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Article

IOT BASED SECURE AND SMART FARMING SYSTEM

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Abstract: Internet of Things (IoT) smart and secure farming solutions are made to monitor agriculture fields by automating irrigation systems and utilizing sensors. It refers to managing farms using contemporary information and communication technologies to grow to maximize the amount of human work needed while increasing the number and quality of products produced. An IoT-based smart and secure farming system helps farmers save costs in several ways. Field programmable gate array (FPGA) boards and ESP8266 were used on the transmitter interfaced with the DHT11, soil moisture sensor, PIR motion sensor, and buzzer and communicate wirelessly using the sender and receiver sides equipped with ESP8266 to send the data without the internet. After collecting sensor data from the DHT11 and soil moisture sensor, the FPGA uses the secret key to encrypt the data before sending it from the transmitter side using the multiple ring oscillator-based TRNG architecture, which consumes only 2 LUTs and 2 DFFs and an exclusive-OR (XOR) function. After being decrypted at the receiver, the sensors' values were appropriately displayed and transferred to the ThingSpeak cloud for real-time monitoring. The proposed TRNG-based IoT system is low-power and highly secure, making it ideal for standalone applications.
Keywords: Smart Farming, IOT, ESP8266, FPGA, UART, Thing Speak Cloud

1. Introduction

Agriculture is one of the most important sectors that affects any country's economy and society. In terms of production, consumption, exports, and development potential, the food processing sector plays an important role for boosting any country's economy. Agriculture consumes 85% of freshwater resources globally, and this trend is expected to continue due to population expansion and growing food demand. In agriculture, the IoT is a network of connected devices, sensors, and machines that gather, transmit, and act on data to optimize farming operations. IoT enables the precise application of water, fertilizer, or pesticide at the appropriate time and location, minimizing waste and cost while increasing yield. IoT can be used for smart agriculture [1]. Smart agriculture uses IoT and big data to enhance efficiency and productivity [2]. Some of the most extensively used smart agriculture equipment includes weather stations that aggregate data from numerous smart farming sensors. These sensors record data about the environment and upload it to the cloud, helping farmers to adjust their reactions according to climate circumstances. All of these IoT elements together are a farm productivity management system — a single, cloud-based dashboard that collects, evaluates, and reports on all the farm’s IoT devices and sensors. Modern agriculture is all about data. These data help farmers to make real-time decisions. By using these data, farmers can perform various activities such as when to irrigate and what to fertilize. Digital agriculture uses IoT sensors, drones, automated irrigation systems, and cloud-based platforms to enhance productivity and sustainability. But digital agriculture suffers from various risks such as hacking, data breaches, and ransomware attacks [3] due to these risks' increasing vulnerability. Digital agriculture must be secured. Security systems can be used to protect the farm from theft, damage, and cyber threats [4]. To enhance the irrigation efficiency, soil moisture, and temperature sensors. A motion detection sensor along with a NODEMCU ESP8266 microcontroller chip can be used [5]. By using these components, farmers can optimize the irrigation while using minimum resources. FPGAs can be used for building smart and secure farming systems. FPGAs are popular for these applications because they are quick, can perform several tasks at the same time, can be reprogrammed, and can handle complicated control functions. It provides built-in memory for storing digital data, ranging from small flip-flops to huge memory blocks. For smart agriculture, examples of communication technologies are Bluetooth (range 100 m), ZigBee (range 1 km), LoRaWAN (range 20 km), and EC-GPRS (range 5 m) [6]. Smart farming demonstrates that FPGA may enhance security and performance in IoT-based agricultural systems. To collect data in these systems, the transmitter side connects sensors to a microcontroller such as the ESP8266. Before data is sent, the FPGA is employed on the transmitter side to perform activities such as data encryption, key generation, and secure processing. The receiver block decrypts the sensor data received from the transmitter block and displays the decrypted data on the IoT. TRNGs (true random number generators) are very popular for generating random keys for performing encryption and decryption of sensitive data. ADPLL-based TRNG architectures [7, 8, 9] can be used for securing agricultural field data. This work designed and developed an IoT-based secure and smart farming system using Artix7 FPGAs and ESP8266 chips along with sensors. Compared to conventional smart farming systems, the proposed system uses a multiple-ring oscillator-based TRNG architecture to secure agricultural field data. The used TRNG architecture is designed using VHDL and implemented on an Artix7 FPGA chip. The proposed work is able to securely transmit DHT11 temperature sensor and capacitive soil moisture sensor data wirelessly to the receiver side for a 24x7 duration. In the proposed system, the transmitter side is equipped with an FPGA, ESP8266, DHT11, capacitive soil moisture sensor, PIR motion sensor, and buzzer, while the receiver side is equipped with an ESP8266 chip for receiving encrypted sensor data, performing decryption, and displaying these data to the ThingSpeak cloud for real-time monitoring. The proposed system is very reliable, fast, reprogrammable, automatic, and cost-effective, as it is implemented using an FPGA. Experimental results are captured using serial monitors of the ESP8266 chip and ThingSpeak cloud.

