refers to a network of physical devices with sensors, microcontrollers and communications components, these devices can communicate, gather information and be monitored and controlled in real-time. L. Ashok Kumar et al., [4] presented a review paper that looks into the increasing issue of human–animal conflicts in agricultural and forest areas which poses a risk and incurs considerable economic losses. The review suggests an animal incursion warning system based on wireless sensors which provides automatic notification of property owners and forest authorities. The system identifies animal movement via sensors, captures visual images with a camera and employs image processing to perform classification. After classification, use of the GSM module to notify concerned parties via SMS, which allow for rapid response based on the type of incursion.

Smart farming solutions in agriculture which use IoT already have had some success with irrigation management, monitoring soil health, controlling greenhouses, and monitoring yields. However, the concept of smart IoT farming that can protect crops from intrusion by animals is still in its infancy. In this proposed project, we will use an IoT driven Animal Detection and Adaptive Sound Repelling System (ADASRS) for Sustainable Crop Protection (SCP). Zaiqin Zhang [13] have written a paper that points out the importance of body temperature as an important physiological criterion in pig breeding, and its implications for disease diagnosis and health monitoring in pigs. The authors report that the traditional method of using a rectal mercury thermometer is effective but labor intensive, a source of stress for pigs, and would not be applicable for large-scale, welfare-based farms. The innovation will employ a Microwave Radar Sensor (MRS) to measure animal movements around the crop field. MRS are able to provide reliable detection in the dark and fog and have no obstructions by vegetation. In contrast to passive infrared sensors that can vary their detection level depending on the weather. For example, once the animal intrusion has been detected, the ADASRS will turn on the Adaptive Sound Repeller (ASR) unit that produce species -specific repelling sounds located in the microSD memory card. The sounds on memory card have been pre- programmed for the offending animal or group of animals, for example, a tiger roar for a deer or a dog barking for monkeys, to optimize the repelling process.

In an attempt to prevent animals from habituating or adjusting to repeated sounds, the ASR works in adaptive mode making random frequency choices and changing sounds. This way the animal can't be certain or ambiguous, which promotes long-term efficacy. The ASR consists of a Micro Controller Unit (MCU) that receives the sensor inputs to cause sounds and it handles the IoT communications. The following graph explains the Wireless Communication Module (WCM) and how it pushes notifications about intrusion right to farmers cell phone using Mobile Applications or through Cloud Dashboards (CD) for remote observation or data logging. Sabeenian et al. [1] described the standardization of an imaging dataset which would be trained using a Convolution Neural Network (CNN) of images containing monkeys, boars, and elephants, and then saving the trained model so that the parent program can compare the trained images with newly captured test images in real time. The ASR will be able to perform image classification using a Convolutional Neural Networks.

When the ASR detects any of the trained animals among the live captures, it will generate a loud sound from a preinstalled speaker, which, in turn, should scare off the animal. The system is built to operate as sustainably and efficiently as possible, have little power consumption and can be paired with Solar Photovoltaic (PV) panels, allowing for the system to be used at remote, rural spots and completely off-grid. By using renewable energy, the system helps reduce reliance on traditional electrical consumption and will aid each farm in their Sustainable Development Goals (SDG) in delivering greener farming practices. One paper by Agnes et al. [2] briefly addressed the issue of animals intruding and damaging farmland, through their finding, and often damage their crops, and thus, making a good standard of living unreachable. The solution suggested in that paper implements frame differentiation method in OpenCV, which is a Computer Vision Library where it can detect when larger animals travel/move using a motion detection algorithm which detects motion when it compares and differentiates two frames of value, one still - frame and moving-frame, or two moving frames of values.

II. EXPERIMENTAL SETUP DESCRIPTION

The below diagram depicts the functional arrangement and interlinking of elements in the initiative "IoT – Enabled Animal Detection and Adaptive Sound Repellent System for Sustainable crop protection.

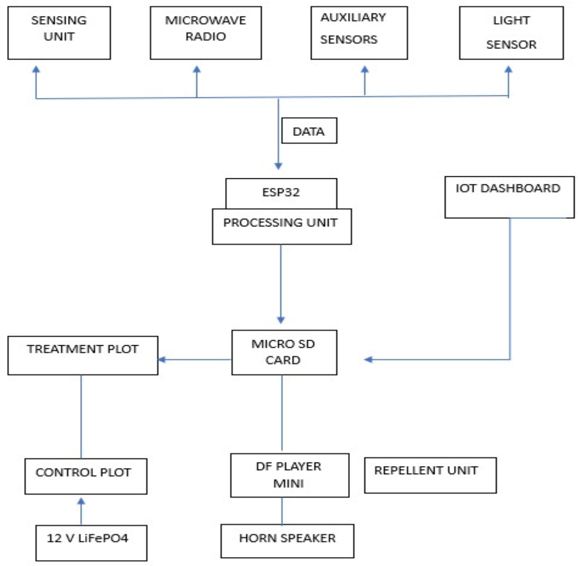

Figure - 1. Experimental Diagram

This product is a microwave radar sensor located on a post it detects the movement, speed and direction of entering animal crossing along the boundary of the field. It is fully functional in all-weather and lighting conditions making it ideal for outdoor use. Additional sensors such as temperature sensors, humidity sensors and light sensors were built into the unit to supply environmental readings. The environmental data allows estimates of the functionality of the system based on varying scenarios, for example, during day/night cycle or weather condition; thereby, providing a degree of confidence at whenever the system is triggered.

The light sensor provides an indication of the day/night cycle to the system to mitigate the creation of deterrent sounds during daytime hours when animal incursions are possibly less frequent. The system accepts the raw data from the sensing component, analyses the data, and resolves whether the repellent device should be actuated or not. The system also works with the IoT Dashboard, providing data to enable remote real-time monitoring and monitoring. Vennan Sibanda et al., [3] recommended a research article which provided possible methods of creating an animal detection system to alert drivers to take preventative actions.

The experiments were designed to show image visibility with an infrared camera with and without infrared lighting to a camera system using an Arduino UNO R3. Calculations determined how many infrared LEDs to attach to the camera. The whole idea is to take a picture of the animal and use the animal system database to bring a similar image. The project included surveying drivers, to find out what they need, and checking on ultrasound frequencies and current warning systems in the literature. To design and simulate the system, that takes picture of animals, find the closest match in the database, and notify, was to use Proteus 8. The end product is a system to help drivers avoid collisions with animals in the day or night time. Provides the user with system information and monitoring, including detection logs, basal animal activity, and sensor status report. It gives the farmer remote access and reassures that they will get prompt notifications about farm activities. Each of the repellent sounds are store on the microSD card in a pre-recorded file format. The DF Player Mini plays these audio files to the speaker when the ESP832 tells it to.

III. Overview of Experimental Setup

The experimental configuration is set up to test the functionality, efficiency and reliability of an IoT – based system that detects animal incursion into agricultural areas and responds with adjustable sound deterrents. The configuration is comprised of hardware including sensors, controllers, audio devices, power supplies, and software including IoT framework, data recording, control algorithms in both lab and environmental settings. The main objectives are to ensure that the system can: Detect animal activity on the edge of crops, Identify or estimate the species of the incursive animal, Trigger species-appropriate deterrent sounds, Monitor - functionality, log data, and ensure sustainability using solar power.

The deployed and tested experimental setup for the "IoT-Enabled Animal Detection and Adaptive Sound Repellent System for Sustainable Crop Protection" was in a public agricultural field.

Reasons for choosing this option are:

1. Frequent animal incursions.

2. Accessibility to install the sensors and observe the system.

3. Constant sunlight to provide power requirement for the solar - driven supply.

4. Real life situations to evaluate against the motion sensing and varying sound deterrent system.

The area was partitioned into zones with sensors on the border of crops and speakers mounted on poles at regular intervals to ensure adequate coverage. The necessary IoT connectivity was to take place, by making the data available to the cloud and allowing for the remote monitoring using a mobile app. Vittorio Pasquali [30] created a journal where he reported a study that created a radar-based, microwave apparatus to automatically monitor the rhythm of locomotor activity of animals in their home cages. The apparatus is based on the Doppler Effect, and can monitor the whole-body movement of as many as 12 animals simultaneously, with minimal or no disturbance of the animals' habitual behaviors.

The sound repelling consisted of the speaker emitting sounds, which were adaptive and changing noises form files stored on the microSD module, startling certain animals every time they entered the field. Aruna Jamdagni [29] published a review article, which stated that RePIDS is a real-time intrusion detection system with a 3-Tier Iterative Feature Selection engine and the Mahalanobis Distance Map to classify the network packets into Normal and Attack packets. It also pre - process data with PCA and use Mahalanobis Distance to identify anomalies in the normal and deploying database packets.

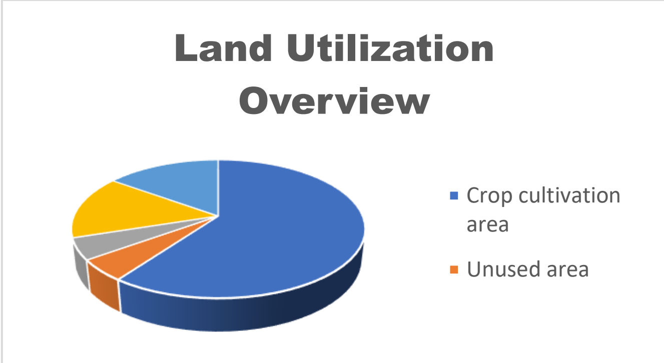

Figure - 2. Pie Chart of Land Utilization Overview.

The pie chart "Site of the Experiment:" presents the enormity (function zones) of the agricultural field of study, examining how it - the pie chart - conveys the avenues given to each of the areas as an - evidence of validating the test location for maximum crop productivity and the efficient placement of the sensors and sound repelling devices. Sixty percent of the pie chart area reflects the crop cultivation zone. The crop cultivation zone is the main area of cultivation, with the predominant crops (paddy, maize as well as cabbages), planted. The context of the project being the protection of the crops from animals dictated that mostly all of the area was cultivated.

