IoT Enabled Intelligent Mote for Agriculture Application by Implementing LoRa Architecture

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By

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Transforming Education Transforming India

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DECLARATION

This thesis is an account of research undertaken between August 2017 and April 2021 at The Department of Electronics and Communication Engineering, Lovely Professional University, Phagwara, India.

Except where acknowledgement is the customary manner, the material presented in this thesis is, to the best of my knowledge, original and has not been submitted in whole or part of degree in any university.

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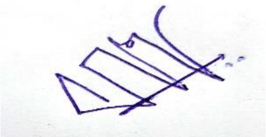
CERTIFICATE

This is to certify that the declaration statement made by the student is correct to best of my knowledge and belief. He has submitted the Ph.D. thesis “IoT Enabled Intelligent Mote for Agriculture Application by Implementing LoRa Architecture” under my guidance and supervision. The present work is the result of her original investigation, effort and study. No part of the work has ever been submitted for any other degree at any University. The Ph.D. thesis is fit for the submission and fulfillment of the condition for the award of Ph.D. degree in Electronics and Communication Engineering from Lovely Professional University, Phagwara.



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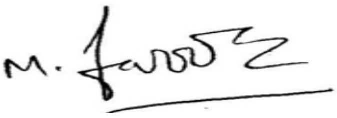

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ABSTRACT

According to the United Nations estimate, by 2050 the global population will touch around 9.8 billion. Concerning the growth of the population, the estimate also reveals that the amount of food production needs to increase by more than 60%. Agriculture is the primitive method for food production all over the world. To feed this amount of the population by 2050 there is a requirement of significant transformation in agriculture practices. For the same, farmers have to increase the food production by growing the crops in large amounts and also by optimizing the yield of the agricultural land with new technologies. However, the green revolution has significantly enhanced food production through irrigation methods and fertilizer. Moreover, it has minimized the famine especially in Asia, and also tripled food production from 1960 to 2015. Due to the green revolution, the utilization of water resources and fertilizers has increased to enhance productivity. However, it drastically affects the environment as the amount of land for food production is declining and additionally, due to climate change, temperature, soil quality, and topography, only a small portion of the earth's surface is sustained for agricultural usage. Concerning these challenges, the united nations have set the target of implementing sustainable food production practices in agriculture for enhancing productivity with minimum effect on the environment and also strengthening the agricultural land for adapting to extreme weather, climate change, flooding, and drought. To meet the targets of the United Nations, a novel agricultural practice is evolved in agriculture i.e. Precision Agriculture. Precision Agriculture is the modern agricultural practice that utilizes the advantage of information and communication technologies for increasing the productivity of agriculture. The information and communication technologies like a wireless sensor network, internet of things agriculture encourage to monitor the status of the crop by evaluating and quantifying the parameters including plant health, irrigation, crop yield, soil health, and fertilizer & pesticide effect from any remote locations. At present distinct agricultural systems are presented in the research to assist the farmers for agricultural monitoring, however, the systems are limitations in terms of connectivity, cost, and complexity.

The primary goal of this thesis to focus on the design and development of a precise, efficient, and reliable system with low cost and complexity to the farmers for monitoring the agricultural field. To achieve the goal, the thesis is organized into four objectives. For the same an architecture is proposed where it integrated distinct system like sensor mote, gateway and hand-held device for real time monitoring of the agricultural field. The distinct system including sensor mote, gateway and hand-held device are integrating with long range communication to enhance the connectivity among the devices. Initially the significance of implementing customization for the design and development of the hardware and firmware are addressed clearly. Further the establishment of long-range network in between the sensor mote and gateway is processed for initiating the data transmission from the agricultural field to the cloud server. IoT based hand-held device is embedded with long range communication and Wireless Fidelity (Wi-Fi), where it receives the sensor data of the agricultural field from the gateway through long range communication and from the cloud server through Wireless fidelity. The sensor data obtained in the IoT based hand-held device is utilized for applying the machine learning techniques to predict the suitable crops. The experimental results show promising scope towards precise, low cost and complexity system that primarily assists the farmers to monitor the agricultural field.

DEDICATION

“All action is of mind and the mirror of the mind is the face, its index the eyes.” MARCUSTULLIUS CICERO

This thesis is dedicated to my family especially to my parents and all my well-wisher.

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Firstly, I would like to thank God who enabled me to use my wisdom and knowledge for this research work. Moreover, the patience that God has given me in all the hard times during this period of time is unforgettable.

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Date: 27-04-2021 Mahendra Swain

CONTENTS

List of Tables

List of Figures

List of Abbreviations

ABI: Application Binary Interface

ADC: Analog-to-Digital

ADOV: Ad-hoc On-demand Distance Vector

AI: Artificial Intelligence

ANN: Artificial Neural Network

AOA: Angle of Arrival

APIT: Approximate Point In Triangulation

BER: Bit Error Rate

BS: Base Station

CSS: Chirp Spread Spectrum

BLE: Bluetooth Low Energy

DA: Data Analytics

DV: Distance Vector

DSDV: Destination-Sequenced Distance-Vector Routing

EABI: Embedded Application Binary Interface

FEC: Forward Error Correction

GDP: Gross National Product

GPS: Global Positioning System

GSM: Global System for Mobile communication

GPRS: General Packet Radio Service

GND: Ground

GUI: Graphical User Interface

ICSP: In Circuit Serial Programming

IoT: Internet of Things

I2C: Inter integrated Circuit

IP: Internet Protocol

LCD: Liquid Crystal Display

LoRa: Long Range

LoRaWAN: Long Range Wide Area Network

LPWAN: Low Power Wide Area Network

LTE: Long Term Evolution

ML: Machine learning

MQTT: Message Query Telemetry Transport

NB-IoT: Narrowband IoT

OS: Operating System

PCB: Print Circuit Board

PER: Packet Error Rate

PA: Precision Agriculture

RF: Radio Frequency

RS: Remote Sensing

RSSI: Received Signal Strength Indicator

RTOF: Round trip Time Of Flight

SF: Spreading Factor

SNR: Signal-to-Noise Ratio

SPI: Serial Peripheral Interface

SVM: Support Vector Machine

ToA: Time of Arrival

UART: Universal Asynchronous Receiver-Transmitter

Wi-Fi: Wireless Fidelity

WSN: Wireless Sensor Network

CHAPTER 1

INTRODUCTION

The chapter discusses the background of the agriculture and progress of technology implementation in agriculture for enhancing crop productivity. In the beginning, the significance and challenges in agriculture are present with real-time statistics. Later on, the modern approach in agriculture i.e. precision agriculture. The significance of emerging technologies like wireless sensor networks (WSN), Internet of Things (IoT), Long Range (LoRa), and machine learning (ML) are addressing in the PA. The problem identification of the study and motivation of study are also present in this chapter. Finally, the research objectives are providing in this chapter. Finally, the chapter concludes with thesis organization.

1. 1 Introduction

According to a United Nations estimate [1], the world population will strike 9.8 billion in 2050, indicating that a 25% increase over the existing population. Moreover, the population of urbanization is accelerating at a rapid pace, and it is estimated that 68% of the world's population are expected to live in urban cities by 2050 [2]. Concerning these estimates, the amount of food production will be twice by 2050 for meeting the demand of the population [3]. Agriculture is the primitive method of production of food for the survival of living beings on this earth. Agricultural development is a crucial component in the socio-economic development of developing countries and also provides food, employment, and income to the rural population. Agriculture is the mechanism of production of food, fiber, feed, and many other desired products through the cultivation of certain plants[4]. Agriculture provides most of the world’s food and materials and it also supplies wood for paper and construction products. Generally, traditional farming is utilized in agriculture for the production of food and other materials. However, after the evolution of industrialization, to meet the necessity of raw materials for industries drastically shift in the cultivation pattern, as a large amount of the cash crops is growing instead of the food crops. Concerning this demand, many farmers have started cultivating the food crops in large amounts and this led to the loss of fertility capability of the land. Moreover, to supply the raw material to industries in a short interval of time, the farmers have utilized a large number of fertilizers and chemicals on the land without knowing the capability of soil and other resources. Furthermore, over the last few decades, the overall usage of agricultural land for food production has declined, and additionally, due to the effect of climate, temperature, soil quality, and topography, only a small portion of the earth's surface is sustained for agricultural usage[5].

Generally, to enhance farm productivity, the crop performance is to be realized and estimate under a broad variety of soil, irrigation, environmental, and fertilization circumstances. Productivity is a significant metric of land conditions as it presents the variations in land quality and limitations of land effectively. The primary goal of agricultural soil management is to establish the optimal environments for the development of young plants, germination of seeds, healthy plant growth, plant production, root growth, harvest, and grain formation [6]. The productivity of a farm can be improved by establishing which crop variety delivers the maximum yielding under identical conditions of soil, climate, fertilization, and irrigation. In order of analyzing the crop performance, the farmers are encouraged to bring the soil of their farming land to the respective authority for checking the status of soil fertility and other significant soil parameters that impact the productivity of crops [7]. After analyzing the soil by soil experts, they will suggest the appropriate crop to be grown and also suggest a nutrient profile for achieving better productivity. The evaluation of suggesting crop health report is a complex procedure, inappropriate soil sampling, time-consuming in generating the crop health report are the limitations of traditional farming. Additionally, the traditional farming is only limited to handling the field uniformly, however it overlook the essential spatial variability of the majority farming land[8]. This was amplified by the rapid increase in field size due to mechanization pressures. Precision agriculture (PA) is a management activity that has been made accessible by the incorporation of adequate information technology and presents a system in which agricultural land managers will grasp and control the farms more effectively [9].

Precision agriculture is the process of maximizing the yielding of crops and encouraging management decisions through the utilization of high-tech sensors and measurement tools [10]. PA is a globally innovative approach for enhancing the production, effective management of fertilizer, minimizing the labor time, and irrigation management [11]. Modern agriculture farming depends up on tracking the status of the crop by evaluating and quantifying the parameters including plant health, irrigation, crop yield, soil health, and fertilizer & pesticide effect [12]. It is a challenge to the crop producers for managing all these factors simultaneously. However, remote sensing (RS) is capable to assist in the implementation of the precise monitoring of agriculture progress and health condition [13]. The constraints of remote sensing in PA are primarily due to sensor parameters such as limited spectral range, gross spatial resolution, limited repeat coverage, and slow response time [14]. Wireless sensor networks (WSNs) are the amalgamation of multiple wireless nodes for monitoring the physical metrics of the environment[15]. Generally, the wireless nodes consist of sensors, wireless communication protocol, and a micro-controller permits interconnecting with gateways for transmitting information of sensors. WSN is the cost-effective mechanism for improving the yield of agriculture and it is employed in distinct agricultural applications including forecasting health of crop using soil nutrient data and monitoring climate [16]. Nevertheless, few obstacles disrupt WSN's agricultural implementation, such as energy efficiency, communication range, scalability, determination of optimal deployment systems, and tolerance of failure[17]. The energy efficiency and communication range of the WSN are dependent upon the type of the wireless communication protocol that is implemented for the agricultural application. Zigbee is short range communication protocol that implemented in the agriculture for water quality management, irrigation supervision and pesticide control [18]. Zigbee along with Global System for Mobile communication/General Packet Radio Service (GSM/GPRS) are implemented for supervising and controlling the environment condition of green houses. In agriculture applications, majority of wireless sensor technologies are utilizing the short-range communication for maintaining the energy efficiency of the nodes. However, the limitations of short-range communication is hindering the effective implementation of WSN. To overcome this GSM/GPRS is implemented for long-range communication but the GSM/GPRS transmits consumes high power during transmission. After the evolution of long range (LoRa) wireless communication the limitations of WSN in terms of energy requirement and the problem of maximum range are overcome.