2. LITERATURE SURVEY

In [10], by using hardware and software components, an IoT-based intelligent smart farming system is developed. Temperature, humidity, and soil moisture sensor data are sent to an Arduino Uno for display on the serial monitor, and these data are sent to the Raspberry Pi via an Arduino Uno board for displaying in the form of graphs by using the ThingsBoard server. The proposed system is able to produce correct sensor results and boost agricultural produce.

A smart irrigation system based on IoT was designed and implemented for precision agriculture and water conservation in paper [11]. The proposed system produces an efficient water management system by using DHT11, soil, raindrop, PIR motion sensors, and an ESP8266 WiFi chip. Compared to other timer-based irrigation systems, the proposed system's water usage efficiency improved by 42%. Paper [12] outlined the use of a smart farming system by using an IoT technology to enhance the agricultural production. A smart farming system is based on two parts: 1. Sensor system and 2. Control system are developed using Arduino technology for improving production processes in planting [13]. The sensor system contains various sensors, whereas the control system contains

blower, watering, and roofing system. Python GUI is used to design control systems. Sensor results are displayed on an LCD display and serial monitor, and they are also stored in a database in Excel sheet format. By using a Raspberry Pi, an IoT-based smart irrigation system is developed for monitoring plant growth [14]. The proposed system is equipped with various sensors, automatic water motor control, and a webcam to monitor plant growth. An agricultural stick [15] based on an Arduino Uno board, cloud computing, and solar technology was proposed for live monitoring of temperature and soil moisture sensor data. The Thingspeak.com website is used to display live temperature and soil moisture sensor data and time. A cost-effective, smart agriculture system based on IoT is developed for monitoring the crops' growth [16]. By using a pH, soil, and water level sensor and an Arduino Uno board, an IoT-based smart farming system is developed for monitoring crop yield in agricultural farms [17].

3. PROPSED IOT BASED SMART AND SECURE FARMING SYSTEM

The proposed system integrates multiple sensors at the transmitter side along with ESP8266 and FPGA to ensure real-time monitoring, data protection, and secure communication. The system is to observe environmental factors, including temperature, humidity, and soil moisture, using sensors such as the DHT11 and a soil moisture sensor. It enhances farm security by detecting animal and human movement using a PIR motion sensor. When motion is detected, a buzzer alerts farmers. The main objectives of the proposed system are

- **Real-time Environmental Monitoring**:

The system continuously measures important environmental conditions, such as soil moisture, temperature, and humidity. These factors are very important for healthy plant growth. [18].

• **Automated Irrigation and Climate Control:**

The system automatically controls irrigation based on sensor readings. When the soil moisture level falls below a set limit, the farmer needs to water the field.

• **Security Enhancement**:

PIR motion sensors and a buzzer are used to detect animals or unauthorized persons entering the farm area. When movement is detected, the buzzer alerts the farmer, helping to protect crops and farming equipment.

• **Data-Based Decision Making:**

The system provides real-time data and stores past data, allowing farmers to understand field conditions better.

Using ESP8266 modules, sensors, and an FPGA, the secure IoT-based smart farming system is intended to monitor environmental conditions and offer agricultural security. The transmitter side and the receiver side are the two components of the system.