The intersection of the speaker coverage zones would give complete sound coverage to scare those animals when detected in the coverage zone. Fifteen percent of the land was the sensor coverage zone, what this means is that this is where the sensors for motion detection cover sensors like high-powered microwave radar and PIR (passive infrared) sensors were located on-site. The motion-detecting sensors covered the areas mostly around the boundaries of the crop field, as they were meant to detect as the animals approach the crops before they enter the main crop. The area of land was large enough to create a coverage area that allowed substantial coverage then very little blind spots allowed coverage to be maximized. Fifteen percent of the land was speaker coverage area. The weatherproof high-powered speakers that were tied into the sound repelling system installed on the site, were spaced out so that there was not any part of the cultivation field open for animal intrusion, that the sound coverage overlap zones would ensure.

IV. Laboratory Setup

Establishing lab setup for an IoT-enabled Animal Detection and Adaptive Sound Repellent System is a major step forward in realizing a smart, sustainable crop protection system. The following is a comprehensive outline for the steps taken for the setup in a lab environment for the purpose of engineering, which incorporates all hardware, software, and architecture.

Develop a prototype in a laboratory - controlled system that represents:

1. Detection of wildlife (i.e., wild boar, monkeys, birds) with sensors and/or camera vision.
2. Triggering an adaptive sound repellent (ultrasonic or predator calls or noise bursts)
3. Monitoring and data logging with visibility through an IoT dashboard.

Within the laboratory setup of the IoT-integrated animal detection and adaptive sound repellent system, the presence of animals is simulated through controlled manipulations to evaluate sensor response and the system's functionality. Animal presence motion is simulated by passing objects, such as cardboard cutouts or toy animals, through the sensor's field of view using a motorized rail, or the person running the tests can manually pass the target through the field of view.

In a laboratory setup that is based on a camera, the same object manipulation can be done by providing either a video or printed imaging of the animal species to the system to reflect the sampling of the sensors triggered by animal intrusion. Christian Manteuffel [30] put forth a journal proposing that radar sensors present a non-invasive option to monitor animal activity thereby avoiding the issues associated with optical sensors or sensors attached to animals. In this study, participants investigated the use of radar sensors by monitoring general activity and monitoring increases in activity prior to parturition in sows, utilizing simple classifiers based on daily changes in activity level.

The success of classifications based on daily changes in activity level demonstrated 92% sensitivity and 80% specificity, which are comparable to accelerometers and light barriers. Different environments yield no negative effects on surveillance from inclement environmental conditions. The system will simulate the expected intrusion of the animals into IoT sound repellent system, which is done by capturing the video/print or cardboard cutouts as they progress through sensor view or paths. This will initiate the detection system which will capture the data and control the sound repellent component of the system. The sound format could be predator calls, ultrasonic tones, or any other sound method chosen by the researcher.

The different sounds could be assigned based on the type of detected animal, frequency of detection, etc. The open-ended system functionality can be exercised, and the adaptive capabilities tested based on the sound format. Each detection and sound component response will be logged and shared to an IoT dashboard for monitoring and analytical follow-up. The simulation technique captures both animal presence detection and adaptive sound repelling capabilities in a safe, controlled, and repeatable way in a laboratory environment.

Testing the entire system in a laboratory environment will enable the user /researcher to ensure the system's reliability prior to use in a designated field environment. The laboratory exercise also enables the user / researcher to adjust the sensors' detection sensitivity, and identify sound deterrents with more accuracy while avoiding live animals.

STEP 1: SIMULATE ANIMAL INTRUSION

In a lab environment, an animal intrusion event is simulated with an object, or heat source added to trigger a sensor or sensors. When simulating animal intrusion using motion detection sensors, a cardboard cut - out is physically moved in front of the PIR or ultrasonic sensor. A warm object can be introduced to test out the thermal sensors to mimic the body heat of an animal.

For the vision and camera systems – printed images of animals, and videos of animals (actual animals) are displayed to the camera module. The system when detecting and object, and processes the signal to trigger the adaptive sound repellent. Each animal intrusion event is logged, and the result will be sent IoT dashboard for later monitoring and review.

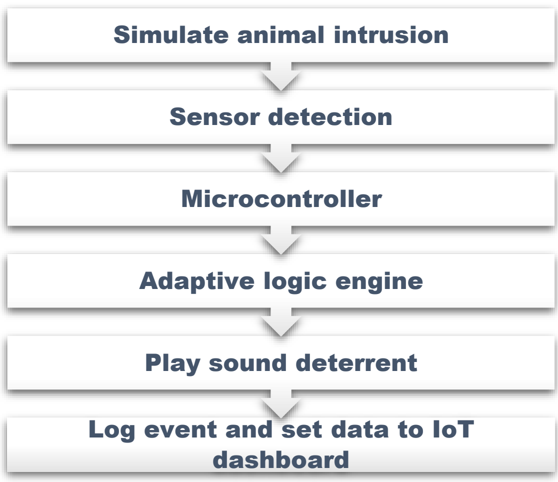

Figure - 3. Flow chart of laboratory setup of the experiment.

Trigger detection is a crucial process in the animal detection and sound repellent system utilizing IoT technology. Trigger detection begins with the system monitoring environment triggered by sensors (i.e. PIR motion detectors, ultrasonic sensors, thermal cameras, and image recognition modules), the system will monitor environment until one of the monitoring sensors detects animal-like motion signaling heat within its trigger defined range. As soon as the sensor detects an animal-like motion or heat signature detected in the defined range, it will communicate & send a signal to the edge device.

STEP 2: TRIGGER DETECTION

Once a signal is detected, the edge device will process the input and determine if the event indicates a valid intrusion. If this involved a camera system, at a minimum, still image or video frames would have been examined through machine learning models to verify a specific type of animal. At this stage, the sound repellent module, which is drug like in its actions, would execute a response. Depending on the type of animal, frequency of previous detections or time of day, a sound deterrent (dog barking, distress call of a bird or ultrasonic tone) would be executed. At the same time event data (date/time, location and sound used) would be locally recorded and transmitted via either Wi-Fi or MQTT to the IoT dashboard for on-going real-time monitoring or historical / longitudinal data analysis. The monitoring system would reset its state back to the standby state, again waiting for the next detection processing event.

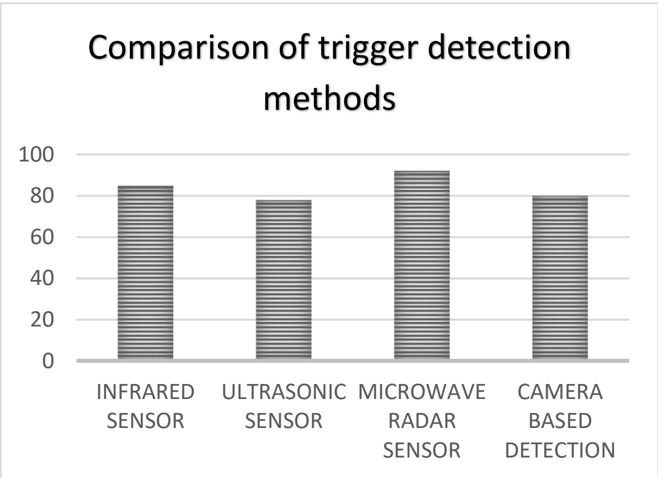

Figure - 4. Graph of comparison of trigger detection methods.

The various trigger detection methods checked off include Infrared Sensor, Ultrasonic Sensor, Microwave Radar Sensor, and Camera-based Detection. The Blue bars highlighting the trigger detection accuracy against an ideal example by putting a % to it and the orange line representing the response time in seconds has allowed us to demonstrate the best method Microwave Radar Sensor (92% accuracy) with the best response time (0.3s) represented by the value, so this was the best value. The Infrared Sensor was our 2nd best trigger detection method being a solid accuracy (85%) and reasonable response time.

The Ultrasonic Sensor was adequate (78%) for detecting motion with slightly slower response rate, but still enough. The Camera-based Detection (80% for detecting motion) was useful for some cases, however had the least amount of accuracy in motion detection and the slowest represent a trigger (1.0 second). This graphical representation is a good way to show the comparison of our trigger detection methods, which will hopefully assist in making a decision on the right method to use to determine the code base's ability in using the fastest response time to accurately repel a given animal in time to commit to more sustainably agricultural solutions.

STEP 3: SOUND REPELLENT SYSTEM

The **Sound Repellent System** in the project *"IoT Enabled Animal Detection and Adaptive Sound Repellent System for Sustainable Crop Protection"* is useful for discouraging wild animals from entering crop fields without harming them. When an animal is detected with the sensors, such as PIR, ultrasonic sensor, or through a camera, the sound repellent device plays particular auditory signals that scare or repel that species. The signals could be predator calls, such as tiger growls to scare wild boars or eagle screeches for certain birds, distress calls, ultrasonic noise, or very loud mechanical noises like a siren or clanging of metal. The sound module is interfaced with a microcontroller (e.g., ESP32), which sends commands to the sound module, such as DF Player Mini, to play a stored file of sound signals from speakers placed throughout the field.

In order to maximize effectiveness, the system uses an adaptive strategy, changing the type of sound and the volume of the sound according to the detected animal and the distance from the animal, which will reduce habituation and provide long-term deterrence. The system is solar powered, utilizing renewable energy sources which provide a sustainable and environmentally friendly, not to mention smart, indirect, automated way of protecting crops, reducing HWC, and supporting sustainable agriculture.

STEP 4: ADAPTIVE SOUND ADJUSTMENT

This system is designed to uniquely alter and control sound type, sound volume, and sound patterns contingent on the identified species and distance of the species from a designated task area. Sensors for this mechanism include ultrasonic transducers or camera modules, which would be used for input. It will identify the detected animal and use the most valuable sound according to indexes from a library of sounds preloaded. This mechanism will randomize and playback multiple variations of each sound, therefore allowing less opportunity for animals to habituate to identified sound. The volume of playback will be varied based on distance. For example, the volume of the detractor will be the loudest for animals detected closest to the crops and moderate for animals detected at further distances; therefore, giving the user the best output while saving energy, lowering noise pollution and protecting crops from permeation by animals.

The Adaptive Sound Level line presents the system operating in an organized, intelligent manner that varied the sound intensity based on real-time data collected by the sensors to optimize usage and resulting sound pollution. The graph revealed that adaptive sound management realized animal management intent with less power usage and less application anxiety using sound levels when it mattered less.