Table.1.1 Technical specification of wireless communication protocols

Parameters	**XBee**	**Bluetooth Low Energy**	**Wi-Fi**	**GPRS**	**LoRa**	**NB-IoT**	**Sigfox**
Frequency range	868/915 MHz and 2.4 GHz	2.40 GHz	2.40 GHz	900 to 1800 MHz	869 to 915 MHz	Licensed LTE frequency bands	868 to 915 MHz
Transmission Range	100 m	10 m	100m	1-10km	5 km	NA	10 km
Network size	Approx. 65,000	Limited application	Approx 32	Approx 1000	10,000 no of (nodes per BS)	52,000 devices/ channel	1,000,000 no. of (nodes per BS [24]

Network Topologies	Peer-to-peer, tree, star, mesh	Star-bus topology	Point-to-hub topology	Cellular system topology	Star-of-stars	Star topology	Star topology
Channel bandwidth	Equal to 2 MHz	1 MHz	22 MHz	200 kHz	<500 KHz	200 kHz	<100 Hz
Power consumption in Tx mode	Around 36.9 mW	Around 10 mW	Around 835 mW	560 mW	100 mW	NA	122 mW
Limitations	Line-of-sight between the sensor node and the coordinator node must be available	Short communication range	High power consumption and high latency (13.74 s)	Power consumption problem	Network size(scalability), data rate, and message capacity	Incapable of a seamless handover between cells and does not provide low latency application	Low data rates

Table.1 depicts the various wireless communication protocols that already exist for the implementation of WSN. This table provides completed specifications of the wireless communication protocols with transmission range, frequency band, power consumption, network size, network topology, and channel bandwidth. Lora wireless communication is based on capable of communicating the data to long-range with less energy consumption [19]. Lora is working on Chirp Spread Spectrum (CSS) technique and transmits up to a range of 5 km (urban), 20 km (rural) as referred to by the LoRa alliance [20]. Lora is implemented with a star topology, in which gateway and cloud server are interconnected with the assistance of internet protocol (IP). From the table.1, the emerging three LPWAN technologies namely LoRa, narrow band-IoT (NB-IoT), and Sigfox are also discussing the requirement of IoT for a wide range of applications. Of all three LPWAN technologies, LoRa is considered as is an independent network and provides an opportunity to utilize the frequency bands without any cost [21]. NB-IoT is a licensed band, where it is also a dependent network that charges for using the bands. When it comes to Sigfox, the Sigfox network is deployed by network operators where they users on subscription-based and also in terms of security & power consumption the LoRa is better than Sigfox [22]. Additionally, in the agriculture field, the deployment of nodes is having a significant role as nodes because it provides information regarding the number of nodes that are necessary for covering the whole agricultural field. Here the nodes should be embedded with a localization mechanism in it for communicating the data to the sink node and gateway in the shortest path. The localization of the sensor nodes in agriculture is also an important factor for identifying the node located in a large area of agricultural field.

With the advancement and availability of sensor technology and communication protocol, real-time monitoring of the crop is possible, as real-time monitoring assists to analyze the growth of crops under distinct real-time conditions including soil quality, water maintenance, pH levels of soil, etc.[23]. Real-time monitoring is possible with the internet of things (IoT), as IoT is capable of obtaining the time series data from spatial data and sensor networks [24]. IoT-based agriculture systems generating a large amount of data from the sensors, imaging technology, and this data can be utilized for anticipating crop productivity in the succeeding period through predictive analytics. Predictive analytics encourages the farmers to realize the optimum period for distinct farm management including harvesting and planting. Machine learning (ML) is the significant mechanism that empowers to perform the predictive analytics for agriculture to predicting the appropriate crop for the next season [25]. ML is a sub category of artificial intelligence (AI) that delivers the better yield prediction built on distinct parameters. ML algorithms such as artificial neural networks (ANN), support vector machine (SVM) and deep learning are the significant for the agriculture [25].

In PA, the monitoring of the agricultural field is a vital factor because it assists to enhance crop productivity. Here, wireless communication plays a significant role in reliable transmission and interconnection between the agricultural field and end-user. The wireless communication that has been implemented for PA are having limitations in terms of short-range transmission and high energy consumption. The portable device with low cost and minimum complexity assists the farmers to monitor and supervise the agricultural field from any remote location. The main motivation behind this proposed work drives me to look into the current scenario of the Indian agriculture system. Challenges of farmers, unpredictable weather conditions, and lack of awareness towards smart farming. The diversification of the Indian economy sector has come up in to matter recently related to the Indian agriculture domain. The main two obstacles that have been identified for the same include the inability of the Indian agriculture domain to meet the supply-demand corresponding to the hyped population indigenously and on the other hand the inconsistency in exporting quality products to the market which are direct factors to the strengthened economy. Besides, a country like India always suffers from serious natural disasters. We envisage that these challenges could be resolved to their maximum extent by using cutting-edge technologies like the internet of things (IoT) and data analytics (DA). Our approach focuses on designing some of the powerful methods by incorporating IoT technologies and DA which explicitly useful in the field of agriculture. In this process, we include LoRaWAN based network, for long-range covering and low power consumption in transmitting data from the sensor nodes to the cloud services.

1.2 Research Objectives

The primary objectives of the proposed research work are focused on the design and development of a précised, efficient and reliable system for agriculture with compliance to the following:

- **RO1-** To design customized intelligent mote.
- **RO2-** To implement firmware on the intelligent mote.
- **RO3-** To establish an inter-mote network using LoRa.
- **RO4-** Information-based handheld controlling device for the farmer.

1.3 Thesis Organization

The thesis organization of the research is as follows: Chapter.1 presents the introduction of agriculture with wireless sensor networks (WSNs), Internet of Things (IoT) and machine learning (ML) Chapter.2 is all about the review of literature related to the technologies like WSN, localization, LoRa, IoT and machine learning implemented for agriculture. Chapter. 3 covers the system description. Chapter. 4 is about building a custom embedded firmware. Chapter.5 explains the establishment of interlink using LoRa. Chapter. 6 discuss the testing and validation. Chapter. 7 presents the conclusion, novelty, and future scope.

Chapter.2 presents the detailed review of literature on precision agriculture and implementation of wireless sensor networks (WSNs), Internet of Things (IoT), and machine learning. Finally, the integration of Long Range (LoRa) communication for WSN is also presented.

Chapter 3 presents the development of a customized hardware device for monitoring the agricultural field. In this, significance and procedure of the customization of hardware are presented including sensor mote, gateway, and hand-held device.

Chapter 4 presents the customization of firmware in the raspberry pi-based gateway. Here the requirement of customization and methodology of customizing the firmware with the assistance of an embedded Linux operating system is present.

Chapter 5 presents the establishment of the LoRa network in between sensor mote and gateway for communicating the sensory data of the agricultural field. Moreover, to check the LoRa network performance during data collection with customized sensor mote and gateway, an experimental setup is performed.

Chapter 6 presents the testing and validation of customized hand-held devices for monitoring of agriculture field. The hand-held device communicates the sensor data of the agricultural field to the cloud server through POST/GET requests. The sensor data available in the cloud server are useful for further data acquisition and analysis, which indeed assists the farmers in enhancing the yield of the crop.

Chapter 7 presents the outcome of the objectives including publication and patents. Moreover, the chapter also presents the novelty of work with future scope.

1.4 Conclusion

In this chapter a detailed description of precision agriculture with challenges and opportunities are discussed. Moreover, this chapter enables to understand the background of agriculture with motivation and problem. The objectives and thesis organization of the research work are discussed in this chapter.

CHAPTER 2

REVIEW OF LITERATURE

This chapter provides a detailed review concerning precision agriculture. Initially, the challenges and demand in agriculture are discussing in this chapter. Precision agriculture is the modern approach for enhancing food production and yielding. The technologies like WSN and IoT are encouraging the wide implementation of PA presenting with previous work. The significance of the LoRa network for enhancing the connectivity issues in WSN and IoT-based PA is addressing in this chapter. As an enormous amount of data is obtaining from the WSN and IoT, it can be utilized for extracting meaningful insights with predictive technologies like machine learning (ML). ML with IoT assists to deliver real-time analytics for the farmers to enhance the yielding of the crop.

