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LoRa-Enabled NodeMCU Nodes for Efficient Agricultural Monitoring in IoT: Integration with Raspberry Pi Web Application

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***Abstract*—Agricultural monitoring is essential for optimizing crop production and ensuring food security. However, conventional methods of monitoring are often costly, labor-intensive, and unreliable. In this paper, we propose a novel agricultural monitoring system that uses a network of low-cost, low-power, and long-range devices to collect and transmit data on various soil and environmental parameters. The system consists of a main central unit based on Raspberry Pi, and several nodes distributed across the field, each equipped with an ESP32 microcontroller and sensors for measuring soil moisture, water level, temperature, and humidity. The nodes communicate with the central unit using LoRa, a wireless technology that offers long-range, low-bandwidth, and low-power communication. We compare the performance of LoRa with other wireless technologies such as Wi-Fi and ZigBee and show that LoRa has several advantages in terms of range, power consumption, scalability, and robustness. The central unit processes the data and displays it on a web interface, which allows the user to monitor the field conditions and control the irrigation system remotely. We evaluate the feasibility and effectiveness of our system through simulations and experiments, and demonstrate that it can provide accurate, timely, and reliable information for agricultural management.**

Keywords—IoT, LoRa, Raspberry Pi, Agriculture, Monitoring systems *(key words)*

I. INTRODUCTION

Agriculture stands as a cornerstone of human civilization, providing sustenance and economic stability across the globe. The practice of agriculture has evolved significantly, incorporating technological advancements to improve productivity, sustainability, and efficiency. In particular, agricultural monitoring plays a pivotal role in optimizing crop production, mitigating risks, and ensuring food security in an ever-changing environment. Traditionally, agricultural monitoring relied on manual observations and labor-intensive methods, which often proved to be costly, time-consuming, and prone to errors. However, with the advent of Internet of Things (IoT) technologies, there arises a promising opportunity to revolutionize agricultural monitoring through the integration of low-cost, low-power, and long-range devices. In response to the limitations of conventional monitoring techniques, this paper proposes a novel agricultural monitoring system leveraging IoT principles and wireless communication technologies. The system is designed to gather and relay real-time data concerning diverse soil and environmental parameters crucial for informed agricultural decision-making. IoT applications enable farmers to analyse data, forecast future conditions, enhancing productivity, reducing costs, and preserving resources. This technology finds utility across various intelligent agriculture domains, including open-field agriculture, greenhouse farming, livestock management, agricultural machinery, grain storage, and more[1][2]. The cornerstone of our proposed system lies in its utilization of a network of low-cost, low-power, and long-range devices strategically distributed across agricultural fields. Each node within the network is equipped with an ESP32 microcontroller and an array of sensors capable of measuring critical parameters such as soil moisture, water level, temperature, and humidity. These nodes serve as the primary data collection units, facilitating the continuous monitoring of field conditions with high accuracy and reliability. Central to the system architecture is the main central unit, which operates on a Raspberry Pi platform. The central unit acts as the nerve centre of the monitoring system, orchestrating data aggregation, processing, and dissemination tasks. Through the seamless integration of various hardware and software components, the Raspberry Pi central unit enables efficient management and control of the entire agricultural monitoring network. Key to the communication infrastructure of our proposed system is the adoption of LoRa (Long Range) technology. LoRa offers distinct advantages over traditional wireless communication protocols such as Wi-Fi and ZigBee, including extended range, low-power consumption, scalability, and robustness. By harnessing the capabilities of LoRa, our system ensures reliable long-distance communication between nodes and the central unit, even in remote or challenging environments. The integration of LoRa-enabled NodeMCU nodes within our IoT framework presents a paradigm shift in agricultural monitoring, offering unparalleled capabilities for scalability, efficiency, and data integrity[3][4][5]. Through a comprehensive analysis and comparison with alternative wireless technologies, we demonstrate the superior performance and suitability of LoRa for agricultural monitoring applications. Furthermore, the paper highlights the user-centric design approach employed in the development of the monitoring system. A web-based interface hosted on the Raspberry Pi central unit provides users with intuitive access to real-time field data and control functionalities. This interface empowers users to monitor field conditions remotely and make informed decisions regarding irrigation management and crop cultivation practices. In the subsequent sections, we delve into the technical intricacies of our proposed agricultural monitoring system, including hardware specifications, communication protocols, data processing algorithms, and user interface design. Through a combination of simulations and real-world experiments, we evaluate the feasibility, effectiveness, and practical implications of our system in enhancing agricultural management practices. In summary, our research endeavours to address the pressing need for scalable, cost-effective, and reliable solutions in agricultural monitoring. By harnessing the power of IoT technologies and LoRa communication, we present a comprehensive framework that promises to revolutionize agricultural monitoring, paving the way for sustainable and resilient food production systems in the digital age.