3.1 Transmitter Side

An ESP8266 microcontroller is utilized at the transmitter side to communicate with various sensors. While the soil moisture sensor measures the volumetric content of water inside the soil and gives us the moisture level as output, the DHT11 sensor detects temperature and humidity. Movement of people or animals in the farm area is detected by a PIR motion sensor. When motion is detected, a buzzer is sounded to give an immediate alert. At regular intervals, the ESP8266 gathers sensor data, and the FPGA is interfaced with the ESP8266 via UART [19, 20, 21]. The FPGA performs hardware-based encryption on the acquired sensor data. This improves system security by shielding data from illegal access and manipulation. Encrypted data packets are transmitted using the ESP-NOW protocol to the receiver ESP8266. This peer-to-peer communication operates "without internet" and offers low-latency, energy-efficient data transfer within the farm. Figure 1 represents the overall block diagram of the proposed system.

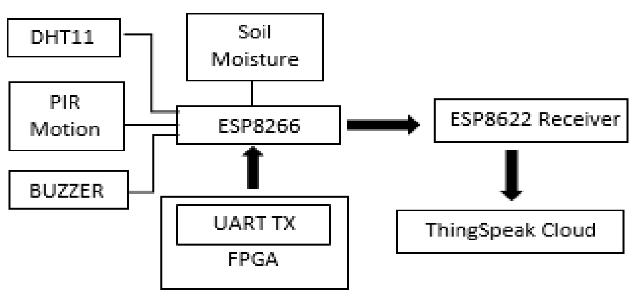

Figure .1: Block Diagram of the proposed IOT based smart and Secure Farming System

3.2 Receiver side

On the receiver side, the ESP8266 receives the encrypted data and performs decryption. It receives the encrypted data packets from the transmitter via ESP-NOW. Only the receiving side is connected to the internet. The decrypted sensor results are transferred to the ThingSpeak cloud platform, where real-time graphs are provided for temperature, humidity, and soil moisture. This approach guarantees safe, effective, and affordable smart farming monitoring. Table I shows the interfacing of various sensors, a buzzer, an ESP8266, and an FPGA board.

Table I: ESP8266 pin description for interfacing with DHT11, Soil moisture, PIR motion sensor and Buzzer to FPGA board

ESP8266PIN	**FPGA**	**VCC**	**DHT11**	**Soil Moisture**	**PIR Motion**	**Buzzer**

<table>
<tr><td>D1(GPIO5)</td><td rowspan="4"></td><td rowspan="5">VCC(+5V)</td><td>Data output</td><td></td><td rowspan="2"></td><td rowspan="3"></td></tr>
<tr><td>A0(ADC0)</td><td rowspan="4"></td><td>Aout</td></tr>
<tr><td>D7(GPIO13)</td><td rowspan="3"></td><td>Dout</td></tr>
<tr><td>D6(GPIO12)</td><td rowspan="2"></td><td>Dout</td></tr>
<tr><td>RXD0(GPIO3)</td><td>JC1(K17)</td><td rowspan="2"></td></tr>
<tr><td>Ground</td><td colspan="5">Gnd</td></tr>
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Components diagram for constructing the proposed system are shown in below figures.