2.1 Precision Agriculture

The word "agriculture" is originated from a Latin word- ager or Agri means 'soil', and 'culture' means cultivation of the soil. In the modern era, the agriculture term has come to incorporate a broad range of practices that are fundamental to agriculture and have their descriptive terms including arboriculture, cultivation, domestication, horticulture, and vegeculture [26]. Agriculture is the foundation of life for the human species as it is the foremost source of food grains and other raw materials. Agriculture is also essential to economic growth in 2018 as it accounts for 4% of the world gross national product (GDP) [27]. Agriculture has the potential to minimize poverty, increase income level, and enhances the food security of the world's 80 % poor people who are dependent on farming and residing in rural areas[28]. The conventional approach of agriculture is experiencing transformation for meeting the food demand. In the last few centuries, we have established multiple modes of agriculture 1.0, 2.0, and now 3.0 & 4.0 in the coming decades. The first revolution of agriculture is from ancient times to 1920 where agriculture was mostly done manually and the traditional practices are still practicing by many farmers as a family tradition. The second revolution is related to the green revolution, high yielding varieties are introducing by investing in fertilizer and irrigation. Green revolution delivered exponentially raises food production worldwide and it drastically minimized the famine especially in Asia[29]. Agricultural production is tripled between 1960 and 2015 due to green revolution technologies and the utilization of water, land and other natural resources has increased for agricultural purposes. At present 23% (11 Million KM^2) of the global habitable [30] and 70% of global freshwater are utilized by agriculture[31]. In the initial stage of the green revolution, only a limited few species of high yielding varieties of wheat and rice are cultivating[32] . The enhancement of cultivation homogeneity reveals that seeds are more susceptible to diseases as it is not having sufficient ability to combat diseases[33]. The utilization of pesticides has intensified is significantly affect environmental externalities to protect from diseases and pests. Agricultural sustainability is a primary concern for protecting the environment and biodiversity as it is significantly assisting in future for potential growth of agriculture. In agriculture, the term "transition from sustainability" applies to a transformation from an agricultural framework to one that builds on a broader theory of sustainable agriculture as the main aim of increasing productivity[34]. Food sustainability implies the establishment of sustainable practices, production and consumption[35]. Precision agriculture (PA) is introduced specifically for contributing the potential increase in food demand and achieving the goal of sustainability and it is third revolution in agriculture[36]. The advancement and wide availability of wireless sensors and communication protocols encourage adopt the of precision agriculture for enhancing productivity[37]. PA is the amalgamation of distinct sensing technology with communication protocols for assisting the farmers to monitor the status of the crop[38]. Wireless sensor networks, IoT, and cloud computing are major technologies that establish PA. Due to the utilization of sensing technology and communication protocol by PA, a wide amount of data related to crop health is available[39]. PA provides the information like plant health, water level, temperature, humidity, etc. of agricultural field. PA precisely the assists farmers to identify those parameters that are necessary for healthy crop at a particular instance of time[40]. The information collecting from the different sources related to nutrients of soil, chlorophyll content in plants and presence of pest weeds. In the fourth revolution of agriculture cross industry technology are integrated for enhancing efficiency and productivity in precision agriculture[41]. Artificial intelligence (AI), blockchain and unmanned aerial vehicle (UAV) are the technology that transform the activities of the agriculture on digital platform. Enormous data generating through WSN and IoT enables to implement predictive analytics for understanding the behavior and conditions of the crops in terms of disease detection, water management, suitable crop, etc[42]. The predictive analytics is achieved with the assistance of AI, as moreover it provides meaningful insights to the farmers for enhancing the crop productivity[43].

2.2 Wireless Sensor Network (WSN):

WSN are interconnected sensor nodes that transmit wirelessly to obtain data about the nearby environment and sensor nodes are generally battery-powered and distributed in an ad hoc, decentralized mode[44][45]. WSN architecture is shown in the figure. 2.1. where it presents the primary component of the WSN are the sensor node and network architecture. Sensor nodes or motes are the sensing device that is deploying in the vast area for sensing the parameters[46]. The sensor node is geographically deployed in a particular outdoor and indoor environment. The sensor node is the integration of sensors, microprocessors/microcontrollers, transceiver radio frequency (RF) module, and power supply[47]. The network architecture comprises a sink node and gateway, where it acts as a processing unit for communicating the data to the internet. The sink node supervises the sensor nodes and communicates the information to the gateway via a wireless communication protocol. Gateway is the integration of two distinct wireless communication protocols. In gateway, one wireless communication protocol act as a transceiver RF module for receiving the information from the transceiver RF module of the sink node. Another communication protocol is an internet provider that initiates internet connectivity to the gateway.

The deployment of the sensor node and network establishment between sensor nodes depends upon the application and requirement. PA can be perceived as one of the most beneficial facilities for WSNs to enhance the production of food crops and reduction of farmers' burden[48]. In PA, WSN utilizes the soil nutrient information to predict the health of the agricultural field and enhance productivity[49]. For irrigation monitoring, the WSN is utilized for monitoring temperature, humidity, and soil moisture. The sensors play a significant role in measuring the distinct parameters of the agricultural field. The sensor obtains the analog data from the physical environment and analog-to-digital (ADC) converts data to digital format[50]. A wireless communication protocol is having a major role in connecting the sensor nodes to the internet. Generally, there are two distinct kinds of wireless communication protocol namely long-range and short-range. Zigbee, Bluetooth, Bluetooth low energy (BLE), and Wi-Fi (wireless fidelity). Global system for mobile communication/ global packet for radio service (GSM/GPRS), long term evolution (LTE), long-range (LoRa), sigfox, and narrow band IoT (NB-IoT).

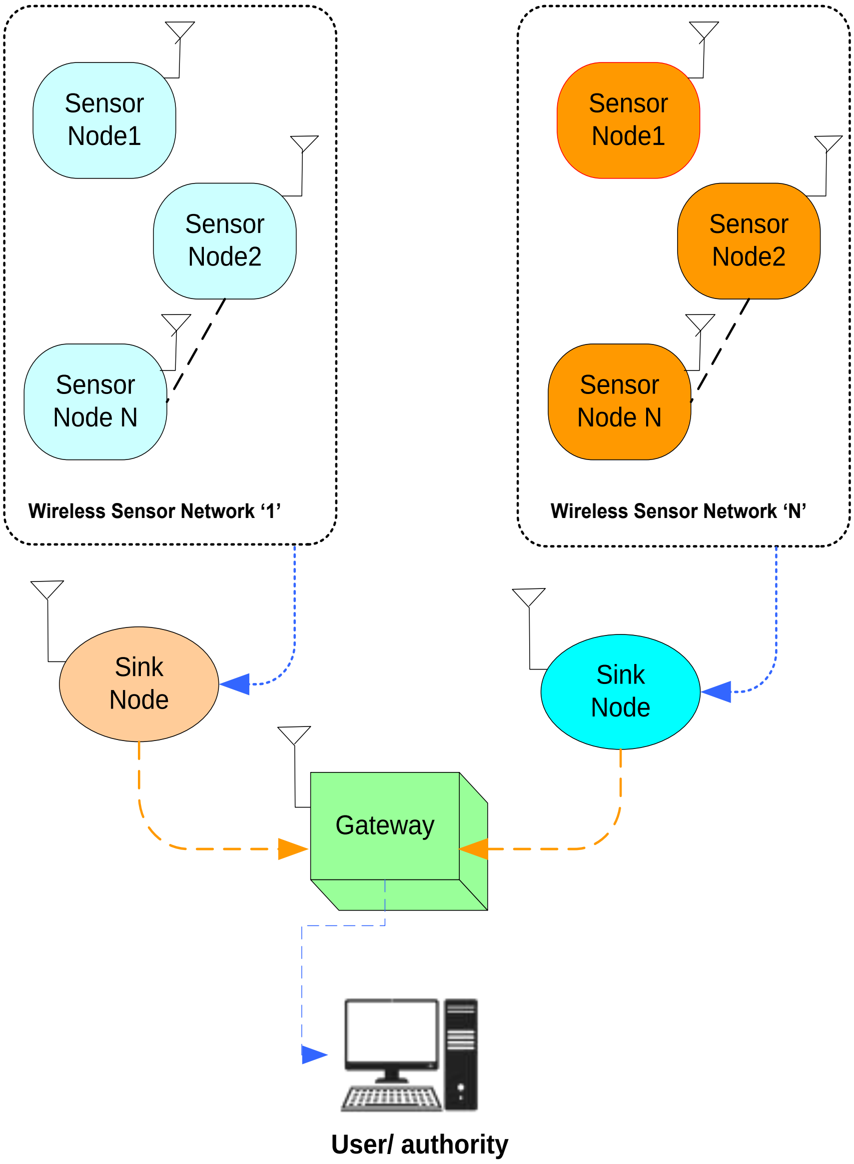

Figure.2.1 Wireless Sensor Network architecture

ZigBee wireless communication technology (IEEE 802.15.4) is chosen over other technologies for the growth of wireless sensor networks due to its minimum cost and minimum power consumption. This protocol is useful for water quality management, supervision of irrigation, controlling of fertilizer and pesticide [51]. Zigbee protocol in the sensor node enables communication with the coordinator node over a transmission range of 100 m and Zigbee can minimize the transmission range up to 30 m for the indoor environment[51]. Concerning the application and transmission range, the amount of deployed sensor and router nodes increase for covering the vast area. Zigbee is employed for examining the impact of signal strength on node spacing, the density of leaf, and the height of the base station antenna[52]. In [53] an evaluation of the path loss model for monitoring the mango greenhouse is done and it is based on ZigBee wireless protocol. Zigbee protocol implemented for measuring the parameters of greenhouse environment like temperature, humidity, CO_2 and soil moisture, etc [54]. GSM and Zigbee technologies are utilized for monitoring and supervising the environmental condition of green houses. Zigbee is assumed in the PA for overcoming the high-power usage in mobile ad hoc WSNs [55]. Zigbee is also implemented in the wide areas of agriculture including monitoring of orange orchards, automation in irrigation, smart beehives, monitoring of livestock, and greenhouse monitoring [56]–[58]. Bluetooth wireless protocol is implemented for initiating communication in portable devices such as mobile and laptops over a transmission range of 10 m. Bluetooth is integrated into the PA for sensing the soil moisture, temperature, and weather information from a remote location using a global positioning system (GPS). A system is implemented for the application of irrigation for enhancing the field productivity and managing water effectively [59]. A Bluetooth-based irrigation monitoring system is implemented for obtaining real time field data. Various hardware and software were developed for monitoring the temperature and relative humidity in green house using Bluetooth[60]. Bluetooth is implemented in integrated control method for controlling the irrigation system in green house on the basis of weather and soil information[61]. The unique features of Bluetooth like consumes less energy, wide implementation and ease utilization enabled farmers to implement in distinct agricultural applications including monitoring of the key environmental parameters effecting the soil fertility and thereby controlling the irrigation systems for a better yield results[62]–[64].

Wi-Fi is presently the most widely used wireless data communication technology suitable for usage in applications related to handheld devices, tablets, smartphones, laptops, and desktops. Wi-Fi has a suitable communication range of 100 m in indoor and outdoor settings, respectively. Wi-Fi broadens various architectures for PA applications by connecting multiple device types through an ad-hoc network. Wi-Fi and 3rd Generation technology have been used for evaluating the application of agriculture through mobile[65]. The farming-related data extracted from the grounds such as soil humidity, soil temperature, CO_2, and strength of sunlight are collected in a gateway until they were passed over a Wi-Fi network to the server [66], [67]. In few studies it is recommended that a Wi-Fi-based agriculture system is a low cost, however, as result, it is revealed that Wi-Fi is consuming a high power of 42.17 J/h. Since Wi-Fi requires high power, a long time for communication, and a high payload. For agrarian applications, Wi-Fi technology is not suitable, moreover, a Wi-Fi server avoids data loss by using data redundancy methods[68]. Additionally, wi-fi is not appropriated for multi-hop communication as it is influenced by users and signal intensity. Simultaneously wi-fi continuously listens to nodes all the time leads to high energy consumption[69].