II. PROCEDURE FOLLOWED

A. *Choosing the best communication network and the reason for choosing LoRa*

There are many different types of communication systems present that can be used in the given scenario of IoT communication and the fact that there are so many of them also gives us consumers and researchers the ability to compare and clearly distinguish between the different ones and select and tune the most optimal one required for our particular use case scenario.

The main ones that are in use are the Wi-Fi technology LoRa Technology and the ZigBee technology. The easiest way to compare these three is to list their advantages and disadvantages for use in the agricultural fields.

LoRa and ZigBee are prominent communication protocols employed in wireless networks, particularly for applications in building automation and environmental monitoring. LoRa utilizes chirp spread spectrum modulation, operating in the ISM bands such as 868 MHz in Europe and offering communication ranges of 10-40 km in rural areas. In contrast, ZigBee is a low-cost, low-power, multi-hop technology suitable for home automation with reliability and easy integration. Experimental studies have explored the performance of both technologies, emphasizing factors like large-scale fading, temperature influence, and simulation tools for network evaluation. In our study, we conducted three experimental scenarios—line-of-sight, horizontal, and vertical—comparing LoRa and ZigBee in whole-building communication. LPWANs are used specifically when there is a need for extended coverage, need of low power consumption network, involving devices with high data rates and with some delay tolerance [6]. The results indicate that LoRa exhibits superior penetration through obstacles like cement and reinforced concrete walls, providing longer communication distances. While ZigBee supports long-distance communication through routing nodes, it faces challenges with data packet loss. LoRa generally demonstrates lower Round-Trip Times (RTT), although in some cases, ZigBee outperforms due to its optimized transmission path [7][8]. For multi-floor measurements, placing equipment near windows enhances transmission effectiveness. Our findings suggest that LoRa offers more noticeable performance advantages for entire building deployments, while ZigBee remains a viable option considering cost and power consumption. LoRaWAN is ideal for Precision Agriculture, offering long-range communication with low power consumption, and is widely used to monitor various agricultural parameters like moisture, humidity, temperature, and pH [9][10]. Future research will focus on optimizing node locations, developing integrated monitoring equipment, and leveraging IoT platforms for prolonged indoor environmental monitoring. Additionally, a comprehensive comparison of experimental and simulation results will enhance the accuracy of models, guiding future research endeavors. In rural regions, multiple trials have shown effective coverage provided by LoRa technology [11][12][13]. The LPWAN technologies takes advantage of highly con-strained radio links with low data-transmission requirements [14].

Apart from that we have several steps that need to be followed to construct our system. The main part is to set up the main Raspberry Pi structure and then to integrate the ESP32 as a node receiver and then to finally send and execute the commands required.

The major steps are listed below:

1. Raspberry Pi setup as a server and central node and command center for the entire field.
2. ESP32 is set up with LoRa receiver to receive commands and also send feedback about the status of the node.
3. LoRa communication network is set up to send and receive information.
4. All sensor units of Soil moisture, Rainfall, Humidity and temperature along with the motor and LED are also set up to monitor the status of the nodes at which they are present thus giving the overall view of the entire field.

B. *Component and their Specifications*

1. *Raspberry Pi 3 Model B:*

The Raspberry Pi 3 Model B serves as the central processing unit (CPU) in the system, offering computational power, memory resources, and connectivity options. With a Broadcom BCM2837B0 SoC, featuring a quad-core ARM Cortex-A53 processor running at 1.2 GHz, the Raspberry Pi 3 Model B provides ample processing capabilities for data aggregation and analysis.

2. *ESP32:*

The ESP32 microcontroller is employed for interfacingwith various sensors and managing wireless communication using the LoRa sx1276 module. Equipped with a dual-core Tensilica LX6 microprocessor, the ESP32 supports Wi-Fi and Bluetooth connectivity, enabling seamless integration with the Raspberry Pi 3 Model B for data transmission and control.

