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IoT-based Farmland Security and Alert System

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Abstract

Farmland protection against animals, fires, and insufficient monitoring is among the major issues. Traditionally, farmland surveillance involved manual monitoring, which is not effective at times of emergencies. This study proposes the design of an IoT-Based Farmland Security and Alert System meant for real-time monitoring and securing agricultural lands. Ultrasonic sensors will be used to detect intrusion attempts, flame sensors for fires while emergency buttons for manual triggering of alerts. The ESP8266 NodeMCU Microcontroller will act as the main module continuously checking data from the sensors and triggering alerts in case of any abnormality detected. Notifications are then sent out to the phone of the farmer using WiFi connection and Telegram Bot API. Additionally, there will be ISD Voice Playback Module for alerts while the ESP32-CAM module takes real-time images of incidents. According to experimentation, the accuracy of detection of intrusions and fires will be 95.2% and 96.1% respectively while the average latency of alert notification is 1.8s. The proposed system is a cost-effective, scalable, power-saving, and highly reliable solution to improve smart agriculture and farmland security.

Keywords: Internet of Things (IoT), Farmland Protection System, ESP8266, Ultrasonic Sensor, Flame Sensor, Intrusion Detection, Fire Detection, Smart Agriculture, Telegram Alerts, Wireless Communication, Agricultural Automation.

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1. Introduction

The agriculture industry is a key contributor to global food production, as well as one of the major economic pillars of many countries. Nevertheless, most of these producers find it difficult to ensure security for their agricultural lands against animals' invasion, fires, and inability to continuously monitor their farms. Existing means of monitoring farms mainly occur within the confines of fences, where the monitoring takes much time, yet no instant notification in the event of an emergency situation will arise. Recent technological breakthroughs in Next Generation Internet of Things (NGIoT) have made it possible to create intelligent farms, which are remotely monitorable, controllable, and communicable through NGIoT.

In this study, the design and implementation of an IoT-based real-time monitoring system that will enhance farmland safety through the monitoring of the environment and alerting the farmer in the event of hazardous situations will be discussed. This project aims at detecting the presence of invaders through the ultrasonic sensors, identifying cases of fire through the flame sensors, and initiating alerts when the farmer presses a pushbutton.

The ESP8266 microcontroller processes and controls the entire monitoring process in the event of any abnormal situation. WiFi technology will enable the system to send notifications to the farmer's smartphone device. With the help of ESP8266 NodeMCU, this agricultural IoT security monitoring system utilizes both ultrasonic sensors and flame sensors to monitor farmlands and protect them from attacks and fires. As demonstrated in our experiment, this security monitoring system is highly effective, quick in response, reliable, and easy to visually monitor using the ESP32-CAM camera.

2. Related Works

In modern agriculture, the impact brought by innovative technologies such as the Internet of Things (IoT) cannot be overlooked. It is through innovations within IoT technology that automation, remote sensing, and real-time decision-making has become a possibility [1]. In the discussion of levels of IOT architecture, communication protocols and applications, there is provided a structure for interaction of the smart systems. On continuing from where Atzori left off, [2] provides an overview of middleware solutions in IoT scenarios that do not only take care of interoperability, scalability and efficient communication of smart devices but also offer a solution for communication between devices.

The use of WSN (wireless sensor network) in monitoring of not only the environment where crops are planted but also monitoring the status of the crops themselves [3]. This shows the importance of sensor-based monitoring in increasing agricultural productivity and efficiency. [4] utilizes GSM communication technology in order to come up with a water efficient irrigation system using mobile communication technology that would give the farmer remote control through a mobile phone.

The efficiency of IoT devices with energy-saving monitoring solutions was discussed, and it was shown that the use of low-power wireless communication plays an important role in measuring the environment [5]. Moreover, with the introduction of such low-cost microcontrollers as ESP32 and ESP8266, the development of IoT devices has been significantly boosted. In the work [6], a smart embedded IoT device has been developed with the help of an ESP32 microcontroller, showcasing the suitability of using this microcontroller for future developments. Along with microcontrollers, various sensors play an essential part in the implementation of smart agriculture technologies.

The work evaluated the capabilities of HC-SR04 ultrasonic distance measurement sensors, proving their efficiency in intrusion detection applications [7]. This paper proposed a firefighting robot controlled by flame sensors and capable of detecting and eliminating fire hazards [8]. The presented paper also developed an IoT-based agricultural monitoring system aimed at continuously measuring the environmental parameters [9]. Recently, An has implemented the use of deep learning techniques along with IoT to advance precision agriculture decision-making and predictions [10].