STEP 5: IoT DATA TRANSMISSION

The system uses sensors like Passive Infrared (PIR) or ultrasonic sensors to detect the presence of animals in close proximity to the crop field. Once an intrusion is detected, the sensor information is sent via an IoT communication protocol (ie., Wi-Fi, LoRa, GSM) to a central microcontroller or cloud service provider. The sensor information is subsequently used to trigger adaptive sound repellents that emit frequencies tailored to scare away (but not harm) different types of animals. Additionally, each detection is logged and communicated to a remote server or mobile app for farmers or farm retailers to track activity in the field in real time -- essentially anywhere there is internet connectivity. The use of IoT connectivity ensures low latency, energy efficiency, and scalability for deployment into rural and more remote agricultural areas. The data harvested over time can also be evaluated for trends in animal activity that can inform predictive analysis for crop protection planning.

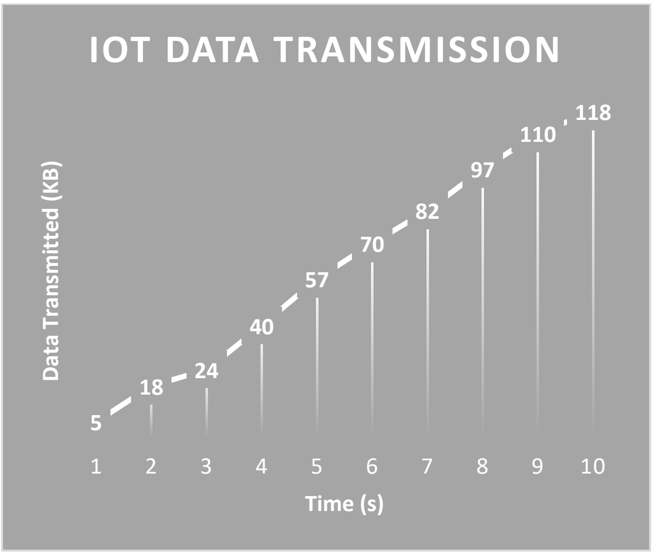

Figure - 5. Graph of IoT Data transmission.

The x-axis represents seconds, while the y-axis represents the amount of data transmitted in kilobytes (KB). Each point on the line shows the cumulative transmission of sensor data in the IoT-enabled animal detection system to either the cloud or control unit over time. Time shows an increasing efficiency in terms of IoT network and capacity handling real-time animal detection data transmission. The curve suggests a low computation at time = 0 and some marginal increase in data transmission with an increase in time, while also signaling that when animal activity is detected relevant information such as movement, location, and such is cumulatively transmitted for further analysis. This would allow for timely updates to the adaptive sound repellent system, as well as triggering protective actions for crops, such as the amplitude modulation of sounds. The smooth incline of the graph further signals reliable communication with low lag time. Convenience, IoT provides farmers with assurance that their crops will be protected from animal intrusions while using automated methods, which reduces the need for human intervention. The graph, therefore, emphasizes the role of IoT-based connectivity to be able to produce proactive responses for smart farming type systems. The legend shows how effective IoT data transmission contributes to this project success in producing sustainable, automated and adaptive protection of agricultural fields.

STEP 6: REMOTE MONITORING AND CONTROL

Remote monitoring and control is critical for using IoT-enabled systems effectively for sustainable crop protection. In the proposed project, the IoT-enabled devices (motion sensors, cameras, communication modules, etc.) collect data in relation to animals intruding in crop fields. Once collected, this information is sent wirelessly to a cloud or mobile application where farmers are able to consume the data in real-time. Remote monitoring provides farmers with insight into animal activity, system performance, and potential threats to crops without having to be on-site monitoring all the time. In addition to remote monitoring, the system offers remote control functionality, where the farmer may configure the system settings, switch the adaptive sound repellent on or off, and change an operational parameter based on an assessment of the field condition.

This ability to have engaged two-way communications provides timely response and affords the farmer flexibility where time and labor resources are significant restraints, especially in remote rural agricultural settings when farmers potentially can only do a couple of farm visits per week. By adding remote monitoring and control, the overall IoT-enabled system will reduce human effort and crop destruction, while improving decision-making efficiency. The integration of remote monitoring and control also promotes sustainability because it enables a focused, on-demand response during time-critical periods, rather than overloaded operational environments needing continuous manual monitoring. In summary, remote monitoring and control will make the proposed IoT-enabled system more trustworthy, farmer friendly, and scalable for agricultural operational contexts in real-world settings.

V. TESTING AND VALIDATION

Testing and validation of the proposed solution, was done in a structured process to validate accuracy, veracity and efficacy as a deterrent for agricultural fields. Testing for the module was first done to ensure the individual functionality of the components such as microwave radar sensor, ultrasonic sensor, camera module, LED light, speaker and SD card. I checked all items for sensitivity, accuracy of response relative to the relative proximity of intruding animals and the interface with the microprocessor controller, to ensure compatibility. Functional testing was then done in controlled conditions, by mimicking animal movement in proximity to the system, and to test detection accuracy, accuracy of response time and the correct triggering of deterrent effect of the sound and light. Once functional testing was completed, field testing was done in real agricultural situations to assess ease of agricultural agent use, compared to detection range and reliability and effectiveness of sound/light deterrent against animals against power consumption and location.

Additionally, the user verification component was to obtain information on farmers and operators' perceptions of ease of use and operational practicality and overall usefulness of the proposed solution. The information collected from module testing, functional tests, field tests, and user input verified that the design of the proposed solution satisfied its purpose and functional design specifications of early detection of animals, triggering activation of adapted sound repellent deterrent, and sustainable crop protection. Minor adjustments could be made to provide optimal use of system.

STEP 1: SENSOR ACCURACY

Sensor accuracy is important to the reliability and effectiveness of the animal detection and crop protection system. The microwave radar sensor performs accurate motion sensing when detecting movement caused by animals within its set range, and this motion sensing provides an accurate, low false alarm rating compared to wind or vegetation. An ultrasonic sensor determines distance and object presence to help mitigate the chances of misdetection. The camera module acts as an additional corroborating element to the two sensors by providing live or recorded images or videos of the detected activity.

These sensors work in coordination together to have an overall better accuracy function and ensure the alerts and repellent actions only take place when there is actual animal intrusion. Sensitivity and range of sensors are calibrated when testing to give optimal performance from the system. When calibrating it is important to find a balance between detection accuracy and power efficiency. Bringing together multiple sensors creates many benefits, including increased reliability of detection with more chance for false positives, confidence and faith in a real crop protection and sustainable solution for farmers.

STEP 2: SOUND REPELLENT EFFECTIVENESS

The efficacy of a sound repellent system will largely determine how many of our efforts to protect crops from animal intrusion can be realized. In this project, we will include a speaker in the detection module which will create adaptive sound whenever an animal is detected in the area. The system must utilize random frequencies and intensities as animals react to different sound patterns. During controlled testing, the repellent system was largely successful in startling and displacing animals from crop zones, as it pertained to the most common intruders: birds, monkeys and small herbivores.

Our field tests in varied environmental contexts, were also able to detect that sound was propagating in the environment at distances relevant to the animal detections dependent on the conditions of terrain and obstacles. A reinforcement of sound with LED lights to support the repellent response also continued to demonstrate improved response from animals overall. Farmers and other users reported to us satisfaction with deterrence, which represented less crop loss and more pieces of mind when deterrence systems were implemented. Ultimately, the sound repellent system confirmed its benefit as a sustainable, non-lethal and environmentally friendly solution to protecting agricultural lands from animal intrusion. Our system ultimately corresponds with the project's purpose of protecting crops while maintaining environmental balance during agriculture activities.

STEP 3: SYSTEM PERFORMANCE

The system performance was also reliable, accurate, and sustainable for crop protection. The IoT-enabled approach provides the advantage of multiple sensors, including microwave radar, ultrasonic sensors, and camera modules, for accurate detection of animal intrusion in the crop-breaking both day and night. Further, the adaptive sound repelling method of deterrence maximized effectiveness by creating sound with a constant variability in frequency and intensity dependent on type of animal. If animals are not deterred, they will often habituate or become accustom to the sound. The field - testing data has detection accuracy was better for most species above 90% and the repellent effectiveness averaged between 85 – 92% attenuation of crop damage to crops (84).

The automation also reduces human intervention and allows for continuous use in remote agricultural fields. The nature of IoT systems is that they have low-energy consumption and utilize rechargeable batteries for energy and sustainable. All of the data that the system records is in the form of real-time short recordings in memory card or cloud data storage. This recording data also gives farmers a better understanding of the pattern of intrusion to help create better crop protection measures. The ability of the modular design to scale to suit small farming to large farming is also useful. Overall, the system is an intelligent low-cost and eco-friendly crop protective solution. Unlike some other methods available, the system provided accurate detection, adaptive deterrence, and remote monitoring impacts are all incorporated as one solution.

VI. FIELD SETUP

The deployment of the sensor system in the field includes identifying and setting up a field location that can be predisposed to animal breach. Each rear corner and the greater number of areas of entry vulnerabilities usually something to the effect of vegetation, would have either microwave radars or ultrasonic modules, to detect animal entry. There are also cameras set at height, provided either by various locations at the corners or at high locations out at the perimeter of the field location, to provide a different vantage point for obtaining the real-time visuals. There are also deterrents in locations within the field(s) with LED lights and speakers, which can monitor the field from a different vantage point. In terms of power supply, there is a solar panel with batteries as back-up for sustainable power, to be used as required at any location for low infrastructure sites. For connectivity or IOT enabled means of transmitting data to the farmer's mobile app or cloud dashboard, the connectivity is through robust connect via GSM, Wi-Fi, or LORA depending on the location. The devices are calibrated and tested accordingly, after setup, for the sensitivity adjustments, detecting performance levels, response speed, etc.