3. *LoRa sx1276:*

The LoRa sx1276 module facilitates long-range communication between the agricultural monitoring system and base stations. Operating in the sub-GHz frequency bands, the LoRa sx1276 module offers low- power consumption and extended communication range, making it ideal for remote monitoring applications in agricultural environments.

4. *Soil moisture sensor:*

The Soil Moisture Sensor measures the volumetric water content in soil, providing crucial information for irrigation management and soil health monitoring. Utilizing capacitive sensing principles, the sensor interfaces with the ESP32 microcontroller to transmit real-time soil moisture data to the Raspberry Pi 3 ModelB.

5. *DHT11:*

The DHT11 sensor measures temperature and relative humidity levels in the environment. Integrated with the ESP32 microcontroller, the DHT11 sensor utilizes a digital signal output protocol for accurate environmental monitoring.

6. *Rainfall sensor:*

The Rainfall Sensor detects the intensity and duration of rainfall events, aiding in water resource management and crop yield prediction. Interfaced with the ESP32 microcontroller, the rainfall sensor utilizes a tipping- bucket mechanism to quantify rainfall data, which is transmitted to the Raspberry Pi 3 Model B for analysis.

7. *Servo Motor:*

The MG995 servo motor is a versatile component widely used in robotics and automation. With its high torque output of up to 13 kg-cm and metal gears, it offers robust performance suitable for a variety of applications. Operating at a voltage range of 4.8V to 7.2V, this motor provides precise control and smooth operation through its 180-degree rotation capability. Featuring ball bearings for reduced friction and increased durability, the MG995 servo motor is compatible with standard servo PWM signals, making it an ideal choice for hobbyists, makers, and professionals seeking reliable and efficient motion control solutions.

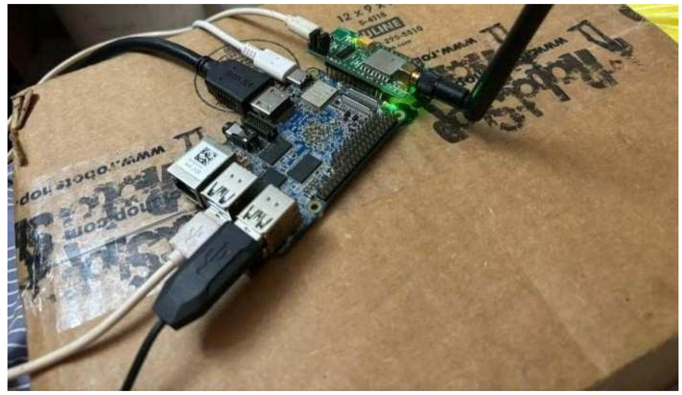

Fig. 1 Raspberry Pi main server with LoRa.

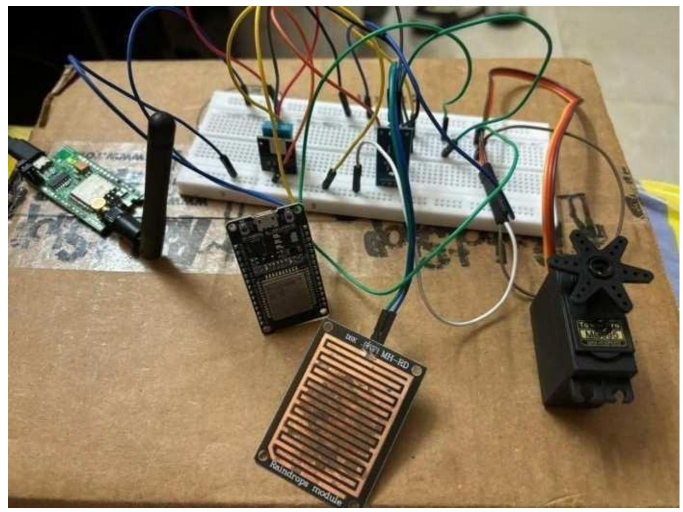

Fig. 2 The Node ESP with all sensors and LoRa.

Fig. 1 and Fig. 2 is the visual representation of the system proposed for agricultural monitoring system with LoRa modules.

III. RESULTS

Upon the successful implementation of our system, we observed the transmission of data to the ThingSpeak server, with a corresponding image displayed in Fig. 1. The outcomes pertaining to LoRa technology were particularly noteworthy, as the Received Signal Strength Indication (RSSI) values were meticulously recorded for each transmission. Notably, the RSSI values exhibited a quadratic decline with increasing distance, a phenomenon indicative of signal attenuation over distance.