3. Proposed Methodology

The current research proposes a unique IoT-based security and monitoring system that offers continuous surveillance and timely alarm generation with regards to farmland environments. This system is based on the use of different types of sensors, wireless networking protocols, and image-based monitoring systems in order to ensure maximum farmland security and decrease dependence on manual monitoring procedures.

Figure 1 demonstrates the overall design of the current system. The system includes ultrasonic sensors, which help detect any intrusion, a flame sensor that is used to check whether a fire occurs, and a push button to generate manual alarms. All these sensors are connected to an ESP8266 NodeMCU microcontroller, which is a core processor of the current system. An ESP8266 microcontroller receives the data obtained by different sensors and compares them to threshold conditions set by a programmer in order to detect emergencies or abnormalities.

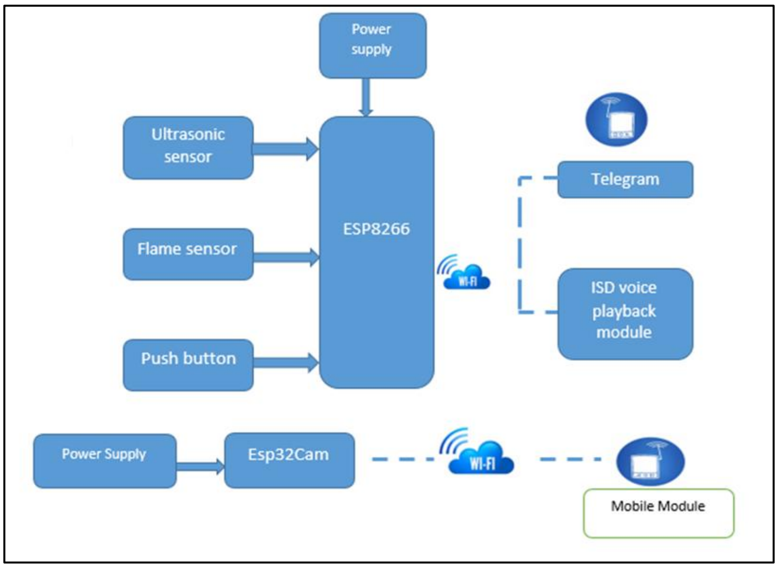

Figure 1. Block Diagram of the Proposed IoT-based Farmland Security and Monitoring System

When the ultrasonic sensor senses the presence of an object within the predetermined threshold value, the system determines that it is an intruder alarm. Likewise, when the flame sensor senses fire in its surroundings, the alerting system is activated immediately. In case of emergencies, the farmer can turn the system on manually by pressing the push button switch. As soon as the ESP8266 receives the information about any abnormality, it sends an immediate notification by sending the message via WiFi using Telegram bot API.

At the same time, the ISD voice player provides an audio alert to drive away the intruder from the scene. To improve the effectiveness of the surveillance and ensure verification of the alerts, the proposed system is also equipped with the ESP32-CAM module for real-time image capturing capability. As soon as the alerting signal is generated, the ESP32-CAM camera captures images of the field and sends them to the user via Telegram cloud.

The operation flow of the entire system can be viewed in Figure 2. First, all sensors, communication systems, and processing systems get initialized, and then they will be connected to the WiFi network. Subsequently, the ESP8266 constantly detects data from the sensors in real time. In accordance with the input values of the sensors detected, the system will proceed with verification of events and triggering the alert system. Flag-based event verification helps avoid re-transmitting the alerts.