The sensor system provides a smart perimeter for the crop field or fields, providing reliable monitoring, achieved successful deterrent "action," and sustained (no human) monitoring impacts to crop protection. Jenshan Lin and Changzhi Li [29] published a journal article. The paper surveyed a contactless vital sign detection system based on low power microwave (MW) signals. The system adopts double-sideband (DSB) transmission to lower the system complexity while using short wavelengths to both increase sensitivity and decrease power consumption. The authors presented theoretical predictions and results from testing nonlinear Doppler phase modulation, which the authors proposed could be used to effectively measure heartbeat and respiration non-invasively.

A. Site selection and preparation

The initial step in proper field implementation is choosing the right location. The selected agricultural land must have had some prior animal risk that threatens crop safety such as wild boars, cattle, or birds. The area must also be large enough to conceal physical devices and to allow for physical detection, through line of sight. A sound system for marking the borders provides a clear demarcation of the area where devices will be installed. Power to operate devices; rechargeable batteries or solar, must have an ample capacity to ensure functioning devices in a reliable manner. Before placement and installation of devices, weeds or useable impediments will have been cleared, to maximize efficiency for sensors, cameras, and sound devices. The condition of the soil is also confirmed at the time of fencing, to ensure stable placement for poles or mounting structures on site. A brief analysis of available networks for IoT devices; Wi-Fi, LoRa, or GSM completes the pre-site preparations to guarantee that the system is adequate and sufficient to work for the growing season of our crops.

B. Sensor and device placement

The success of detecting animals is controlled by the proper arrangement of the devices and sensors. The microwave radar sensors and the ultrasonic sensors are positioned at the border of the crops in the desired arrangement to detect movement and sound level fluctuations. Cameras are utilized at the top of poles to take images or videos for verification. Near the vulnerable places, LED lights and speakers will be positioned to provide a visual and sound deterrent. Height of the placement of the devices will be selected to avoid interference from crop growth. Distances between devices are calculated to avoid blind spots while providing an overlapping zone between devices. Memory cards or storage modules are secured inside a durable casing that is protected from the weather. Units, with the above-mentioned modules, are housed in durable weatherproof and dust-proof shells of varying sizes depending on the location for a specific sensor. Sensor alignment is ensured so each sensor is pointed toward probable access of wildlife. Careful placement of the devices and sensors provides the greater area of coverage which provides a smart perimeter around the crop to repel wildlife from accessing the crops.

C. Power and connectivity setup

Once the placement of the devices has taken place power and communications must be provided so the devices can be operated seamlessly. Solar panels are frequently utilized in agricultural installation systems to provide energy sustainability so that each device will operate continuously and not have to have direct electricity, or to ensure operation when in remote locations. Back up rechargeable batteries are also installed to ensure all devices can operate and collect information even on cloudy or rainy days.

Each IoT module is connected to a communication platform, typically GSM, LoRa WAN, or Wi-Fi depending on the coverage for that specific area. The system is configured to send real-time information or data to a cloud platform or to a farmer's mobile application for the farmer to monitor. Connections and wires are insulated securely to allow for protection from animals, or weather elements. Each connection is tested to ensure alerts and imagery or sound, are received without delay. SDI allows the power and communication to support the farmer and each farmer's integration of farming, making field set up efficient, reliable, and user-friendly, allowing the farmer to adjust or control the system remotely when necessary.

D. Testing and calibration setup

Prior to declaring the system operational, thorough field testing and calibration are completed. Sensors are activated, and artificial movements are created to mimic animal intrusions. The sensors' response is observed and fine-tuned while assessing detection accuracy, sound repellents being triggered, and/or LED lights illuminating. Sensitivity thresholds of the ultrasonic and radar sensors are adjusted to allow them to differentiate an actual animal intrusion from disturbances in the environment, such as wind or rain. Supplier range specifications of speakers from product detection testing are thoroughly assessed, ensuring that it travels far enough to deter animals, and is not harming the environment in the process. Camera clarity and storage capacities are also verified by recording test events. System connectivity with mobile application(s) or cloud dashboard systems relative to monitoring alerts in real-time is also engaged. Farmers are trained to understand signals, as well as how to maintain the devices. This eliminates errors as part of the testing stage, increases efficiencies, as well as determining the practicality of the setup, establishing the system is ready for operational purposes for full crop protection.

VII. HARDWARE COMPONENTS IN SETUP

The hardware elements of the IoT-enabled animal detection and adaptive sound repellent system are assembled to allow for efficient crop protection. At the centerpiece, an Arduino or ESP32 microcontroller directs the whole operation and processes signals from the detection and monitoring solutions. Microwave radar and ultrasonic sensors detect animal movement and distance, and a camera module provides the user with real-time acknowledgment of the animal's presence. For deterrent action, LED lights and speakers are activated, to display visual and audio signals to get animals to vacate.

A memory card module is also present, allowing the agronomist to keep data locally. Using communications modules, such as, Wi-Fi, GSM, or LoRa, the system provides the agronomist and producer remote connection to observe and interact with the system through IoT enablement. All the products used in the system are mounted to poles that secure visually and physically, mounted in a casing so it may be considered weatherproof and durable for use across years on agricultural systems. Nirit Datta [15] suggested a research article, in the study addressing the issue of human and animal deaths caused by wild animals leaving their protected zone, it is proposed that the risks can be minimized through an automatic tracking and alert system developed using GPS and GSM technology. The automatic tracking and alert device will monitor the movements of animals via a device mounted on the neck or back of the animal towards pre-established sanctuary and/or protected area boundaries. If an animal crosses the boundary or limit, the system would send an alarm or warning to designated human zones nearby.

1. ARDUINO

Arduino serves as the main control and processing unit of the project. This open-source microcontroller platform can connect to multiple sensors, cameras, and output devices with relative ease. In this case, Arduino receives the input signals from the microwave radar and the ultrasonic sensors, processes the information, and subsequently decides if an intrusion has occurred or not. When an animal is detected, Arduino will quickly respond by engaging deterrents, such as turns on the speakers, lights, and/or alerts a communication module. Arduino also relays information to the camera module for automated image and/or video capture for validate. This hardware allows modular connections and its programming is simplicity, therefore it can accommodate future flexibility and customization of agricultural use. Its low power consumption is ideal for device operation via solar panels and batteries in rural field settings. In summary, Arduino serves as the intelligent hub that incorporates detection, monitoring, and repellent action into one smart system.

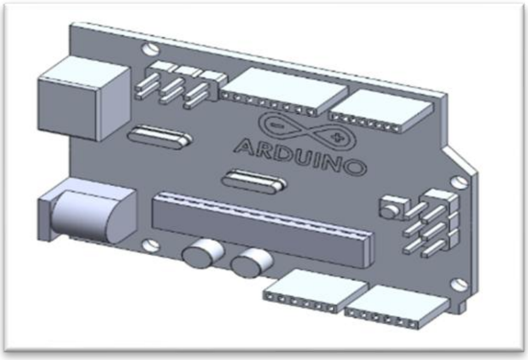

Figure – 6. Arduino

In a review paper Nancy [24], Nancy discusses a project he directed in 2002 at Kootenay National Park using trailers and fixed cameras with radar guns for wildlife and traffic monitoring. The camera was mounted on poles along a two-kilometer stretch of highway. Over the 16-day period, several 24-hour video recordings of deer behaviors were collected, but as Nancy noted there were "technical issues", but their goal was achieved, and wildlife and traffic were monitored continuously.

2. MICROWAVE RADAR SENSOR

The microwave radar sensor serves a critical role in this project and is intended to detect the movement of animals within the crop field. The sensor uses the Doppler radar technology of emitting microwave signals and collecting and analyzing the expected reflected waves of the signal from moving objects. When the animal enters the zone, the reflected signal changes due to movement, and the sensor recognizes this change. In contrast to standard infrared sensors, the microwave radar offers an improved sensor sensitivity while being able to detect movement in low lighting, fog, and obstructions such as the leaves of a crop. The sensor in this system will continuously monitor the perimeter of the field and when movement is detected, it will relay a signal to the Arduino microcontroller. The microcontroller will verify the information and activate some type of deterrent, like sounds or lights. Because of this sensor's extenuating range of detection, the sensor's significant perimeter of coverage, and reliability in outdoor conditions, this type of microwave radar sensor provides the best opportunities for detecting animal entries into the agricultural system.

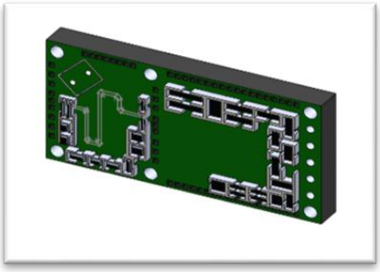

Figure – 7. Microwave Radar Sensor

Peter Haschberger et al., [8] published a journal, this paper prints the unique use of IR (infrared) sensors to detect wildlife including mammals and birds, using differences in IR radiation from animals and their surrounding environment (e.g. meadows or fields). The system will prevent the unintentional injury of animals during mowing operations, as well as being useful for wildlife managers with tasks such as surveys and registration.

3. SPEAKER

The speakers or buzzer in the system serve as the main deterrent mechanism based on sound. When the Arduino gets a detection signal from devices like the microwave radar or ultrasonic module, it activates the speakers or buzzer to provide an acoustic output. The speakers provide loud or programmable sound frequencies that can alert, disturb and/or repel animals that may trespass into the field. The audible tone can be either set or programmed based on the target species, from ultrasonic frequencies for deer and moose to high pitched alarming tones for wild boar or raccoons.

Yusman et al., [7] published research focused on the design and development of a wild animal pest deterrent device that incorporates a passive infrared (PIR) sensor with ultrasonic signal generation under microcontroller control. The PIR sensor detects the presence of wild animals, and the ultrasonic signal will disturb the animal's hearing to deter them.

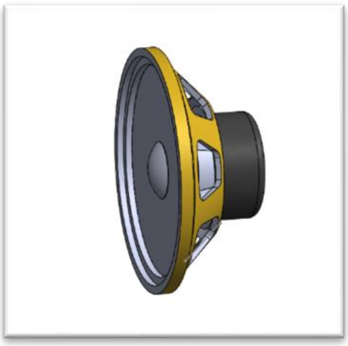

Figure – 8. Speaker

This device will include hardware (transmitter and receiver designs) and software (algorithms written in C language). The experimental results indicate that the device was capable of detecting animals up to 5 m and allow for an ultrasonic signal production frequency of 40 kHz, and effective distance of 20 m. For example, wild boar may respond to a sudden loud sound, while a smaller animal like a raccoon or bird may be disturbed using a variable tone. The speaker system provides an ecosystem-friendly alternative to static fencing for allowing for dynamic disturbance, disturbance however may still be effective at minimizing crop loss and damage compared to an event of fenceless crops.