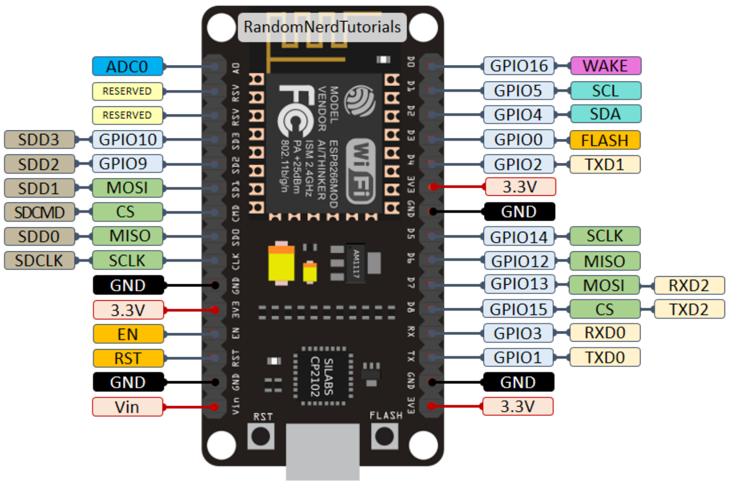


Figure 2 **:** Node MCU ESP 8266 diagram

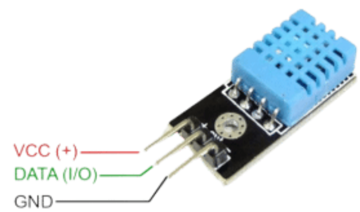
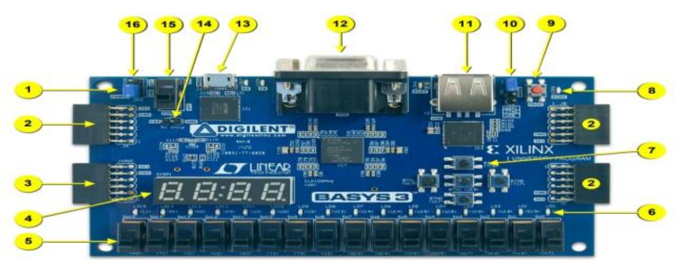


Figure 3: DHT11 sensor diagram

Figure 4 : Capacitive Soil Moisture Sensor

Figure5 : PIR Motion Sensor



Basys 3 FPGA board with callouts.

Callout	Component Description	Callout	Component Description
1	Power good LED	9	FPGA configuration reset button
2	Pmod port(s)	10	Programming mode jumper
3	Analog signal Pmod port (XADC)	11	USB host connector
4	Four digit 7-segment display	12	VGA connector
5	Slide switches (16)	13	Shared UART/ JTAG USB port
6	LEDs (16)	14	External power connector
7	Pushbuttons (5)	15	Power Switch
8	FPGA programming done LED	16	Power Select Jumper

Figure 6: Artix7 Basys3 FPGA diagram

Figure 7:Buzzer diagram

3.3 Key generation

In the proposed secure IoT-based smart farming system, key generation plays an important role in protecting sensor data. Since the transmitter side of ESP-NOW communication does not have internet access, secure encryption is necessary prior to data transmission. The encryption key is generated and controlled by the FPGA module. During system setup, this key is safely kept in the transmitter ESP8266–FPGA unit as well as the receiver ESP8266. After gathering sensor data from the DHT11 and soil moisture sensor, the FPGA uses the multiple ring oscillator (MURO)-based TRNG [22] architecture to generate the secret key to encrypt the data before sending it from the transmitter side. Figure 8 represents the diagram of the used ADPLL [23, 24, 25]-based MURO-TRNG architecture to generate the secret key for performing encryption and decryption. Used MURO-TRNG designed using VHDL and synthesized using the Xilinx Vivado 2015.2 tool. By using XOR function, sensors data and secret key are encrypted in the transmitter side, and on the receiver side, received encrypted sensors data are XORed with same secret key to decrypt the sensors data. Before uploading the received data to ThingSpeak, the recipient side decrypts it using the same pre-shared key as the transmitter. Unauthorized access is avoided since the key is safely held in both devices and is never sent in an open manner.

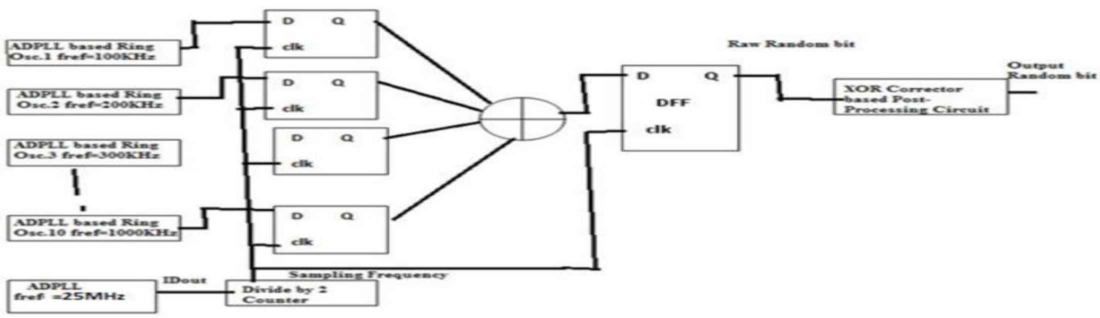


Figure 8: ADPLL Based MURO – TRNG Architecture [22]