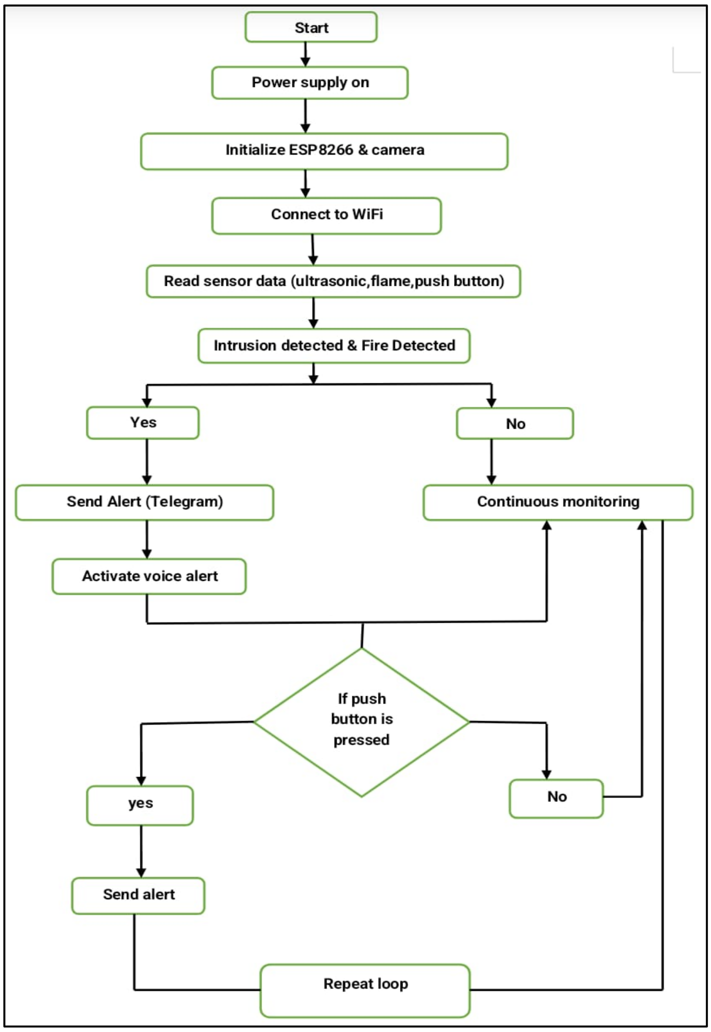

Figure 2. Overall Workflow of the Proposed System

Moreover, due to the continuous operation of the system throughout the 24 hours of a day and 365 days of a year, additional considerations have been made with regard to battery power supply and energy management. The energy consumption by the proposed system is optimized by the use of low-power hardware devices like ESP8266 NodeMCU and energy-efficient sensors. To facilitate prolonged continuous operation of the system in farmland settings, the proposed system will utilize rechargeable batteries that utilize solar panels to recharge the batteries. Additionally, various power optimization strategies will be employed in the system, which include but are not limited to sensor duty cycle operation, ESP8266 NodeMCU going into sleep mode when idle, and only activating ESP32-CAM sensors upon an event occurring.

As for the implementation process, it follows the algorithm described in the IoT-Based Real-Time Farmland Security and Alert Mechanism algorithm. The ESP8266 starts by initializing all sensors and communications channels, then connects to WiFi, monitors the distance to intrusions, checks for flames, and monitors the emergency button state. On detection of any critical condition, the device activates the alerting flag, plays voice alerts, captures photos with ESP32-CAM, and sends real-time notifications to the farmer via Telegram. When the critical condition is resolved, the device resets the alerting flag and goes back into monitoring mode.

Algorithm 1: IoT-Based Real-Time Farmland Security and Alert Mechanism

Input:
Ultrasonic sensor data D, flame sensor status F, emergency push button state P
Output:
Telegram alert notification, local voice alert, captured farmland image

1. Initialize ESP8266 NodeMCU, ESP32-CAM, ultrasonic sensor, flame sensor, push button, ISD voice module, and Wi-Fi communication interface.
2. Configure GPIO pins and initialize Telegram Bot API credentials.
3. Establish Wi-Fi connection using predefined SSID and password.
4. Set intrusion threshold distance D_{th}.
5. Initialize alert flags:
   $$\text{Intrusion\_Flag} = 0,\ \text{Fire\_Flag} = 0,\ \text{Emergency\_Flag} = 0$$
6. Start continuous monitoring loop.
7. Acquire distance value D from the ultrasonic sensor using echo pulse duration measurement.
8. Read flame sensor output F.
9. If
   $$D < D_{th}$$
   then:
   a) Set Intrusion_Flag = 1
   b) Generate intrusion alert message
   c) Activate ISD voice playback module
   d) Enable ESP32-CAM image capture
10. If flame is detected ($F = HIGH$), then:
    a) Set Fire_Flag = 1
    b) Generate fire alert message
    c) Activate local voice alarm
    d) Trigger ESP32-CAM image acquisition
11. Read emergency push button state P
12. If push button is pressed ($P = LOW$), then:
    a) Set Emergency_Flag = 1
    b) Generate emergency alert notification
    c) Activate local emergency voice alert
13. If any alert flag is active, then:
    a) Send alert notification to the user via Telegram Bot API

b) Capture farmland image using ESP32-CAM
c) Transmit captured image through Telegram cloud server
14. Store current alert status and apply flag-based validation to prevent duplicate alert transmission
15. Reset flags when sensor conditions return to normal state
16. Repeat Steps 7–15 continuously for real-time farmland monitoring and surveillance