The RSSI values provided in decibels (dB) serve as crucial metrics, reflecting the signal strength of individual data transfers. This parameter is directly associated with the quality of data transmission and the spatial proximity of the nodes to the central server. The observed trends in RSSI values not only affirm the efficacy of the LoRa technology but also underscore its potential in enabling robust and efficient communication across varying distances within the agricultural monitoring network.

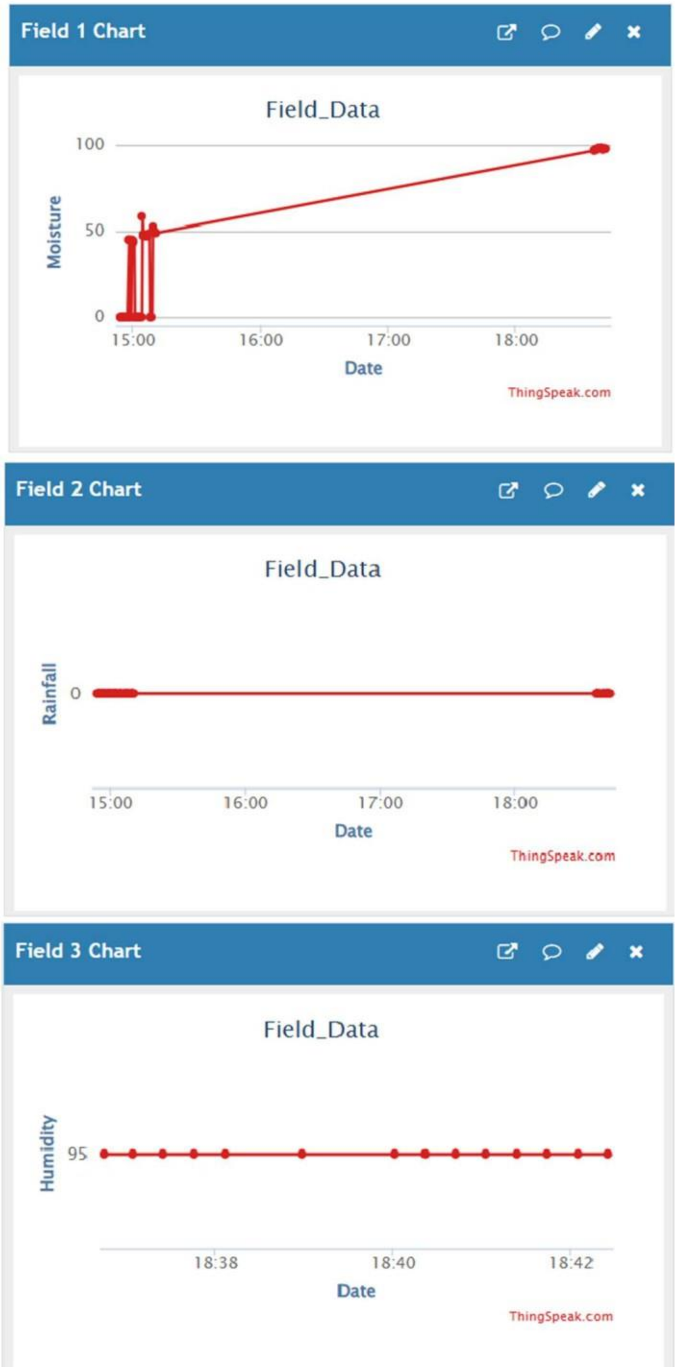

Fig. 3 The data shown on ThingSpeak server.

Fig. 3. Represents the output of the soil moisture, humidity, and temperature.

IV. CONCLUSIONS

In brief, our research introduces an innovative agricultural monitoring approach using emerging IoT technologies, particularly LoRa, to overcome conventional method limitations. Through a network of low-cost, low-power LoRa devices, we've demonstrated the feasibility and effectiveness of our system, highlighting LoRa's advantages in range, efficiency, scalability, and reliability, crucial for remote environments. Our system integrates ESP32-based nodes with various sensors for real-time soil monitoring, managed by a Raspberry Pi central unit, enabling intuitive data collection and analysis. Thorough evaluations confirm the system's capability to provide accurate, timely information, enhancing agricultural management, operational efficiency, and food security efforts.

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