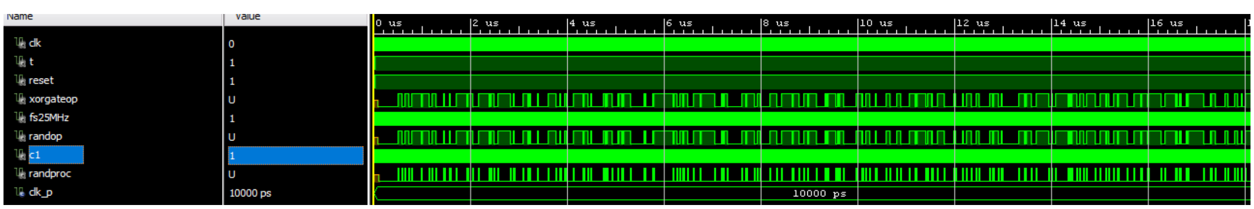


Figure 9: Simulation output waveform for MURO-TRNG at reference frequency 25MHz [22]

The simulation output waveform [22] for the used MURO-TRNG architecture at the reference frequency of value 25 MHz for generating random keys for the transmitter and receiver sides is shown in Fig. 9.

4.EXPERIMENTAL RESULTS AND DISCUSSION

Figure 10 shows the complete setup diagram for the secure IoT-based smart farming system. The main result of our project was tested according to VHDL code and ESP8266 programming, and the system has two sections: the transmitter side and the receiver side. The Xilinx Vivado 2015.2 tool was used for design and synthesis of the proposed wireless communication system, which is executed on the Artix-7 FPGA device. Figure 11 represents the diagram of interfacing various sensors and FPGA with the ESP8266. Random keys generated by the MURO-TRNG architecture are transmitted to the ESP8266 chip via UART communication. UART transmitter operates at 9600 baud rate uses Artix7 FPGA chip pin K17(PMOD JC1) to pass generated random keys from MURO-TRNG architecture to ESP8266 chip via RXDO(GPIO3) pin. Transmitter and receiver side diagrams along with their serial monitor outputs are shown in Figs. 12 and 13, respectively. Firstly, the ESP8266 interfaces with DHT11 GPIO5 pin (D1). This sensor is used to measure temperature and humidity in the farming field. During the experiment, the DHT11 sensor measured temperature values between 20°C and 34°C and humidity values between 30% and 90%, depending on environmental conditions. The ESP8266's analog input pin (A0) was connected to the capacitive soil moisture sensor and is used to measure the water content in the soil. It gives analog output values, which are read by the ESP8266 microcontroller. When the soil moisture sensor output value is less than a predefined threshold value of 300, then the soil is wet. When the soil moisture sensor output value is greater than a predefined threshold value of 300, then the soil is dry. This threshold value is fixed after conducting experiments several times with the soil moisture sensor. The temperature, humidity, and soil moisture data were encrypted by the FPGA by using the TRNG output as a key before transmission. After decryption at the receiver side, the same values were displayed correctly and uploaded to the ThingSpeak cloud platform for real-time monitoring.

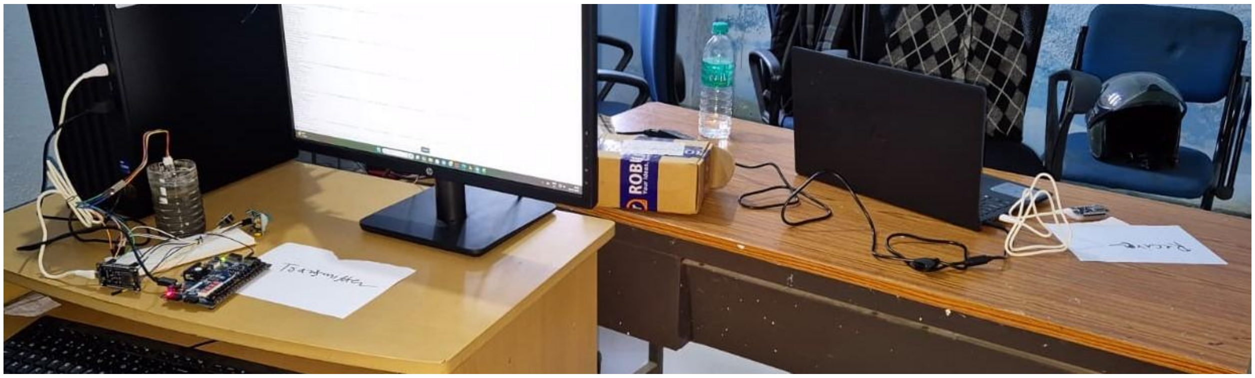
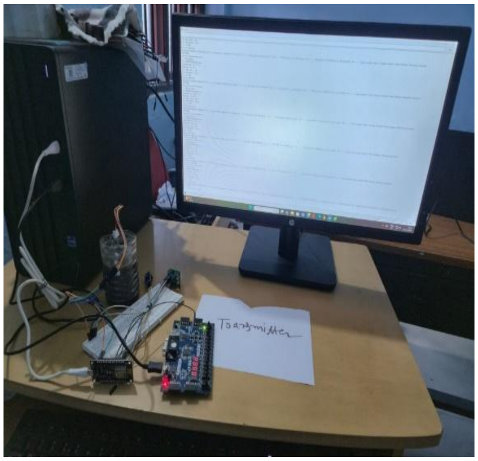