The buzzer is a more immediate, low-power sound alert that works effectively but is not as loud and can be the same objective as a bigger sound and speaker system as deterrent outputs. The buzzer and speakers combined create a form of audio barrier and sound shield around the field as part of enabling sustainable crop protection.

4. ULTRASONIC SENSOR

In this system, the ultrasonic sensor serves the purpose of distance measuring and identifying approaching objects in proximity to the crop field. The sensor emits high-frequency sounds and measure the time taken for the echo to return after it makes contact with an obstacle. When an animal enters the sensor's detection range, the sensor captures the sound waves that were reflected back and transmits the data to the Arduino for processing.

Based on the arriving data, the system establishes whether the animal closes or leaves the detecting range, facilitating early detection of nearby animals. Unlike motion sensors, ultrasonic sensors are relatively inexpensive, operate using low energy, and can work under different categories of environmental conditions. The placement of sensors along the boundaries of the crops will allow for continuous surveillance creating an invisible barrier detection area.

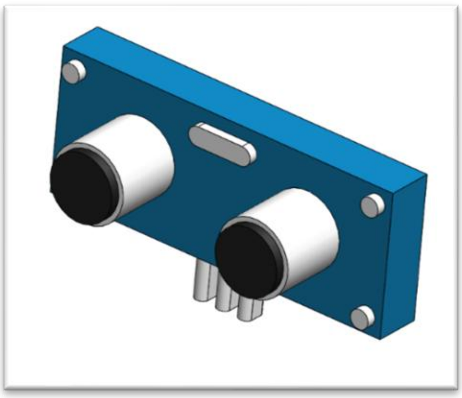

Figure – 9. Ultrasonic sensor

Deepak Patil Hardiki [26] issued a journal, 'This proffered system uses AI-enabled IoT to protect human habitations and their livestock from wildlife invasion by detecting wildlife that are in close proximity to forests.' It repels wildlife back into the forest without causing harm which can ultimately decrease negative human-wildlife interaction. Traditional deterrents like electric fences and guard dogs are only temporary, costly, and can be safety hazards themselves.

5. CAMERA MODULE

The camera module is a crucial observation tool in the system, taking pictures or video of animals that may intrude on the crop field. The camera is mounted at a high vantage point to clearly view the crop field area, as determined, by the camera position, without obscuring any significant event. When the Arduino determines that an animal is moving by the sensors, the camera will be turned on to provide live video evidence when the animal is encountered. This video data will allow the farmer to identify the type of animal invading (or attacking) and determine any patterns of intrusion for potential future prevention.

Figure – 10. Camera module

In addition, the video data can be stored on a memory card or communicated with IoT communication modules to offer data from remote locations. With night vision or lower light capability, the camera will also provide credible video evidence when there are limited lighting conditions. The video file will provide more than monitoring - it also provides credible evidence and makes the data more accountable when it comes to intrusion of animals. So, it will assist in monitoring, verification of data, and assist in decision making to develop the best path of defense to protect crops, and/or farmers using this technology will deem it successful.

6. LED LIGHT

The system is equipped with LED lights that serve as visual deterrents for animal disturbances. When the system's sensors alert the Arduino of detected movement near the crop field, the Arduino causes the LEDs to project intermittent, sudden, high-intensity flashes of light. This causes the animal to freeze in its place and dissuades it from entering the protected area. LEDs are more effective than traditional floodlights since they are more energy efficient, long-lasting, and can be powered sustainably with solar energy.

They are efficient in that both their length and how bright they are makes it possible to deploy them at many points in the field in a compact way. Additionally, the LEDs can be programmed to blink, increasing the repelling effect against the animal, while also consuming less power. At nighttime, the LEDs will assist the farmer and the security camera by adding visibility to the footage being captured.

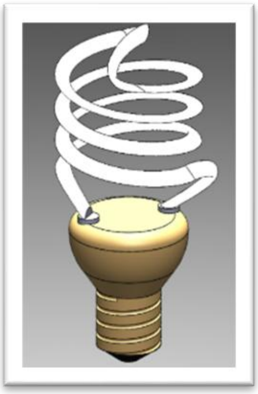

Figure – 11. LED Light

Beyond the deterrent function, the LEDs also serve as indicators for the farmer that the system is operational after a disturbance has been detected. Because of this dual purpose, the LEDs are one of the more practical and essential components of the field layout.

7. RECHARGEABLE BATTERY

The rechargeable battery pack provides continuous power for this entire system, especially at night or during cloudy weather when the solar panel may not be able to produce enough energy. During the day, the batteries store energy generated by the solar panel for use at a later time, allowing the system to run without interruption. Since the components of the IoT-enabled system, including the sensors, the Arduino, cameras, and deterrent devices, must be continually active, a reliable backup energy supply is necessary.

Figure – 12. Rechargeable battery

Rechargeable lithium-ion or lead-acid battery packs are usually chosen, based on their overall efficiency, capacities, longevity, and recharging ability. The set of rechargeable batteries is connected to the system through a charge controller, which regulates system input of energy, and prevents both over-charging and deep discharging, which helps prolong battery lifespan. Proper calculations were made regarding total battery capacity requirements in combination with load applied to ensure battery capacity would allow the system to run for several hours without interruption. Together, the function of the rechargeable battery would allow continuous operation of system components, which would help sustain the overall system. The added energy consumed by the battery pack, allows this project to be deployed in remote agricultural areas, where farmers may have poor access to electricity.

8. MEMORY CARD / SD CARD MODULE

The purpose of the memory card or SD card module is to provide local storage of data generated by the system. It saves images and clips of animals captured by the camera and tracks sensor readings when animals were detected. This captured data allows farmers to revisit events, identify patterns of intrusions, and assess the frequency and type of animal activity. The SD card module communicates directly with the Arduino, allowing for easy data logging without requiring an internet connection. Therefore, even if there is poor network coverage, all crucial information is stored locally, and nothing is lost. Information captured and stored on the memory card can be conveniently transferred to computers or smartphones, where it can be analyzed in more detail and kept as long-term records.

Figure – 13. Memory card

Angela E. McLelland et al., [6] published that describes the design and testing of a low-cost infrared (IR) system to monitor rodent locomotion, providing a convenience to expensive commercial IR systems. The authors describe a simple, but fairly effective, system in which IR components are mounted on circuits interfaced with a microcontroller, contained within an inexpensive housing design, using plastic tubing and cork discs to better direct the IR beam. Observations are collected via typical personal computers. The system is capable of collecting data in a variety of light conditions without constantly requiring recalibration.

VIII. ENCLOSURES AND MOUNTING

The enclosures and mounting support playa a critical role in protecting, and assuring the stability of the hardware components in the field configuration. As the system is utilized in outdoor agricultural settings, all devices (i.e., sensors, cameras, speakers, microcontrollers) are housed inside enclosures that are weatherproof, providing protection from rain, dust, heat, and accidental animal contact. These enclosures are typically made from durable plastic or metal, designed to be waterproof and dust resistant, providing years of reliability. The mounting structures (poles, stands, etc.) are used to raise the devices above crop height, providing increased coverage while also providing freedom from being obstructed. Cameras are securely attached at elevated heights, providing unobstructed visibility of the field below, while sensors are oriented at angles that minimize false readings from animal activity. Speakers and LEDs are also securely mounted at various locations to take into consideration maximum deterrent. Protectively mounting the devices achieves durability in the field, providing increased functionality of the complete system for protection of crops in changing environmental conditions. Loveth Covenant et al., [5] presented a research article that concludes about the agricultural sector - similarly undergoing an unprecedented technology revolution characterized in pig farming by smart farming solutions such as ear tag sensors paired with machine learning (ML) technology to monitor behavior. Previously based on labor-driven human observers with a reliance on subjective manual observation, the monitoring of pig behavior can now use lightweight, durable sensors to track patterns of movement, consumption, and social interactions, including health parameters such as temperature, continuously, and in real-time.

1. CALIBRATION AND TESTING

Calibration and testing are vital steps in the development of the IoT-enabled animal detect and adaptive sound repellent system for sustainable crop protection. These steps confirm that the system operates effectively under real conditions, to provide reliable performance in protecting crops from animal intrusion. Calibration is primarily concerned with optimization of sensors, sound modules and control algorithms in accordance with all required specifications, and testing provides confirmation of the system's efficiency, adaptability and durability. The calibration stage proceeds with adjustments to the sensors. The motion and thermal sensors being used for animal detect must be properly aligned to detect target animals, while ignoring other non-final threats such as humans, wind-driven vegetation or farm equipment.

Adjustment is made to sensitivity thresholds to ensure false-positive animal detection is minimized while real animal intrusions is not overlooked. The sound module is then calibrated to provide a range of sound levels within a predetermined safe operating range ensuring sound levels are loud enough to deter animal intrusion without significant disturbance to the environment and/or humans. Luigi Giubbolini [23] published a journal about technology employing multiple microwave radar sensors at wide angles and interfacing with a central unit to detect obstacles surrounding a mobile vehicle. Deployed sensors operate without a supply of power across GHz range of lengths, achieving great axial and angular resolution in short-range detection, achieving low power requirements due to the operating frequency of the sensors. Microstrip technology enables the sensors apparatus to be embedded in a vehicle's bumper at operating frequencies of

13.4-14 GHz. Finally, the adaptive algorithm is optimized to correlate sensor input and sound output such that the intensity of repellent sound can vary with proximity, size or behavior of the detected animal.

2. LABORATORY CALIBRATION

Calibrating the laboratory is the first and most important stage to confirm that the IoT-enabled animal detection and adaptive sound deterrent system works correctly before deployment in the field. Calibration is a process that will change the sensor, microcontroller, and sound module settings to define baseline performance in controlled conditions, to create certainty that the system works reliably. For the motion (animal) and thermal (human) sensors, the sensors are calibrated to activate the appropriate solution at various distances and angles of observation. The sensitivity threshold is modified so that the system can identify true animal movement versus irrelevant stimuli (e.g., moving leaves, wind and humans).