4. System Implementation

As part of this research work, software as well as hardware was implemented as part of the proposed design. The hardware comprises the ESP8266 microcontroller, the ultrasonic sensor, the flame sensor, the push button, the ISD voice module, breadboard, jumper wires and power source. For programming purposes, the ESP8266 will be coded in using the Arduino IDE. Control logic coding will however be done in embedded C language. Telegram Bot API is used to send alert messages in real time using WiFi as medium of IoT communication between devices. The ESP8266, together with the ultrasonic sensor, flame sensor, and the push button, constitutes the hardware components of the proposed design. The ultrasonic sensor has its TRIG and ECHO connected to the ESP8266 and measures distances. In turn, the flame sensor gives out digital signals once it detects fire. Meanwhile, the push button is set as INPUT_PULLUP. The ISD voice module is then connected to ESP8266 outputs for sound alerts. All hardware components are assembled using the breadboard.

The coding process is done on the ESP8266 using Arduino IDE for support in libraries for WiFi and security. The coding process initializes all sensors before connecting to WiFi and reading data in a loop. There is also a program that contains conditions for detecting intrusions, fires, and other emergencies. In case there is any intrusion, fire, or other emergency, the program will notify about it via Telegram, and at the same time trigger voice output. To include image taking into the program, ESP32-CAM is included into the project to take pictures and monitor things.

There are various testing cases designed to test the system performance within real conditions. The system uses object detection for intrusion and fire detection, along with the manual activation of the system in case of emergencies. System efficiency will be evaluated through the use of ultrasound sensors placed at different distances between each other and checking if these sensors will initiate the alert condition. The reaction of flame detectors to controlled flame sources will be checked to see how quickly the sensor can trigger a warning to the staff. The operation of the push button feature will be tested when the button is pushed, and it should automatically activate the alarm. Connecting the ESP8266 device to the WiFi network triggers automatic and immediate real-time notification to the Telegram service; notifications will be transmitted in less than 2 seconds. Also, the quality of the output produced by the voice announcement module and accuracy of object detection will be tested within various environmental settings.

5. Results and Discussion

A prototype of a system that can detect threats such as intrusion or fire from the farm lands by utilizing an ESP8266 NodeMCU microcontroller has already been built with an ultrasonic sensor, a flame sensor and a push button for triggering the emergency mode of operation. The entire components are connected with the microcontroller through a breadboard that provides the necessary energy in order to make sound notifications from the speaker. These devices have been put into use in a virtual model of the farm land, where all of the sensors are monitoring the surroundings in which they are located, and if any abnormal occurrence is sensed, then a notification is issued by means of IoT.

Figure 3. Hardware Prototype of the Proposed System

In case of using an application such as telegram, it becomes possible to receive immediate notifications through a telegram bot. Figure 4 shows how, through this arrangement, it becomes possible to get immediate notifications for the purposes of fire detection, intrusion detection (in the range of 30 cm) and emergencies in milliseconds. Every alert is accompanied by a timestamp and is communicated to the user at once. This immediately makes it possible to respond accordingly and continue the monitoring process in real-time regarding the overall condition of the farms. From this information, one can conclude that not only does the system ensure real-time communication but also uses the IoT technology.

Figure 4. Telegram-Based Real-Time Alert Notifications

Figure 5. Real-Time Farmland Image Captured Using ESP32-CAM

The image from the camera module clearly demonstrates the process of real-time monitoring through the use of this technology. This camera will visually allow for monitoring of the agricultural land site from a distance, and will thus enable the user to monitor the well-being of the crops without necessarily being at the location. Besides enabling the user to visually check whether the crop is in good condition, the camera will provide images showing the actual physical structure of the Farmland Model, including the sensors and boundaries of the setup. Another important use of the camera image is to visually support the information obtained through sensor data, e.g., intrusion or environmental changes.

The visual data can therefore be relayed back to the end-user through the IoT communication capabilities of the proposed model, making the agricultural land security monitoring system more reliable and efficient. The proposed IoT-enabled agricultural land protection system was tested using real-time scenarios and some of the parameters involved were accuracy, delay, power consumption, reliability, and efficiency. The proposed model was able to produce the same results in detection of intrusion, fire, and emergencies within the same timeframe without being delayed at all in any of the test cases.