Figure 10: Complete set up diagram of the secure IoT-based smart farming system

Figure 11 : Interfacing of various sensors with ESP8266 and FPGA interfacing diagram



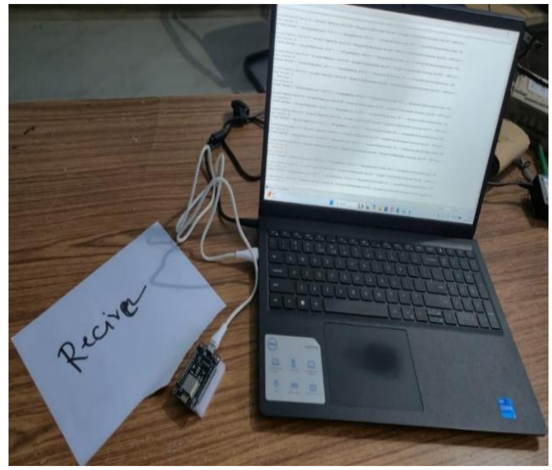
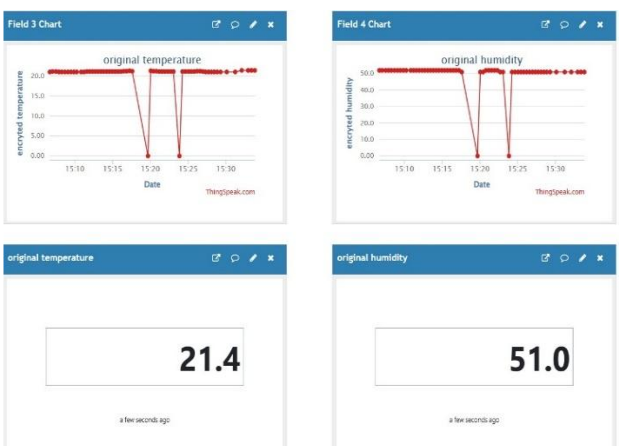


Figure 12: Transmitter Side Diagram

Figure 13: Receiver Side Diagram

The ESP8266 digital input pin (D7) is connected to the PIR (Passive Infrared) motion sensor and is used to detect human or animal movement in the farming field. The PIR sensor gives a digital output signal. The output value is either HIGH (1) or LOW (0). When movement was detected, the output changed to HIGH. At this time, the buzzer was activated to give an alert sound. The receiver successfully collected encrypted data from the transmitter through ESP-NOW communication. After receiving the data, the ESP8266 decrypted it and displayed the correct sensor values. The receiver was connected to the internet only for uploading data to the ThingSpeak cloud platform. The cloud dashboard showed real-time graphs of original (temperature & humidity) and encrypted (temperature & humidity) data, and original (soil moisture dry & wet) and encrypted (soil moisture dry & wet) data. Thingspeak website outputs for original temperature and humidity data are shown in Fig. 14, and their encrypted outputs are shown in Fig. 15. This figure shows that encrypted temperature and humidity have different values in comparison with original temperature and humidity data.