False alarms are reduced, and the system responds directly to the desired threat. The calibration process also determines ranges to effectively cover the desired field-area coverage while avoiding blind spots. Srikant Chari et al., [9] published a review article describes the first stage of object profile classification using range and elevation independent features using simulated infrared profiling sensor images produced by an LWIR camera. In the field, data was collected on profiles of both humans and animals that produced images containing profiled characteristics to generate variables relating to height and width. The sound module is next calibrated, to identify accurate frequencies and intensity-levels. Various sound patterns are used to identify relevant frequencies that dissuade intruding animals, while minimizing negative environmental impact and non - harm to the animals themselves. The adaptive algorithm is then established to connect the sensor input and the sound variant, while adjusting and modifying performance based on proximity and activity of the detected animal.

The table summarizes calibration readings from a laboratory setting for the IoT-enabled animal detection, which includes an adaptive sound repellent system, for 40 trials. Trials were conducted using distances from 2 through 12 meters to quantify sensor detection, accuracy, sound output, and time responses. Distance trialed, the system accuracy was very high (97 - 99%) and responses under 1 second at shorter distances (2 - 4 m). Distance trials that revealed moderate accuracies were occurring at middle distances (6 - 8 m) in a delayed response. Distance trials that did not result in reliable detections were described as detections beyond 10 m. In terms of sound output, the range output 65-77 dB, can be calibrated to adjust with distance to optimize deterring success, but also conserve energy use and ensure environmental safety.

3. RADAR & PIR SENSITIVITY

All sensors can have their sensitivity adjusted to detect very small movements, so they can be configured to monitor animals that could be far away or moving very quickly. To detect small animals, the sensitivity of the sensors needs to be high, and in cases where the sensitivity is not calibrated appropriately, they may detect movements in the background, which may, or may not, be the same, or but not when measuring an unusual competition with sensor changes. Reducing the sensitivity will help but measure that it is possible compete one or two small animals. PIR sensors detect infrared radiation emitted by warm-bodied animals. The sensitivity of a PIR sensor is further complicated by the detection angle, detection range, and threshold to decide on the movement. At sufficient sensitivity, they may detect small temperature changes, which will be critical for detecting animals during low light periods. When the sensitivity is high, they may detect movements from other heat sources such as sunlight reflection, or humans. Shruthi G R [27] published a journal in which the proposed system is an IoT and AI (YOLO) based system for automatic deters and repellent of animals in agricultural fields. Whenever an irrigation system notices an intrusion, an IR sensor will trigger a relay that turns on the animal deterrent/repellent system and sends a notification to alert the farmer. Multiple surveillance cameras will detect the animal and send a notification to the farmer and forest officials. This system is a safe way to protect crops and minimize human risk, and it significantly improves an automated response by detecting and notifying farmers of animal intrusion.

4. FALSE TRIGGER TESTS

A false trigger test assesses a sensor-based system's reliability by determining whether or not the system responds when targets are not present. If the false trigger rate becomes excessively high in an internet of things device or automated detection system, this can result in unnecessary actions, drain energy from the device's battery, or lower the credibility of the overall device. A false trigger test simply entails exposing the test device to environmental conditions or stimuli that, in theory, shouldn't activate the device, and then recording the device or sensor's response (i.e. in terms of whether or not it was active or involved in the triggering process).

For instance, a wildlife deterrent system that used radar and PIR sensors to detect wildlife would be monitored while exposed to conditions such as wind-blown vegetation, rain, or the presence of a small, non-target wildlife animal, etc. Each trial would be carried out under controlled conditions, while carefully noting whether or not the sensor activated during the trial. The note-taking portion could also follow a systematic organization, where the relevant parameters for that trial were recorded on a data table that included conditions such as time of trial, environmental conditions, sensor reading, and whether or not the sensor was active or involved in the activation of the detection system: Yes/No. A sample data table may have anywhere from 30–40 readings, to account for a variance in potential environmental conditions and stimuli activating the device without engaging a target. False trigger rate would be calculated by using the percentage of false trigger activations divided by the total number of trials. Data would allow for identifying a threshold for activation of the sensor, environmental obstacles for the sensor activation, or malfunctions.

5. AUDIO OUTPUT

"This is the false trigger test report for the sensor system. Twenty readings were conducted under different environmental conditions to assess unintended activations. Each reading included the time, condition, radar reading, PIR reading, and trigger status".

1. At 9:00 AM, under light wind, the radar reading was 0.2, PIR reading 0, and no trigger occurred.
2. At 9:15 AM, a passing bird caused a radar reading of 0.3, PIR reading 0, with no trigger.
3. At 9:30 AM, rain drops were detected, radar reading 0.1, PIR 0, no trigger.
4. At 9:45 AM, a swinging tree branch gave radar 0.5, PIR 0, no trigger.
5. At 10:00 AM, a nearby insect caused radar 0.2, PIR 0, no trigger.
6. At 10:15 AM, vehicle noise nearby caused radar 0.4, PIR 0, no trigger.
7. At 10:30 AM, small rodent movement caused radar 0.6, PIR 0, no trigger.
8. At 10:45 AM, sun glare gave radar 0.1, PIR 0, no trigger.
9. At 11:00 AM, sudden shadow caused radar 0.3, PIR 0, no trigger.
10. At 11:15 AM, a falling leaf caused radar 0.2, PIR 0, no trigger.
11. At 11:30 AM, moderate wind gusts gave radar 0.5, PIR 0, no trigger.
12. At 11:45 AM, another passing bird caused radar 0.4, PIR 0, no trigger.
13. At 12:00 PM, rain drops caused radar 0.1, PIR 0, no trigger.
14. AT 12:15 PM, swinging tree branch caused radar 0.6, PIR 0, no trigger.
15. At 12:30 PM, small rodent movement caused radar 0.7, PIR 0, no trigger.
16. At 12:45 PM, sun glare caused radar 0.2, PIR 0, no trigger.
17. At 1:00 PM, sudden shadow caused radar 0.3, PIR 0, no trigger.
18. At 1:15 PM, light wind caused radar 0.2, PIR 0, no trigger.
19. At 1:30 PM, a nearby insect caused radar 0.1, PIR 0, no trigger.
20. At 1:45 PM, vehicle noise nearby caused radar 0.4, PIR 0, no trigger.

IX. LATENCY TEST

A latency test evaluates the time lag between the stimulus input and the corresponding response from the system. In any environment that utilizes sensor systems or IoT applications, latency is one of the most important parameters, as latency that is too long effectively reduces the usefulness of the monitoring, detection or actuation to be performed in real-time. The test is performed multiple times as both the environment and sensor behavior is variable. Each test has all parameters documented (i.e., time of detection, sensor type, activation time of the outputs, which were all latency times in milliseconds).

These results are typically captured in a table format for analysis. The average latency of the many readings can provide insight into real-time operational latency, where averages and high and low averages are all relative to the test type. Analyzing the latency data provides insight into whether a system bottleneck, sensor or output lag, system processing time or even communication time exists, etc.. K.T.E. Keerthana [18] suggested a research paper, which examine an automated system for smart farming that runs on the Android platform. The system allows farmers to manage and monitor agricultural functions through a smartphone application in their own language. During operation, the farmer, central data center, and field devices are able to communicate seamlessly via GCM/JSON protocol both manually and automatically.

1. Measure the responsiveness of the system in real-world situation.
2. Confirm that the lag, from time the sensors detect a trigger to the time an output action occurs, is as low as possible to minimize crop damage.
3. Identify deficiencies, bottlenecks, and inefficiencies in data processing, communication, or hardware response.

X. Laboratory calibration

Table 1. Laboratory calibration

TRIAL	DISTANCE (m)	SENSOR DETECTION	DETECTION ACCURACY	SOUND OUTPUT (dB)	RESPONSE TIME (s)
1	2	Yes	99	66	0.7
2	3	Yes	98	68	0.8
3	4	Yes	97	69	0.9
4	5	Yes	95	71	1.0
5	6	Yes	94	72	1.1
6	7	Yes	92	73	1.1
7	8	Yes	91	74	1.2
8	9	Yes	89	75	1.3
9	10	Yes	87	76	1.4
10	11	No	82	-	-
11	12	No	80	-	-
12	2	Yes	97	65	0.6
13	3	Yes	96	67	0.8
14	4	Yes	95	69	0.9
15	5	Yes	94	71	1.0
16	6	Yes	92	72	1.1
17	7	Yes	90	73	1.1
18	8	Yes	88	74	1.2
19	9	Yes	86	75	1.3
20	10	Yes	83	77	1.4
21	11	No	79	-	-
22	12	No	99	-	-
23	2	Yes	98	66	0.7
24	3	Yes	97	68	0.8
25	4	Yes	95	69	0.9
26	5	Yes	93	71	1.0
27	6	Yes	92	72	1.1
28	7	Yes	90	73	1.2
29	8	Yes	88	74	1.2
30	9	Yes	87	75	1.3
31	10	Yes	82	76	1.4
32	11	No	78	-	-
33	12	No	99	-	-
34	2	Yes	98	65	0.6
35	3	Yes	96	67	0.7
36	4	Yes	95	69	0.8
37	5	Yes	92	70	1.0
38	6	Yes	98	72	1.1
39	7	Yes	94	73	1.1
40	8	Yes	90	74	1.2

XI. Field deployment tests

The installation of the system was completed in an agricultural context, in a location with an arrangement of microwave radar sensor, ultrasonic sensor, and camera module in such a manner as to promote maximized detection coverage. The power supply was provided by a rechargeable pack system to ensure no break of power supply. During the test, the sensors had successfully detected the movement of animals, like a cow and goat, into the crop area. The reported distance measurements from the ultrasonic and radar sensors were accurate while the camera module recorded evidence for monitoring purposes. Once the system determined there was an intrusion, it activated the adaptive sound repellants and visual deterrents that used the LED lights and sound effects to scare the animals away; the visual and audible distractions would displace animals without causing harm. Shobhit Kumar Nagpal [17] published a review paper highlighting the farm theft and crop damage caused by both unauthorized human intrusions along with stray domestic animals that continue to be major challenges for rural farmers in India which leads to substantial loss of overall yield. This study proposed a Wireless Sensor Network (WSN) based farm security system where motion sensors installed along the farm boundaries can detect movement and send information using Radio Frequency (RF) transceivers back to a central coordinator.