General Packet Radio Service (GPRS) is a GSM-based mobile phone packet data service. GPRS is having a challenge of variable delays and performance because the technology relies on the number of customers using the same networks and resources of communication. In this study, the GPRS module and the WSN are integrated for implementing an automatic crop irrigation system for enhancing the quality of water through the data obtaining from the temperature and soil moisture[70]. WSN based system is implemented for drip irrigation with the assistance of GPRS, where the WSN with GPRS transmits data to the data center[71]. Wireless nodes are integrating with GPRS for sensing and communicating the plant, soil, and atmosphere data to remote servers [72]. The information in the remote server encourages future analysis. From the previous studies, it is concluded that Bluetooth, Zigbee, and Wi-Fi protocols consume low energy however it is limited to a transmission range of 100 m. When it comes to the GPRS it is concluded that the energy consumption of the GPRS is also high when comparing with Bluetooth, Zigbee, and Wi-Fi. In WSN, there is a requirement of a wireless communication protocol that is capable of transmitting the information to the long-range and minimum energy consumption. The evolution of low-power wide-area networks (LPWAN) overcome the communication challenges of the WSN. Lora, Sifox, and NB-IoT are the LPWAN technologies. Of three LPWAN technologies, LoRa is the best candidate for long-distance and low-power transmissions with free subscription for transmission.

Localization is crucial for identifying the physical locations of sensors in the deployment area. Concerning the deployment land in agriculture, it is important to identify the required number of sensor nodes and the distances at which they need to be positioned so that sensor nodes can establish communication links among themselves. The usage of Localization algorithms to determine suitable node architecture and their placements in agriculture field has been discussed. Various parameters are evaluated using these algorithms, such as accuracy, reliability, and scalability. The major categories of localization algorithms i.e., range-based, range-free-based are classified as shown in Figure 2.2 [73]. Moreover, these two types are classified into two kinds, namely, fully range-based and hybrid range-based.

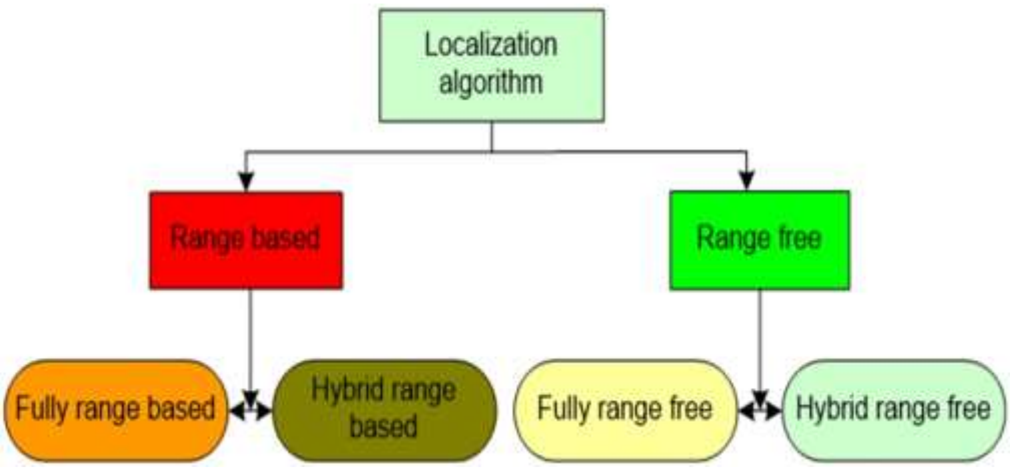

Figure 2.2 Classification of localization schemes for sensor networks

Range-free localization algorithms determine the location of an unknown deployed sensor node [9]. Range-free methods utilize RF-based communication methodologies between nodes to determine their location. In range-free schemes, the angle of arrival (AOA), specific hardware, and distance measurement is not considered[74]. Range-free schemes comprise the centroid system, approximate point in triangulation (APIT), distance vector (DV) hop, and hop terrain are described as follows:

a. **Distance Vector (DV) hop localization:** In DV hop, the distance between the nodes is estimated using hop count, and the hop count of at least three anchor nodes is distributed across the network[75]. The hop count of a node is incremented by one when the neighbor node transmits the information to another neighbor node. The hop distance is evaluated as the distance between two nodes/number of hops.

b. **Centroid localization**: This is the most basic scheme that uses anchor beacons, containing location information (Xi, Yi) [74], where n is the number of the anchor nodes Ai.

$$(X, Y) = \left(\frac{\sum_{i=1}^{n} x_i}{n}, \frac{\sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{Yi}}{\mathrm{n}}\right) \tag{1}$$

c. **Approximate Point In Triangulation (APIT):** In APIT, the location information is obtained by anchor nodes through a global positioning system (GPS) and the unlocalized node receives the location information via overlapped triangles[76].

d. **Gradient:** In the gradient algorithm, the unlocalized node utilizes the multilateration method to estimate the position of nodes. Moreover, it utilizes hop counting and the hop increment while being distributed to neighboring nodes.

Range-based localization is built on angle estimation and distance estimation. The main practices in this form of localization are the angle of arrival (AOA), Ad-hoc On-demand Distance Vector (AODV), time of arrival (ToA), and received signal strength indicator (RSSI):

a. **Time Of Arrival (ToA)**: This localization algorithm refers to the time of arrival, abbreviated as ToA, which is the time it takes for a signal to move from the transmitter node to the receiver node [77]. The distance between two nodes is calculated using roundtrip-time of flight (RTF) and is expressed in Equation (2) as:

$$d = \frac{[(T3 - T0) + (T2 - T1)] * V}{2} \quad (2)$$

Sensor coordinates (x1,y1), (x2,y2), (x3,y3), and (x4,y4) calculated using response information, and the TOA-based distance measurement method can be applied to calculate the distances between them and the moving node S as d1,d2,d3, and d4, respectively. Given the coordinates of the moving node S, (x, y), the following equation can be utilized to measure the moving node's position coordinates:

$$d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} \quad (3)$$

where i = 1, 2, 3, 4.

b. Ad-hoc On-demand Distance Vector (AODV): AODV is a routing protocol built on the distance-vector algorithm that combines the DSDV target serial number and DSR on-demand routing discovery[77]. This protocol primarily consists of routing discovery and routing maintenance, with the former only being requested to save overdue routing.

c. Angle Of Arrival (**AOA):** The location of an unlocalized node is estimated through the angles at the points at which the anchor signals are obtained [78], [79]. Here the unlocalized nodes implement a triangulation procedure for estimating the location.

d. RSSI: In this method, distance estimation between receiver and transmitter is obtained by evaluating the signal strength at the receiver [80], [81] The power of the signal decreases when the distance between receiver and transmitter decreases.

A comparative analysis of fully range-based and hybrid range-based algorithms is shown in Table. 2.1. Fully range-based algorithms are used to determine the distances or angles between nodes to allow an unknown node to be identified easily, whereas hybrid range-based algorithms use various distance and angle measuring methods. Different parameters, such as node density, range, scalability, and reliability of algorithms, are shown in Table 2.1. These exploit geometry to improve hybrid

AOA/TDOA-based localization (EATL). Fusion of RSSI and TDOA measurements from the wireless sensor network provides robust and accurate indoor localization (FRTL). Hybrid range-based algorithms perform better than fully range-based algorithms.

Table. 2.1 Localization algorithms (range free vs. hybrid range-based) [82]

Parameters	Fully Range Free Based Algorithms			Hybrid Range Based Algorithm		
	CA	NCA	DV-HoP	ATPA	EATL	FRTL
Node deployment	Both uniform and random	Random	Random	Random	Both uniform and random	Random
Node density	Low	Low	High	High	Low	Medium
Existence of obstacle	Yes	Yes	Yes	Yes	Yes	Yes
Anchor node presence	Yes	Yes	Yes	Yes	Yes	Yes
Range estimation	Computational	Computational	Computational	Computational	Computational	Computational
Range combination	Centroid	Centroid	ToA, TDOA	ToA	TDOA	RSSI
Localization co-ordinates	RD	3D	2D	2D	2D	2D
Scalability	Yes	Yes	No	Yes	Yes	Yes
Accuracy	Low	Low	Moderate	Very High	Very High	High

Table 2.1 shows that hybrid range-based algorithms perform better in range combinations using TOA, TDOA, and RSSI. The scalability and accuracy of the fully range-based algorithms are comparatively lower than those of hybrid range-based algorithms.

2.3. Internet of Things

Internet of Things (IoT) is the interconnection of distinct networks for sensing, interacting, and communicating [83]. IoT assists to implement real-time monitoring to any application through internet connectivity[84]. To improve smart farming strategies, a considerable amount of work has been done with IoT technology in the agricultural sector[85] [86]. By exploring many complications and obstacles in farming IoT has brought a great revolution in the agriculture environment[87][88]. With the advent of technology, it is now projected that agriculturalists and technologists are utilizing to solve challenges that farmers face, such as water shortages, cost control, and productivity issue [88]. All these problems have been identified by IoT technologies and delivering approaches for optimizing efficiency while reducing costs. Efforts made on WSN encourage us to acquire and transfer data from sensors to the main servers [90]. The data obtained from sensors generate information about various environmental conditions to accurately manage the entire device. Besides, IoT offers well-organized resource scheduling that improves efficiency. IoT and cloud [91]based intelligent irrigation system is developed to obtain data regarding the soil moisture, soil health status, and temperature for reducing the of water consumption. IoT and WSN based agriculture is established for monitoring the air, temperature, soil moisture, and humidity using RF module [92]. The information is sent to remote server with the assistance of gateway and internet. Raspberry Pi based smart irrigation is implemented for sensing the water level, temperature and humidity using the respective sensors[93]. IoT based water irrigation system is implemented, where the controller adjusts the solenoid valve depending upon the level of water in the soil [36]. GPRS and Arduino UNO-based IoT irrigation system is realized for sensing the soil moisture and communicating it to the Thingspeak server for visualized the data trends [94]. IoT-enabled pest prediction and plant disease system is presented for reducing the utilization of insecticides and fungicides and an evaluation is performed on weather data to identify a correlation between pest growth and weather [95]. GSM and Wi-Fi-based agricultural monitoring system is implemented for sensing the soil moisture and detection the other illegal objects entering into the agricultural field [96]. A case study of IoT enables irrigation platform is implemented for obtaining the data from the PA and ecological [97][98]. IoT-based framework represented as Agri-IoT is developed for performing data analytics and implementing real-time processing [99]. IoT-based architecture with a motivation of enhancing the productivity on agricultural farms with the assistance of temperature, soil moisture, and humidity sensor [100]. An IoT and Zigbee protocol-based greenhouse farming is implemented for monitoring the climatic conditions[101]. An IoT and cloud-based architecture is proposed for precision agriculture to obtain data into a cloud server for analyzing[102][103].