Table 1. Performance Evaluation of the Proposed System

Parameter	Measured Value	Observation
Intrusion Detection Accuracy	95.20%	Accurate detection within threshold range
Fire Detection Accuracy	96.10%	Reliable flame sensing performance
Alert Transmission Delay	1.8 seconds	Real-time Telegram notification
Image Capture Response Time	2.3 seconds	Fast ESP32-CAM operation
Power Consumption	4.8 W	Suitable for continuous monitoring
WiFi Communication Reliability	97%	Stable IoT communication
False Alarm Rate	3.10%	Minimal unwanted alerts

An experiment was carried out using the proposed IoT-based farmland security system to investigate how effective it is in detecting intrusion, fire hazard, making alerts, and facilitating remote monitoring under different conditions. During the test, the system was subjected to intrusion movements, simulation of flames, and manual triggering of emergencies. As shown in Table 1, the ultrasonic sensor was able to detect objects moving in a radius of 30 cm in 95.2% of cases. The ESP8266 controller used the signals from the sensor and sent a notification to Telegram within 1.8 seconds. Additionally, the ISD voice module generated alarms to notify nearby workers and deter animals from intruding into the farmyard. Regarding the fire detection capability, it was established that the flame detector can detect the presence of the fire in indoor and semi-outdoor environments at a reliability rate of 96.1%. Notifications for all fires detected by the device were immediately relayed to Telegram Bot API. In addition, images for each incident were automatically captured by the ESP32-CAM (IP camera module). It was established that it took about 2.3 seconds to send the image after the event was detected.

Moreover, the system was able to perform effectively as intended when put into operation during emergency scenarios that were manually initiated via the push button approach. The emergency notification feature of the system performed effectively and consistently during all testing cycles and there were no incidences where failed communication occurred between the emergency notification system. The application of flag-based validation technique greatly minimized duplication of notifications and the percentage of false alarms was limited to about 3.1%.

Table 2. Experimental Results Under Different Test Conditions

Test Scenario	Sensor Input Condition	Expected Output	Observed Result	Status
Intrusion Detection	Object detected within 30 cm	Intrusion alert and voice alarm	Alert generated successfully	Passed
Fire Detection	Flame present near sensor	Fire alert notification	Fire detected successfully	Passed
Emergency Mode	Push button pressed	Emergency warning message	Immediate alert generated	Passed
Image Monitoring	Alert condition activated	Image captured by ESP32-CAM	Image transmitted successfully	Passed
Normal Condition	No intrusion/fire detected	No alert generation	Stable monitoring observed	Passed

Table 2 presents the results from the testing of the IoT-Based Agricultural Security System via different operations. The first test was to test the intrusion detection system using the ultrasonic sensor (US). This operation was successful because the object was detected from an optimum distance of 30cm and warnings were raised accordingly. The second test was to detect any fire using the fire detector with a flame sensor. This operation also performed successfully in detecting the flames and raising a warning alarm. The emergency button was tested to show that pressing this button raises a warning alarm instantly. The third test was to monitor the system's ability to capture images. This operation was performed using the ESP32-CAM module by capturing and sending an image during an alert condition. The normal operation of the system showed consistency with constant monitoring and no false alarms.

6. Conclusion and Future Work

In this study, a Farmland Security and Alert System based on IoT principles was proposed for effective real-time monitoring and protection of the agricultural environment with the help of cost-effective and power-saving hardware components. Specifically, the suggested system includes an ESP8266 NodeMCU microcontroller and ultrasonic sensors, flame sensors, emergency push button, ISD voice player and ESP32-CAM providing continuous surveillance, intrusion detection, fire detection, generation of alerts, as well as the visual evidence. Experiments confirmed high reliability of the suggested system with intrusion detection and fire detection accuracy equal to 95.2% and 96.1%, respectively. Besides, the average time delay in alert notifications was relatively small and equal to 1.8 seconds. Thus, the Telegram messaging service provided efficient remote monitoring while the ability to transmit images helped to react faster to emergencies. Moreover, the low energy consumption and power saving measures make the proposed IoT-based system suitable for constant 24-hour operation at the agricultural field. Hence, the suggested system offers a cost-efficient, compact and intelligent tool for smart agriculture solutions. In future research, it is necessary to integrate artificial intelligence systems for animal recognition, cloud data analytics, solar autonomy, use GPS and other environmental monitoring measures.

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