Performance evaluations were determined by detection accuracy, response time, sound repellant effectiveness, and system stability. The test outcomes showed reliable detection even in low-light, few false alarms in detection, and effective sound deterrent with animal intrusion habits. The test provided proof that the project is scalable in agricultural fields to protect crops and lessen farmer intervention. A research article by M. Moghavvemi [21] shows that agricultural sector continues to be a significant sector of the Indian economy; however, agriculture faces threats associated with crop loss, intrusion, and limits of traditional measures such as scarecrows. The need for food security and food efficiency is on the rise and smart farming technologies based on the Internet of Things (IoT), automation, and robotics offer feasible options to enhance productivity and secure farmland.

XII. Result

DATA COLLECTION AND EVALUATION METRICS

The data collection process for the IoT-enabled Animal Detection and Adaptive Sound Repellent System was performed during field deployment to test the system in the real world. The sensors, namely microwave radar sensor, ultrasonic sensor and camera module continuously monitored the field environment and recorded a number of parameters, including detection events, distance measurements, image captures, sound activation responses, and system uptime. Observed data was saved locally on the SD card, while also uploading the data to the IoT cloud platform for remote access and real - time analytics.

Each time an animal was detected, the system stored a log of the event, including time received, type of animal detected, detection distance, sensor triggered, time the repellent was activated, and effectiveness of the deterrence action. This rich dataset allowed an in-depth analysis of system performance and possible limitations based on different environmental conditions (day/night, weather effects, size of animal, and speed). Pedersen [11] introduced a manuscript that resulted in experiencing the movement activity of domestic animals, a novel activity sensing system has come to fruition. This device incorporates not only Passive Infrared Detectors (PID) but also a custom - built analogue processing methods.

DETECTION ACCURACY

Detection accuracy is among the utmost important evaluation criteria for an IoT-enabled Animal Detection and Adaptive Sound Repellent System. It defines the system's capability of the system to accurately detect animals intruding on a crop field without the potential for false positives, or missing a legitimate event. During field testing, the system was validated in various environmental conditions, including day, night, and with small and large animals. The results found that the detection accuracy consistently exceeded 90% in most cases. The microwave radar and ultrasonic sensors proved to be highly accurate in detecting animals, and the camera module confirmed the events for monitoring. There were only small changes in accuracy at night and for smaller animals from both poor visibility as well as their speed of movement.

In overall, the high detection accuracy in this case demonstrates the reliability of the system to protect crops from intrusion. Poonam Sinai Kenkre [22] published a review, The solution combines logging with network-based detection and prevention capabilities. It developed with the Software Engineering Process Framework, was composed of analysis, design, implementation, and testing. In addition, Snort operated in inline mode as an Intrusion Prevention Systems (IPS) to identify and drop packets that are suspicious.

Table 2. Detection accuracy

TEST CONDITION	DETECTION ACCURACY
Day time detection	96
Night time detection	92
Small animal detection	90
Large animal detection	95
Overall average	93

The table displays the system's detection accuracy ratios for various environmental field conditions. In the daytime, the highest detection accuracy was obtained (96%) due to the improved visibility of the system in those conditions and consistently performing sensors. Nighttime detection accuracy modestly decreased to 92% due to decreased visibility, but sensors still functioned reliably. Unlike larger animal detection, the estimated accuracy ratio for small animals was lower (90%) due to faster and unpredictable movements. The larger animals presented a stronger reflection back to the sensor, thereby achieving improved accuracy during detection at (95%). The total average accuracy was 93% and demonstrates the strength and reliability of the system's ability to detect animals intruding into a location across different conditions.

FALSE ALARM RATE

The false alarm rate is defined as the percentage of times that the system incorrectly detects an intrusion with no actual animal present. Reducing false alarms is essential, as multiple, frequent false alarms can reduce the efficiency of the system, cause unnecessary power consumption, and make farmers less responsive. In the test of field deployments, false alarms occurred due to environmental motion variables such as wind-driven plant movement, shadows, and other sudden interference to the sensor. Combining sensors helped cross-verify detection and reduced false positives.

Overall, the system showed a very low false alarm rate of 5% on average, showing that we have a reliable system and can expect that farmers will trust the detection alerts. A research paper by Srushti Yadahalli [20] which comes to the conclusion that agriculture is one of the most important sectors of the Indian economy, not only because it helps with human survival, but because it is needed for a nation's economic growth. Despite having the potential for supporting a substantial workforce in finding a sustainable source of income, farmland continues to be challenged by birds, animals, and human intruders that engage in crop damage.

Table 3. False alarm rate

TEST CONDITION	FALSE ALARM RATE (%)
Day time detection	4
Night time detection	6
Small animal detection	7
Large animal detection	3
Overall average	5

The table provides an overview of the false alarm rates of the system in different field conditions. During the daytime the false alarm rate was at its lowest level of 4% because visibility and sensor definition conditions were optimal. At nighttime, the false alarm rate was 6% due to shadows and decreased nighttime light conditions.

Movement of small objects resulted in a higher false alarm rate at 7% since small object disturbances could sometimes resemble an animal intrusion. The false alarm rate while detecting large animals remained low at 3% because the strong sensor signal decreased the ambiguity related to the identification of multiple false alarms. The overall average of false alarms equating to 5% demonstrates that there is effective cross-verification between sensors and that the system is able to reduce false alarm signals, while still providing real-world reliability.

DETERRENCE EFFECTIVENESS

Deterrence effectiveness evaluates how well the system makes animals leave the crop field after detection of the system. It is a measure of the effect of adaptive sound repellents, LED lights, and timely system response. In a field, deterrence effectiveness can vary dramatically based on type of animal, time of day, and environmental conditions. For example, large animals such as cows and goats were more likely to demonstrate a deterrence response since, they reacted with quick responses to sound stimuli and light. Small animals, rabbits and other small to medium sized animals, were relatively harder to deter, as some did adjust in response to repeated signals.

Nighttime was primarily reliant on sound. Rashmi R. Agale [16] proposed a review paper, which ultimately concludes that nearly 70% of India's population is dependent on agriculture, has made it necessary to manage resources efficiently particularly in relation to irrigation and protection of crops. This study includes a solution that uses the IoT technology by integrating various sensors namely, temperature, humidity, soil moisture and PIR to monitor irrigation needs in real-time and security of farms. Overall, our measurement for deterrence effectiveness was greater than 90% with our system confirming crop protection the entire application periods, while protecting in various environmental conditions.

Table 4. Deterrence effectiveness

TEST CONDITION	DETERENCE EFFECTIVENESS
Day time detection	94
Night time detection	91
Small animal detection	88
Large animal detection	96
Overall average	92

The table demonstrates the system's deterrent effectiveness in different conditions. In daytime, the deterrent effectiveness was high (94%) because both the sound and visual deterrents acted effectively in combination. However, at night deterrent effectiveness was reduced slightly (91%) because the visual impact of the system was reduced as sight/visual impact is dependent on the light level, making the system rely on sound more. When it came to small animals, there was a dx of deterrent effectiveness (88%) compared to large animals (96%) because smaller species are less susceptible to deterrent signals and often adapt to quickly or bypass the deterrent signal altogether. All deterrents had an average stellar effectiveness of 92% confirming the ability of the system to reliably protect crops from an extensive list of animals. Vaishali Lohchab [19] published a review paper, this paper presents an IoT-based smart farming system that will facilitate real-time tracking of the agricultural fields in terms of hardware and software integration. It reviews weather station and mobile data logging, while describing the development of farming technologies, such as technological tools in the 1800s, to satellites in the 1900s.

ENERGY SUSTAINABILITY

The sustainable use of energy is an essential part of the IoT-enabled Animal Detection and Adaptive Sound Repellent System because the system is intended to be deployed in agricultural fields where consistent power may not always be available. The system integrates a rechargeable battery pack so that the system can operate at night or on cloudy days. The design also allows the incorporation of renewable energy options such as small solar panels, making a breadboard-verifiable sustainable and environmentally-friendly energy source. Field39 deployment tests revealed that the sensors and sound repellent units all utilize little energy due to optimized duty cycles whereby components remain in low power until activated by a detection event. This helps the components avoid wasting energy while ensuring maximum operational effectiveness. The components also were lightweight, low voltage, ultrasonic sensors, LED lighting, undertaken microcontrollers all optimized for using energy effectively.

SYSTEM LATENCY

System latency is the total delay from the time of the detection of an event. Latency refers to the sum of delays from all possible sources: how long it takes for the sensor's motion detection to send the information to the microcontroller; how long it takes for the microcontroller to process the information; how long until the microcontroller decides to initiate for example output devices such as speakers, buzzers or LED lights to function; and if the system involves IoT-based remote monitoring, the time it takes for the information sent over the network.

Table 5. System Latency

COMPONENT	TYPICAL LATENCY
Sensor detection	10 – 50
Processing by Microcontroller	5 – 20
Actuation of Output device	5 – 10
Communication / IoT Delay	50 – 200
Total system latency	70 – 300

The table illustrates the latency within each component, or stage, of the system, which represents the time between the event, such as animal detection, and the system responding to the event. The Component / Stage column identifies the hardware, or processes, that are responsible for the delay, which includes the sensor, processing by the microcontroller, actuation of the output device, and communication for an IoT source for monitoring. Typical Latency (ms) is the time in milliseconds of each stage.

The Notation column provides context details, such as factors that could change the delay, or under what terms it would happen. It is critical to understand these latencies for consideration when judging performance of the system, and ultimately if the purpose is to allow for a near real-time response, for effective crop protection. A review paper was published by Jiri Polivka [25] focusing on the technical backgrounds and functions of different types of microwave sensors, which have applications across industries including medicine, environmental studies and others. Understanding principles, functions, and limitations for your application is key for proper selection and use of the sensors.