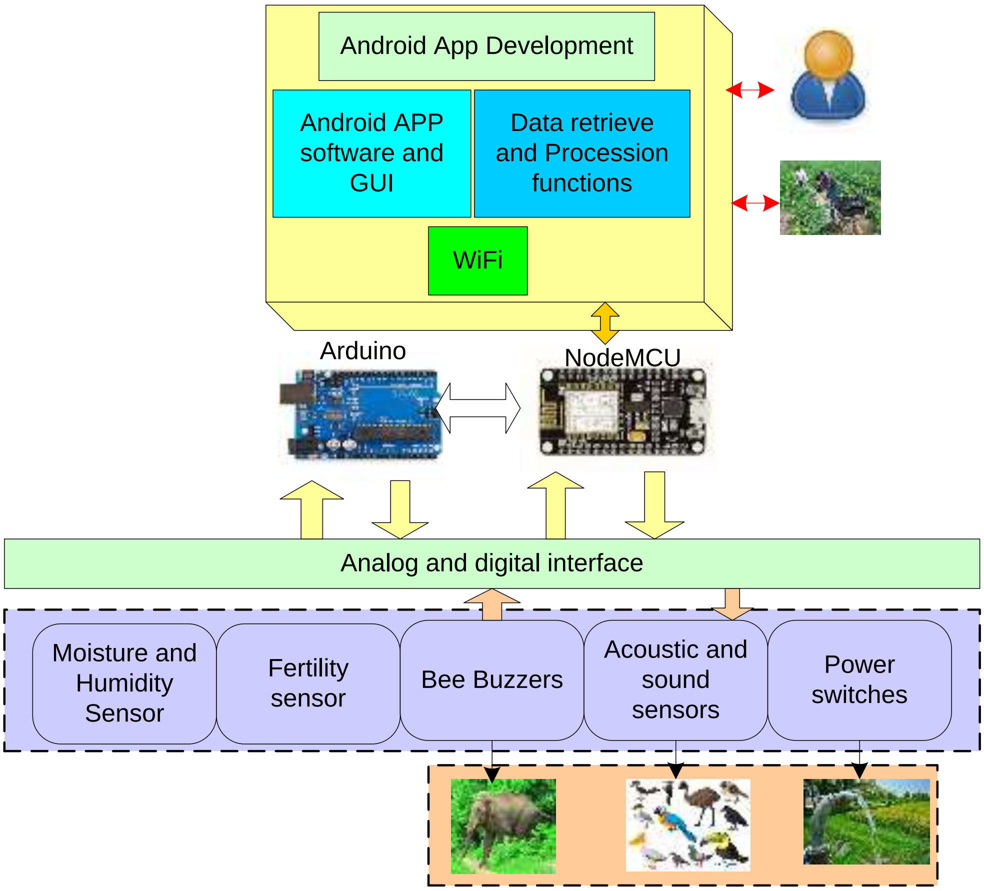

Figure.2.3 Arduino and NodeMCU based IoT enabled PA

In [104]–[106], the researchers have integrated Arduino and Node MCU-enabled IoT agricultural field monitoring and architecture is shown in figure 2.3. The architecture reveals that the sensors like moisture sensors, humidity sensors, fertility sensors acoustic, and sound sensors are integrated into the agricultural field. Moisture humidity and fertility sensor are integrated for sensing the moisture, humidity level, and fertility of the soil. Acoustic and sound sensors for detecting the sounds of the animals that are approaching the surroundings of the agricultural field. As acoustic and sound sensor detects the presence of animals, the bee buzzers trigger the sounds like a warning to animals to go away. All these sensors are integrated with Arduino and NodeMCU. As NodeMCU is inbuilt with ESP 8266 wi-fi module, it enables to transmits the sensor data of agricultural field over the internet to the Android APP or in the personal computer, where the user can visualize the data in the graphical user interface.

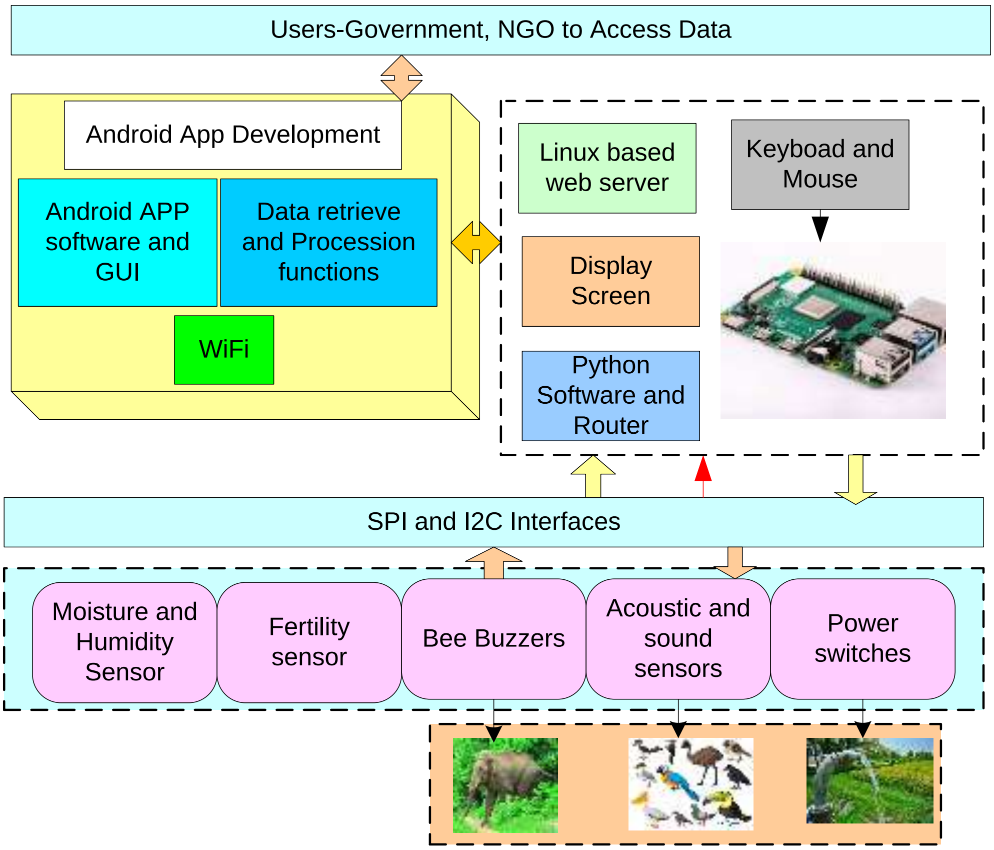

Figure. 2.4 Raspberry Pi based IoT enabled agriculture field monitoring

In [107], [108] the researchers have implemented Raspberry Pi enabled IoT agricultural field monitoring and architecture is shown in figure 2.4. Distinct sensors for monitoring agricultural fields are integrating into Raspberry Pi through the serial peripheral interface (SPI) and inter-integrated circuit (I2C) serial communication. Moisture, fertility, and humidity sensor are embedded in the raspberry pi for sensing the moisture, fertility level, and humidity of the soil. Acoustic and sound sensor for detects the sounds of the animals that are approaching surroundings of the agricultural field. As acoustic and sound sensor detects the presence of animals, the bee buzzers trigger the sounds like a warning to animals to go away. Raspberry pi with the assistance of an inbuilt ESP 8266 wi-fi module enables to communicate of the environmental data of the agricultural field over the internet connectivity to the Android APP or in the personal computer, where the user can visualize the data in a graphical user interface

2.4 Long Range (LoRa)

Lora works on chirp spread spectrum modulation [109][110]. Lora is an efficient communication technique that covers long-distance wireless channels [111]. The frequency band of LoRa varies in a different country and LoRa operates on ISM bands such as 868 MHz in Europe, 995 MHz in North America, and 433 MHz in Asia [112][113]. LoRaWAN is an interference-free communication protocol as there will no disturbance during transmission between transmitter and receiver [114]. Lora implements star topology in which where gateways and servers are interconnected with over internet protocol (IP) connections. Generally, LoRa is suitable for applications where the data rate is low with the long-range transmission. The bitrate of LoRa is less when comparing with Wi-Fi i.e. 20 to 30 Kbps [115]. LoRaWAN architecture is shown in figure 2.5, where LoRa is modulation technique is integrated into the end device and gateway for transceiver purpose.

The LoRaWAN architecture comprises of End node devices, network server, Gateway, and Application Layer.

a) **End node devices:** End node devices are utilized for sensing the physical parameters of the agricultural field including pH sensors, temperature, humidity sensors. End node devices embedding with LoRa transmit the information of the field to the gateway.

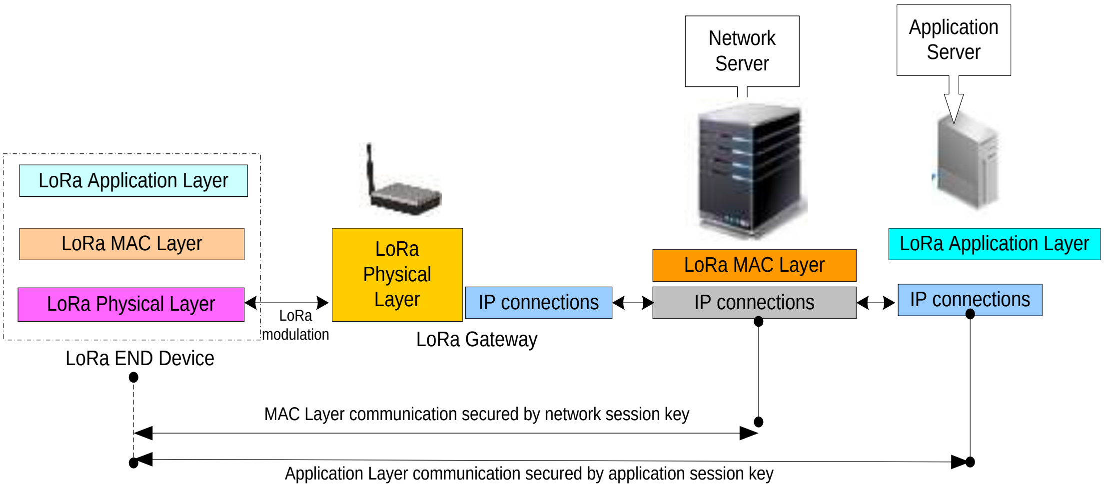

Figure.2.5 LoRaWAN architecture

b) Gateway: Gateway act as a bridge for interconnecting the end node devices to the cloud server. Gateway is integrating with multiple communication for enabling communication among the end nodes and cloud serve.

c) Network Server:

The network server is capable of recording the authenticate data of the end nodes. The network server is interlinked with the gateway via Wi-Fi/ Ethernet connectivity

d) Application Layer:

This is the architecture's final layer, where the device interface controls all of the operations at sensor nodes, etc. It supports a variety of features such as virtual terminals, online services, email, file transfers, and so on. It may be any interface, such as MQTT or Blynk's Graphical User Interface (GUI). This layer communicates with the user directly. It is associated with M2M or process-to-process communication.