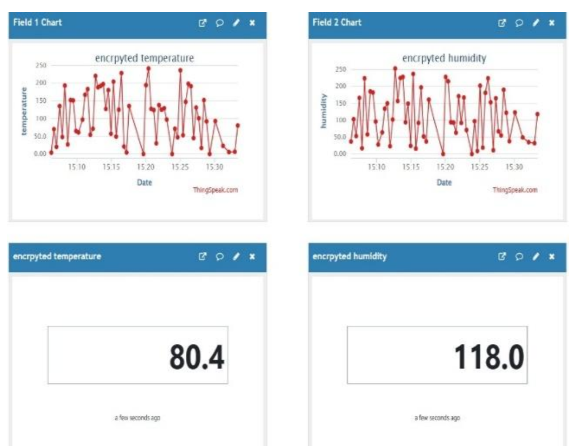
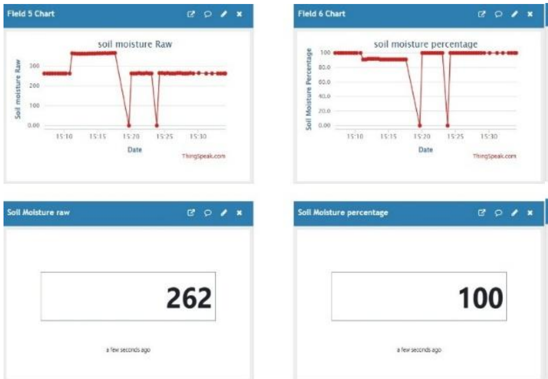


Figure 14 : Original Temp & Humidity data

Figure 15 : Encrypted Temp & Humidity data



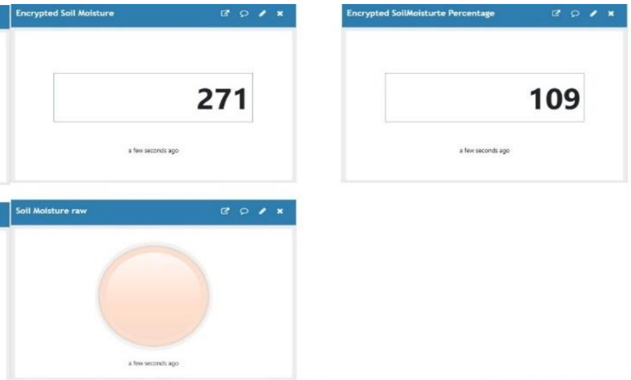


Figure 16: Original Soil Moisture data Figure 17: Encrypted Soil Moisture data

Thingspeak website outputs for original soil moisture and encrypted soil moisture data are shown in Figs. 16 and 17, respectively. This figure shows that encrypted soil moisture data have different values in comparison with original soil moisture data. In figure 17,lamp indicator inidicates the soil mositure status(either dry or wet).Arduino serial monitor output for displaying received sensor data is shown in Fig.18. This diagram shows real-time ESP-to-ESP communication for a secure IoT-based smart farming system. In this diagram, the byte received value, encrypted DHT11 and soil moisture sensor values, and decrypted DHT11 and soil moisture sensor data are shown.

Figure 18: Receiver side serial monitor output

5. CONCLUSION

In this work, we have designed and developed an IoT-based secure and smart farming system using an ESP8266, sensors, and an Artix7 FPGA board. The integration of ESP8266 microcontrollers with sensors like DHT11, soil moisture sensors, PIR motion sensors, and buzzer alerts is used in IoT-based smart farming systems. With the help of these devices, farmers can keep an eye on agricultural conditions in real time and respond quickly when necessary. Precision farming and farm safety are enhanced by the use of an FPGA at the transmitter side, which adds quick data processing, improved security, and real-time analysis. Experimental results show that our prototype is producing sensor results at the receiver side with 100% accuracy. The proposed design uses ADPLL-based low power, MURO-TRNG architecture for generating random keys for securing our farming system. The proposed system responded fast, is highly reliable, and is cost-effective. The proposed prototype can be used for yielding food products that are very costly.

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Data Availability Statement: Dataset available on request from the authors.

Conflicts of Interest: The authors declare no conflicts of interest.

Ethics: not applicable

Consent to Participate: not applicable

Consent to Publish: not applicable

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