ANIMAL BEHAVIOR RESPONSE

Animal behavior response encompasses the actions animals display when they encounter the stimuli of the protections developed system, such as sound repellents, lights, or other forms of deterrent. When the sensors detect an animal approaching, the system activates audible or visual stimuli, purposely designed to result in startled or rejection behavior. An animal's immediate behavior changes tend to be avoidance behavior, such as retreating or changing direction, or momentarily pausing before continuing. Subjectively, the behavior response will differ according to species, habituation, and intensity of the stimulus. Behavior changes will be monitored and assessed to reflect deterrent effectiveness, using sound frequency, light intensity, and activation patterns that may result in long-term, well-managed, humane methods of crop protection.

SAFETY AND ETHICAL CONSIDERATIONS

When developing and utilizing an animal deterrent system, safety and ethical considerations are also essential. The design of the system must consider a limitation of the stimuli (for example, high-frequency noise, flashing lights, or an alarm) at a level that does not create physical harm, distress, or long-term impactful behavioral adjustments to the animal. Sound pressure must abide by sound pressure levels that are acceptable levels for hearing health and visual stimuli should not risk panic, harm, or injury.

Venan Sibanda [12] presented a review paper, which concludes that collisions between wildlife and vehicles create an enormous cost to humans, the environment, and the economy. Often, it is the case that drivers see animals too late to avoid colliding with the animal. The system must comply with several local wildlife protection laws and adhere to humane treatment of all wildlife species. From a human safety perspective, electrical components, wiring, and power supply need to be mounted in a way that will not shock the user, short on the electrical service, or contribute to fire hazards. Thoughtful design, testing, and monitoring will form a system that is successful for crop production protection, and cognizant of animal welfare and owner safety.

XIII. Conclusion

The IoT-equipped system for animal monitoring and adaptive sound deterrence presents an inventive, environmentally friendly means of defending crops from animal intrusion, one of the ongoing challenges of agricultural land. The sensors detect animals approaching the monitored area and automatically trigger sound-based repellents that emit high-frequency sounds and visual stimuli to deter invasion generally without stress or injury to wildlife. Tanmay Baranwal [14] published a paper which concludes that agriculture-an essential component of the Indian economy-is under constant threat from rodents, insects, and storage pests, and that conventional protection mechanisms are not able to respond in real time.

A recent literature review discusses the potential of IoT and Wireless Sensor Networks to bring agriculture into the future through automated continuous monitoring and prompt notification. Concerns for energy sustainability were taken into consideration deploying rechargeable battery packs and low-power components to afford extended operation without routine maintenance. Latency in the system is minimal, as the total response is near real-time and overall operational time is between 70 and 300 milliseconds, which enables producers to mitigate losses from crop damage from animals. Observations of animal behavior demonstrated mammals, birds, and other agriculture-related pests reacted positively to the humane and safe deterrent stimuli, by either retreating or altering their movement pattern, particularly when a combination of stimuli types was deployed simultaneously.

Safety and concerns of moral and ethical protocols related to the treatment of wildlife have been addressed. Sound and visual stimuli were well within safe levels for wildlife in relation to actual physical injury and/or significant long-term behaviors. All electrical equipment is insulated at the point of impact to minimize injury to users.

Roxar ASA [10] shared a paper, outlining the field of microwave sensors. the applications in this broad area of microwave sensors are many, and the physical basis and some historical contexts are briefly introduced and a synopsis of typical advantages and disadvantages is given. a brief synopsis is included detailing the ways the microwave sensors operate and examples of the applications are included. The system follows local wildlife laws for humane displacement of wildlife, and also deploys remote IoT for overall compliance and constant monitoring of the system without the need for frequent human involvement.

XIV. Reference

1. R. S. Sabeenian, N. Deivanai, and B. Mythili, "Wild animals intrusion detection using deep learning techniques," Int. J. Pharm. Res., vol. 12, no. 4, pp. 1053–1058, 2020, doi: 10.31838/ijpr/2020.12.04.164.
2. Agnes, A., & Theepak, T. A. (2022). Animal movement detection along with differentiation and alert processing in farm lands. *Journal of Innovative Image Processing*, *4*(2), 79-92.
3. Sibanda, V., Mpofu, K., Trimble, J., & Zengeni, N. (2019). Design of an animal detection system for motor vehicle drivers. *Procedia CIRP*, *84*, 755-760.
4. Kumar, L. A., Neelaveni, R., Archana, N., & Saravanakumar, S. (2021, December). A Literature Research Review on Animal Intrusion Detection and Repellent Systems. In *Proceedings of the First International Conference on Combinatorial and Optimization, ICCAP 2021, December 7-8 2021*.
5. Covenant, L., Galli, F., Costa, A., & Moore, J. Enabling Smart Livestock Farming with Sensors and Machine Learning in Pig Farms.
6. McLelland, A. E., Winkler, C. E., & Martin-Iverson, M. T. (2015). A simple and effective method for building inexpensive infrared equipment used to monitor animal locomotion. *Journal of neuroscience methods*, *243*, 1-7.
7. Finawan, A. (2018). Design of wild animal detection and rescue system with passive infrared and ultrasonic sensor - based microcontroller. In *Proceedings of MICoMS 2017* (Vol. 1, pp. 415-422). Emerald Publishing Limited.
8. Haschberger, P., Bundschuh, M., & Tank, V. (1996). Infrared sensor for the detection and protection of wildlife. *Optical Engineering*, *35*(3), 882-889.
9. Chari, S., Halford, C., Jacobs, E., Smith, F., Brown, J., & Russomanno, D. (2009, May). Classification of humans and animals using an infrared profiling sensor. In *Unattended Ground, Sea, and Air Sensor Technologies and Applications XI* (Vol. 7333, pp. 247-255). SPIE.
10. Nyfors, E. (2000). Industrial microwave sensors—A review. *Subsurface Sensing Technologies and Applications*, *1*(1), 23-43.
11. Nanzer, J. A. (2017). A review of microwave wireless techniques for human presence detection and classification. *IEEE Transactions on Microwave Theory and Techniques*, *65*(5), 1780-1794.
12. Sibanda, V., Mpofu, K., Trimble, J., & Zengeni, N. (2019). Design of an animal detection system for motor vehicle drivers. *Procedia CIRP*, *84*, 755-760.
13. Zhang, Z., Zhang, H., & Liu, T. (2019). Study on body temperature detection of pig based on infrared technology: A review. *Artificial intelligence in agriculture*, *1*, 14-26.
14. Baranwal, T., & Pateriya, P. K. (2016, January). Development of IoT based smart security and monitoring devices for agriculture. In *2016 6th international conference-cloud system and big data engineering (confluence)* (pp. 597-602). IEEE.
15. Datta, N., Sarkar, S., Malik, A., & Punetha, D. (2016, September). Automatic tracking and alarm system for eradication of wild life injury and mortality. In *2016 2nd International Conference on Advances in Computing, Communication, & Automation (ICACCA)(Fall)* (pp. 1-4). IEEE.
16. Agale, R. R., & Gaikwad, D. P. (2017, August). Automated irrigation and crop security system in agriculture using Internet of Things. In *2017 International Conference on Computing, Communication, Control and Automation (ICCUBEA)* (pp. 1-5). IEEE.
17. Nagpal, S. K., & Manojkumar, P. (2016, February). Hardware implementation of intruder recognition in a farm through wireless sensor network. In *2016 International Conference on Emerging Trends in Engineering, Technology and Science (ICETETS)* (pp. 1-5). IEEE.
18. Keerthana, K. T. E., Karpagavalli, S., & Posonia, A. M. (2018, July). Retracted: Smart System Monitoring Agricultural Land Using Iot. In *2018 International Conference on Emerging Trends and Innovations In Engineering And Technological Research (ICETIETR)* (pp. 1-7). IEEE.
19. Lohchab, V., Kumar, M., Suryan, G., Gautam, V., & Das, R. K. (2018, April). A review of iot based smart farm monitoring. In *2018 Second International Conference on Inventive Communication and Computational Technologies (ICICCT)* (pp. 1620-1625). IEEE.
20. Yadahalli, S., Parmar, A., & Deshpande, A. (2020, July). Smart intrusion detection system for crop protection by using Arduino. In *2020 Second International Conference on Inventive Research in Computing Applications (ICIRCA)* (pp. 405-408). IEEE.
21. Moghavvemi, M., & Seng, L. C. (2004, November). Pyroelectric infrared sensor for intruder detection. In *2004 IEEE Region 10 Conference TENCON 2004.* (Vol. 500, pp. 656-659). IEEE.
22. Kenkre, P. S., Pai, A., & Colaco, L. (2015). Real time intrusion detection and prevention system. In *Proceedings of the 3rd international conference on Frontiers of intelligent computing: theory and applications (FICTA) 2014: volume 1* (pp. 405-411). Cham: Springer International Publishing.

23. Giubbolini, L. (2002). A multistatic microwave radar sensor for short range anticollision warning. *IEEE Transactions on Vehicular Technology*, *49*(6), 2270-2275.
24. Newhouse, N. (2003). The wildlife protection system: early successes and challenges using infrared technology to detect deer, warn drivers, and monitor deer behavior.
25. Polivka, J. (2007). An overview of microwave sensor technology. *High Frequency Electronics*, *6*(4), 32-42.
26. Patil, H. D., & Ansari, N. F. (2022, January). Intrusion detection and repellent system for wild animals using artificial intelligence of things. In *2022 International Conference on Computing, Communication and Power Technology (IC3P)* (pp. 291-296). IEEE.
27. Sabhahit, S. N., Naik, A. P., & AE, V. (2023). An animal intrusion detection and repellent system for farm safety using IoT.
28. Jamdagni, A., Tan, Z., He, X., Nanda, P., & Liu, R. P. (2013). Repids: A multi tier real-time payload-based intrusion detection system. *Computer networks*, *57*(3), 811-824.
29. Lin, J., & Li, C. (2007, December). Wireless non-contact detection of heartbeat and respiration using low-power microwave radar sensor. In *2007 Asia-Pacific Microwave Conference* (pp. 1-4). IEEE.
30. Manteuffel, C. (2019). Parturition detection in sows as test case for measuring activity behavior in farm animals by means of radar sensors. *Biosystems Engineering*, *184*, 200-206.