Since LoRa is a free licensed spectrum, there is concern about security during transmission. LoRaWAN, on the other hand, has three distinct keys during transmission: Unique Network key (EUI64), Unique Application key (EUI64), and Specific key for end computer (EUI128). The Unique Network Key (EUI64) is in charge of ensuring data safe and secure as it travels across different networks. The Unique Application Key (EUI64) enables data protection during data transmission from one node to another in the LoRa network's application layer. End device specific key (EUI128) is a device dedicated key that allows wireless authentication of devices linked to the LoRa network. Each computer is assigned a unique key.

The analysis of LoRa communication in distinct applications can be undertaken based on the parameters of spreading factor (SF), link budget, signal-noise ratio (SNR), bandwidth (BW), link budget, receiver sensitivity, bit error rate (BER), and packet error rate (PER)[116].

a) Spreading Factor

The initial frequency of the chirp is recognized as a symbol. The encoded bits in a symbol are configured by a unique parameter known as the spreading factor (SF). This indicates that a chirp with the spreading factor SF represents 2^{SF} bits per symbol, which implies that one symbol is described by multiple chips that are spread spectrum code pulses. SF is expressed as:

$$SF = \frac{Chirp\ rate}{symbol\ rate} \quad (4)$$

b) Signal-to-Noise Ratio (SNR)

SNR is the ratio of transmitted signal powers to the unwanted signal i.e., noise power. It is preferred that the SNR is minimized to ensure that demodulation at the receiver end is straightforward and the signal can be decoded correctly. To enhance LoRa performance, it uses forward error correction (FEC) techniques and the spreading factor, thus allowing significant SNR improvements. In particular, the SNR range is between −20 and +10 dB. The received signal is less distorted if the range is around +10 dB. Lora has an SNR range of −7.5 to −20 dB.

c) Link Budget

The link budget cab is determined from transmitted power and node sensitivity, and is expressed as:

$$Link\ Budget_{(dBm)} = \left(Antenna\ transmitted\ power_{(dB)}\right) - \left(Node\ sensitvity_{(dB)}\right) \quad (5)$$

d) Sensitivity (S)

Sensitivity is defined as the ability of the receiver to amplify the weak signals that are obtained by the receiver. In LoRa, the spreading factor, noise figure, and bandwidth are considered to be inputs for providing the sensitivity as output. Sensitivity (S) is calculated as:

$$S = -174 + 10log_{10} BW + NF + SNR \quad (6)$$

where BW is the band width of the channel, NF is the noise figure gain in dB, and SNR is the signal-to-noise ratio power in dB.

e) Bit Rate/data rate

Bit rate is defined as the rate at which bits are transferred from one location to another. The bit rate (R_{bit}) of LoRa is expressed as:

$$Rbit = SF * \frac{BW}{2^{SF}} * CR \quad (7)$$

f) Bit Error Rate (BER):

The rate of error bits corresponding to the cumulative number of total bits is considered to be the BER of the transmitted signal. BER is represented as 10^{-4}. If BER is 10^{-4}, then it indicates that 10,000 bits have been transferred, and one bit has an error. A higher BER indicates that network performance is poor.

g) Packet Error Rate (PER):

PER is the total number of received packets divided by the number of error packets after forwarding error correction (FEC). A packet is a data unit used in a radio transmission that is subject to FEC.

Thus, it is concluded that LoRa technology is having the capability of enhancing communication and connectivity in WSN based PA[117]. The features of LoRa including long-range transmission, low data rate, and low power consumption are suitable for the PA purpose.

2.5 Machine Learning

Machine Learning (ML) is playing a significant role in the agriculture domain. ML in agriculture is one of the tools widely used for enhancing the productivity, quality, and quantity of agriculture products. ML assists to examine and analyze the data of distinct fields of agriculture for enhancing the crop [118]. ML offers distinct analytical techniques for evaluating yield prediction and crop disease, etc [119] [120].

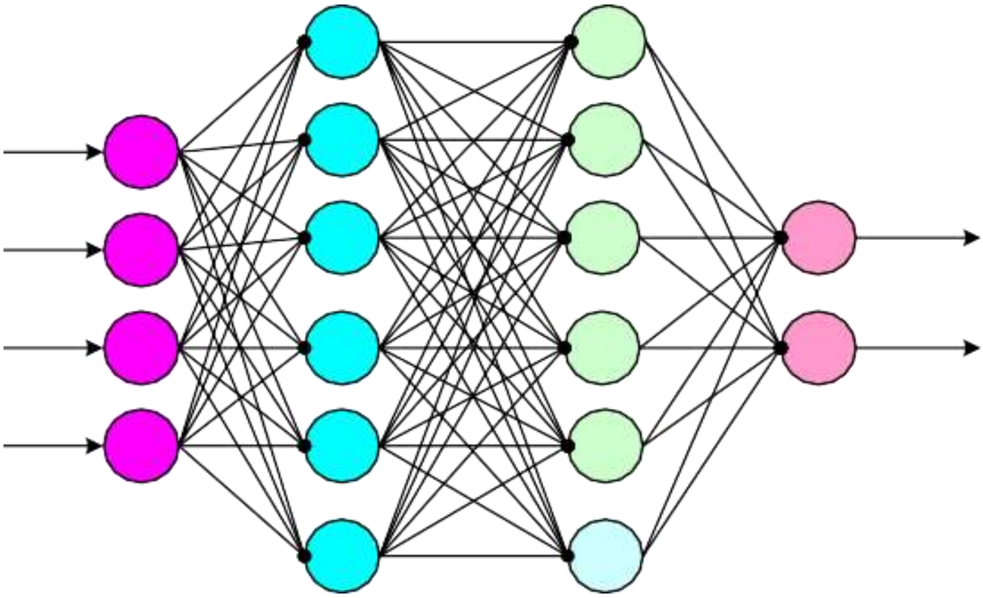

Figure.2.6 A Deep Neural Network with two hidden layers

ML is solving agricultural issues like crop selection, optimal water management in irrigation, disease detection using advanced ML algorithms, pre-soil and post soil management of agricultural land. The ML-based analysis emphasizes on quality of food content, smart irrigation, etc[121][122]. The ML-based predictive model helps the farmer to go with the suitable crop with the unconditional behavior of the weather [123]. Machine learning algorithms like neural network-based models are used for predictive analysis purposes [124] and are shown in the figure. 2.6. Figure. 2.7 presents the mechanism of the ML algorithms for classification and output.

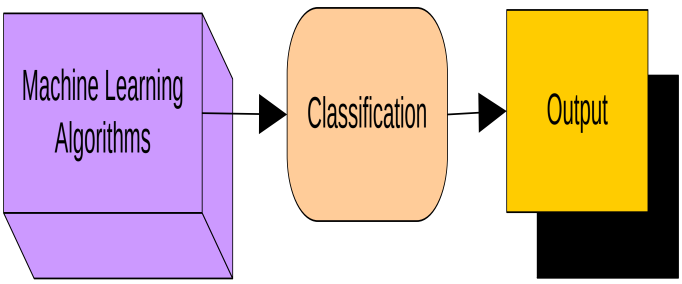

Figure. 2.7 Classification using machine learning

Water is the primary source of agriculture. 70% of global water is utilizing by agriculture. Even after use of large gallons of water, there is scarcity of the water. In context to India, the water uses in agriculture are playing a very crucial role. As the geographical locations changes with respect to the city, the utilization of ground water and canal root system varies.

Yet challenges arise due to drought and flood, this is overcome by integrating ML algorithms. ML algorithms are employing for optimizing the usage of water in comparison with the actual requirement of the water for food production. In the case of the device, the sensor can check the water consumption as per the requirement. The ultra-sonic sensor checks the level of water in the farming land and shared the data with the gateway. Further data transmits to the clod platforms for detailed analysis purposes. The efficient usage water by irrigation has always been integrally connected to agricultural evolution and productive farming. However, handling natural water supplies effectively while still performing a conventional cost-benefit analysis for technology and maintenance overheads is a complicated balancing act.

Table.2.2 Popular ML algorithms used for Crop selection

Crops	**Purpose**	**ML algorithm**	**Results**
Rice	Detection of leave infection	SVM	87.9%
Wheat	Detection of nitrogen stress	SVM	97.2%
Wheat	Detection of leave infection	ANN	99.3%
Rice	Water requirement	ANN	89.3%

ANN is the popular algorithm used in agriculture. Table .1 depicts the application of various machine learning algorithms/models and their corresponding objectives in the field of agriculture including disease detection, irrigation requirement regression, etc. In figure 2.8, 2.9 illustrates the appropriate ML algorithms of the agriculture. Identifying the disease at an early stage of farming helps to recover the growth of the plant in the agriculture field. Machine learning provides a wide range of tools to detect diseases at the early stage like image clustering or classification of healthy or unhealthy plants. Using Classification techniques, it can be easily identified. The algorithm takes the real-time data given by the user; it does the comparative analysis with the existing database where each disease has been identified which means there is already a set of labeled datasets.

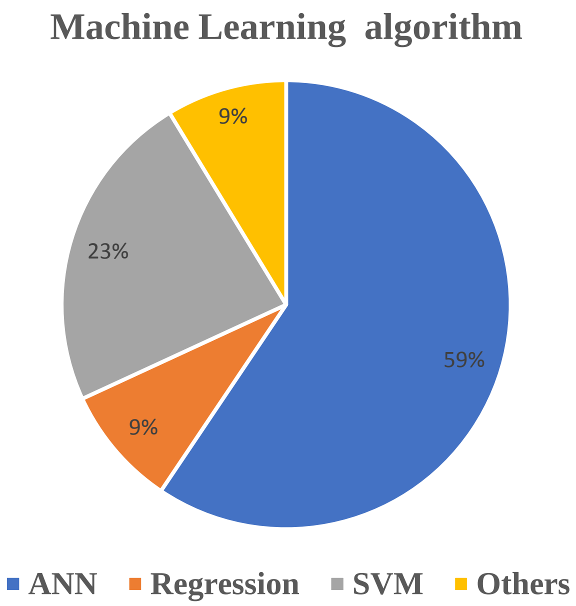

Figure. 2.8 Pie-chart showing the ANN is the widely used ML algorithm

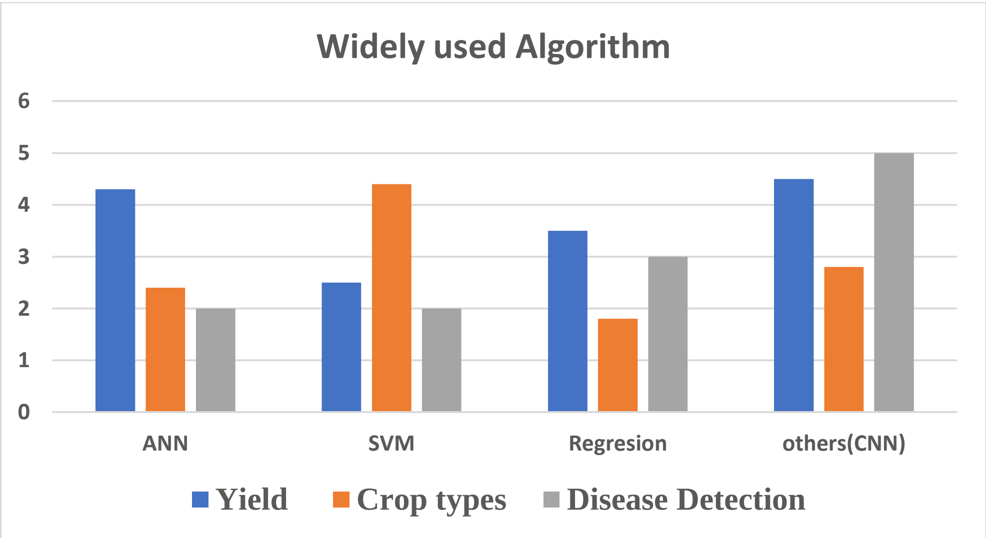

Figure. 2.9 Uses of algorithms in yield prediction, crop types, and disease detection

The distinct ML algorithms that are feasible for the agricultural application are discussing in the following. ML algorithms are artificial neural network (ANN), K-nearest neighbor (KNN), support vector machine (SVM), and convolutional neural network (CNN).

2.5.1 Artificial Neural Network (ANN)

Computational algorithms are artificial neural networks (ANN) or neural networks. It attempts to mimic the action of "neurons" composite biological structures[125]. ANNs are models of computation inspired by the central nervous systems of an animal. It can master machines and understand patterns[126]. A certain number of neurons are present in each layer, connected according to a certain number of neurons in the corresponding layer. The ANN algorithm is a machine learning algorithm that is utilized for classification, regression, and clustering problems. It is the foundation of deep neural networks. It is primarily used to learn complex non-linear hypotheses when the dataset is too big and there are too many features. ANN is applied for the prediction of yielding with weather data in the PA[127], [128].

2.5.2 Support vector machine (SVM)

SVM are supervised learning models that can be used to solve classification and regression problems[129]. They can resolve linear and nonlinear problems and are useful for a wide range of practical applications. In classification, the algorithm draws a line to divide the groups. The line's goal is to maximize the distance between the points on either side of the so-called decision line. The advantage of this method is that after separation, the model can easily guess the target classes (labels) for new cases. SVM is employed for the prediction of rice crop yielding, plant discrimination, and identification of infection in PA [130], [131].

2.5.3 K-nearest neighbors (KNN)

The K nearest neighbors algorithm is a supervised machine learning algorithm that is often utilized in classification issues[132]. It is based on the basic premise that "the apple does not fall far from the tree," which means that similar items are still nearby. This algorithm categorizes data points based on how their neighbors are categorized. A similarity measure of all available cases is used to classify any new case. Technically, the algorithm classifies an unknown object by examining k of its previously classified, nearest neighbor items and determining maximum votes from nearest neighbors with identical attributes to those chosen to define the items. KNN is utilized for disease detection, yield classification, and crop yielding in PA[133].

2.5.4 Convolutional neural network (CNN)

CNN is a powerful neural network for processing data with the outline of a 2D matrix, such as images[134][135]. CNN's are frequently used for image recognition and classification. Images are 2D pixel matrices on which we execute CNN to either identify or characterize the image. The task of image classification is to consider an input image and generate a class or a possibility of classes that better reflect the image. In CNN, we take an image as input, attach significance to its various aspects/features, and then distinguish one from another. When compared to other classification algorithms, CNN needs much less pre-processing. CNN is implemented for identifying nutrients deficiencies and disease detection in PA[136], [137].

2.6 Conclusion

In this chapter, a detailed review of agriculture with challenges is presented. Further, the technologies that have been implemented in agriculture for overcoming the challenges like food production, enhancing yielding, and real-time predictions. PA is the modern approach that has been implemented for better agricultural practices. WSN, IoT, and ML are the emerging technologies that have supported the effective implementation of PA. From the review, it is concluded that IoT-based agriculture monitoring mostly utilized the Node MCU and Raspberry Pi for transmitting the sensor data of the agricultural field to the cloud server. However, this approach is having a limitation in terms of connectivity, as internet connectivity is unavailable in the agricultural field. Moreover, the connectivity issue can be resolved with the assistance of LoRa, as LoRa establishes a wide area network in the agricultural field and connects to the cloud server through gateway. A portable device with low cost and minimum complexity are required to be implemented for providing the facilities to the farmers to visualize the field data from any remote location.

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CHAPTER 3

System Description

This chapter presents the system description and hardware design of the system for realizing the objectives the precision agriculture. Initially the system description of the architecture which including three components namely sensor mote, gateway, and IoT hand-held device are addressing in this chapter. Furthermore, the customization of the sensor mote, gateway, and IoT-enabled hand-held device is present in this chapter. Moreover, the circuit design and final prototype are present in this chapter

3.1 System description

An architecture is proposed for realizing the real-time monitoring of agricultural field using LoRa module and wi-fi module. The proposed architecture consists of three main components like sensor mote, LoRa gateway, and IoT-based hand-held device. This architecture presents the flow of the data among the sensor nodes, gateway, and hand-held devices. Moreover, this architecture assists to implement an IoT-based agriculture monitoring system in such a place where internet connectivity is limited and challenging.

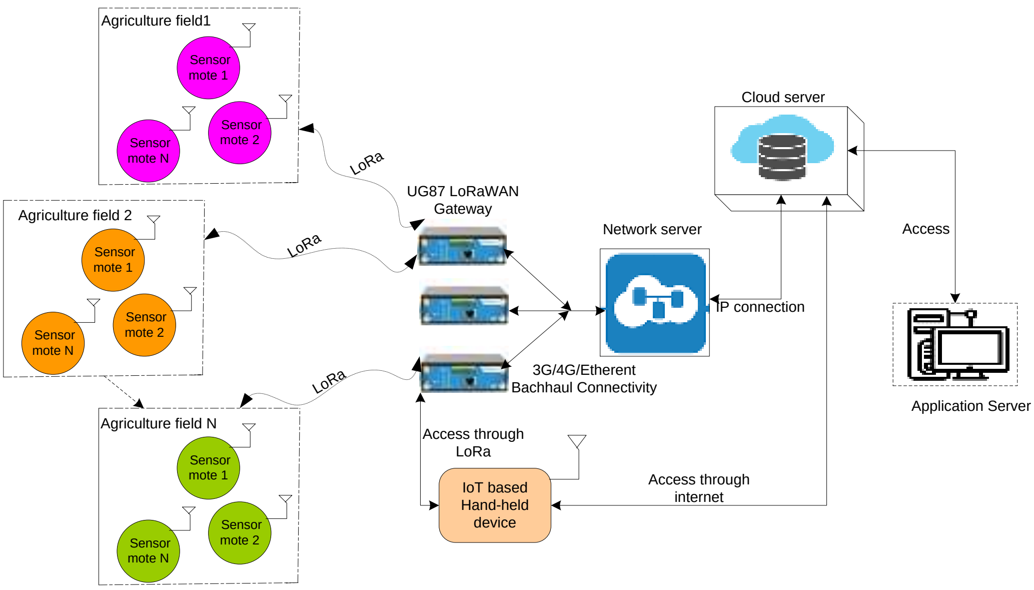


Figure. 3.1 LoRa and Wi-Fi-based architecture for agricultural field monitoring

To overcome this, we have established a low-power wide-area network (LPWAN) between the nodes and gateway that enhances reliable connectivity. Figure.3.1 illustrates the architecture, where the ‘N’ number of sensor motes are deployed in the ‘N’ number of agricultural fields. The ‘N’ number of nodes may vary dependent upon the payload size during data transmission. To transmit the data sensed by the sensors deployed at the agricultural field, the sensor motes are embedded with LoRa wireless communication module [138]. The primary parameter of considering the LoRa among all LPWAN technologies is, LoRa is an open license spectrum and zero subscription with long-range transmission and low power consumption [139]. With the assistance of LoRa, the sensor motes communicate the sensory information to the gateway. As the gateway is integrated with LoRa and Wi-Fi module, it receives the sensory information from the sensor motes through LoRa and communicates it to the cloud server via the internet. The gateway is positioned at the place where the internet connectivity is good. A hand-held device that is based on LoRa and gateway is included in architecture which assists the farmers to supervise the agricultural field from any location. This hand-held device receives the data related to the agricultural field from the gateway node through LoRa communication and also it receives the data from the cloud server through internet. Furthermore, we are discussing the individual components of the architecture and it is as follow:

3.1.1 Sensor mote:

Sensor mote is the primary component for sensing and communicating the distinct parameters of the agricultural field. The distinct components that present in the sensor mote are presented in the figure. 3.2. The sensor mote is equipped with many sensor modules to sense the real-time scenario in the agriculture field like temperature, humidity, pH, etc. All these sensors are interfaced with the controller unit. The controller unit initiates the transmission of the sensory information when it receives from the sensors. The transmission of the sensory data is achieved through the LoRa communication module. LoRa communication module initiates communication between the sensor mote and gateway. Concerning the power supply, the components embedded in the sensor mote require a different power supply. Depending upon this parameter, a power converter is embedded to maintain the power supply concerning the required power for the components. A display unit is also interfaced with a controller unit, which displays the sensor information and other parameters in digital form.

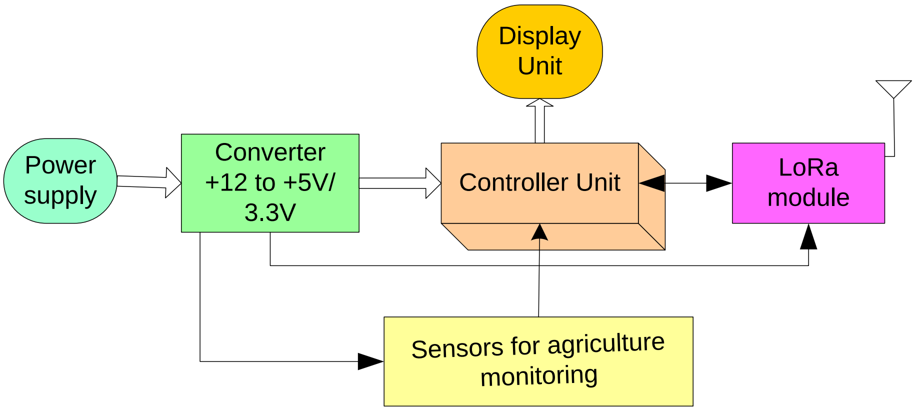


Figure. 3.2 Components of sensor mote

3.1.2 Gateway with NUTTYFI/Node MCU

The gateway enables to initiate communication between the sensor mote and cloud server. The components embedded in the gateway are present in figure.3.3. As the LoRa module is the transceiver unit, it is capable of receiving the information from the sensor mote and with the assistance of the NUTTYFI Wi-Fi module, the gateway transmits the data to the cloud server via internet connectivity.

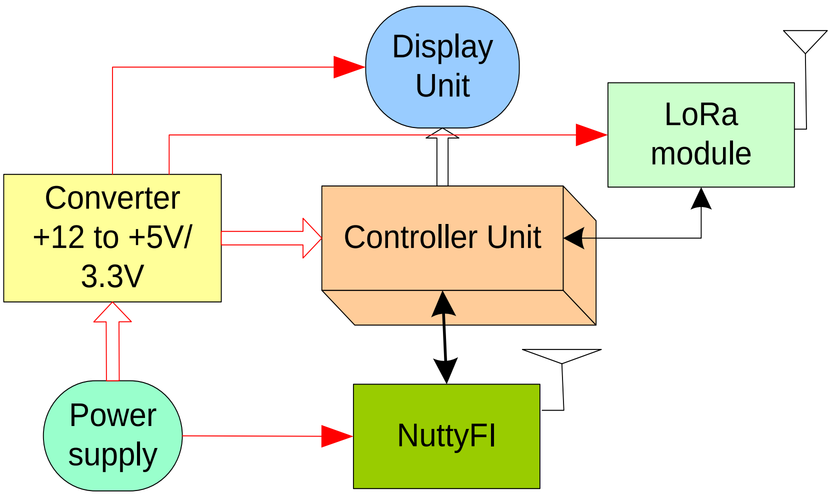


Figure. 3.3 Components of the gateway with NUTTY FI

Wi-Fi module is based on 802.11b wireless ethernet standard and 2.4 GHz frequency band [140] provides the internet connectivity to the gateway. The gateway is positioning at the location where the internet connectivity is stable. The power converter is also available in the gateway for supplying appropriate power to the components presented in the gateway.

3.1.3 Gateway with Raspberry Pi:

In our architecture, the gateway is also enabling the raspberry pi to initiate the internet connection with the cloud server. Raspberry pi is having an inbuilt wi-fi module that is used by the gateway for logging the corresponding data into the cloud server. The components embedding the LoRa based gateway are presented in figure.3.4. As the LoRa module is the transceiver unit, it is capable of receiving the information from the sensor mote. The controller unit initiates raspberry pi to connect the internet for transmitting data to the cloud server. The power converter is also available in the gateway for supplying appropriate power to the components presented in the gateway.

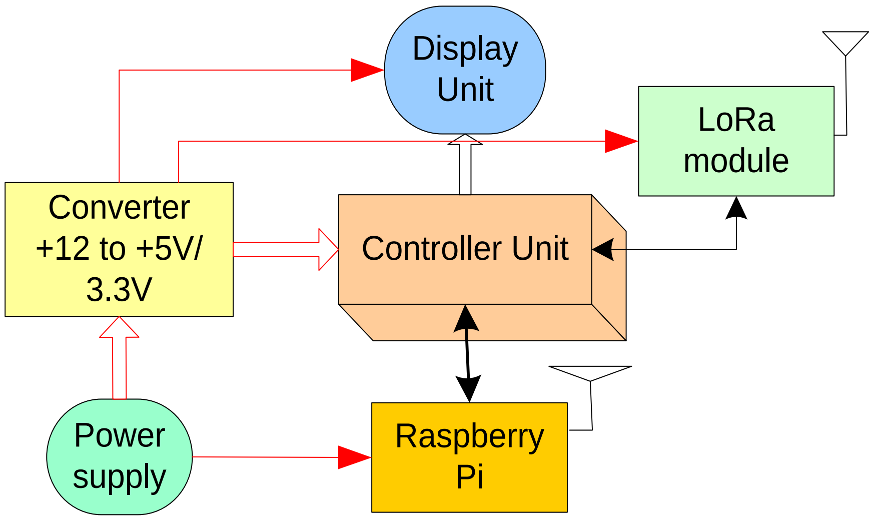


Figure. 3.4 Components of the gateway with Raspberry pi

3.1.4 IoT based hand-held device:

The IoT-based hand-held device is an easy-to-use portable device for the customer segment primarily focused on rural farmers. Using the device they can visualize the agricultural field data on the integrated graphical display. This hand-held device enables the farmers to supervise the agricultural field from any location, as it is integrated with LoRa communication and Wi-Fi. The components that present in the IoT-based hand-held device are illustrated in figure.3.5.

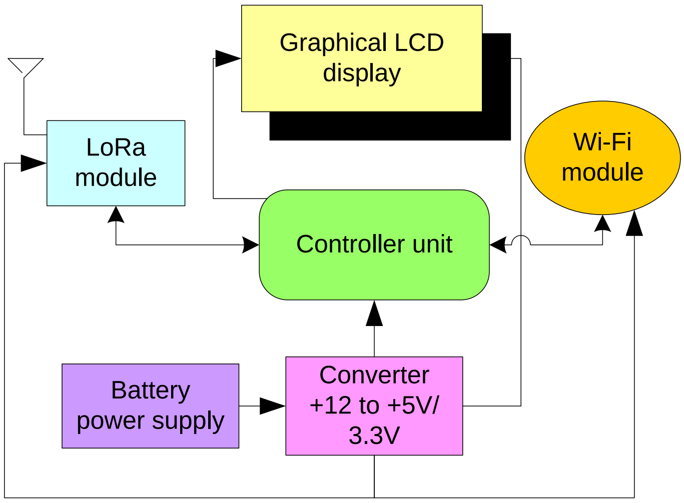


Figure. 3.5 Components of IoT based hand-held device

3.2 Customized design

Hardware design of the sensor mote and gateway is the primary process for designing and customization. The customization of sensor mote, gateway, and the hand-held device is carried out in our study. Generally, customization of the prototype is implemented for reducing the cost and providing a system that is reliable and low complexity. The selection of each component plays a crucial role in the customization. Generally, the power consumption parameter is considered for selecting the component in sensor mote as the sensor mote is deployed in the agricultural field where the external power supply is difficult. The selection of wireless communication is having a significant role in avoiding power dissipation in the sensor mote during transmission of the data. So, a wireless communication module is chosen with low power consumption for transmitting the data to a long range. Here we have selected the SX 1278 LoRa module. Another important component for customization is the microcontroller unit, it is important to choose an appropriate microcontroller for developing an energy-efficient prototype. ATMEGA328P microcontroller is considered in our study as the complexity of data is low and also this microcontroller consumes low power. Data complexity refers to the size of the data received from the sensors required, here the size of data is low. In the sensor mote, we have embedded the power jack for supplying power to the node through batteries. Concern to powering the sensor mote and gateway, +5 V and +3.3 V voltage is integrated for converting to supply the appropriate voltage.

3.2.1 Sensor mote:

The circuit design of the sensor mote is shown in the figure. 3.6. The technical description and connection of the circuit design are as follows: ATMEGA328 is an 8-bit microcontroller that follows Reduced Instruction Set Computer (RISC) architecture which makes it quite friendly for low-cost applications related to IoT and WSNs [141]. The operating voltage of the controller ranges between 1.8 to 5 Volts. The power supply in the sensor mote is the integration of the bridge rectifier with an AC step-down transformer. LM7812, LM7805 are the voltage regulator embedded in the sensor mote for meeting the distinct power supply of 12 V and 5V.

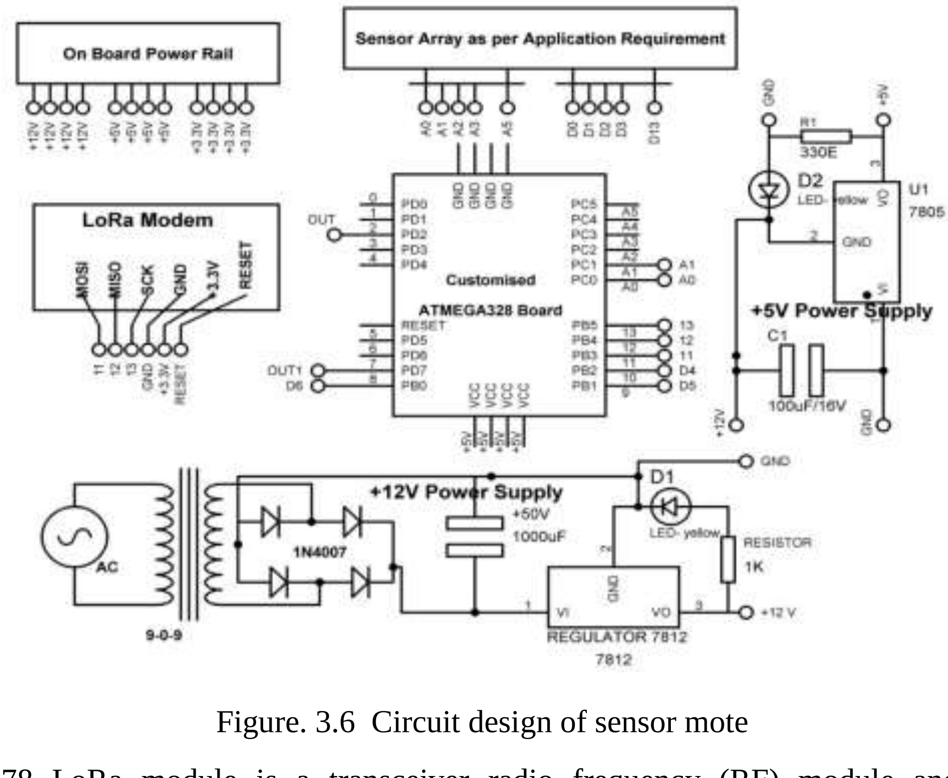


Figure. 3.6 Circuit design of sensor mote

SX1278 LoRa module is a transceiver radio frequency (RF) module and it is developed by SEMTECH. The frequency band of this module is between 137MHz to 525MHz. The maximum transmission data rate of LoRa is 300kbps. The specifications of the LoRa module are as follows 20dBm - 100mW constant RF output vs. V supply, 168dB link budget in LoRa, +, +14dBm high-efficiency PA, Immunity towards noise interference, 200nA retention in the register low current 9.9mA. The connection of the LoRa module with ATMEGA328 is done through the MISO, MOSI, ground, and SCLK. The sensor array having several digital and analog pins. Digital and analog pins are connected with digital and analog sensors like soil pH sensors, DHT11, etc.

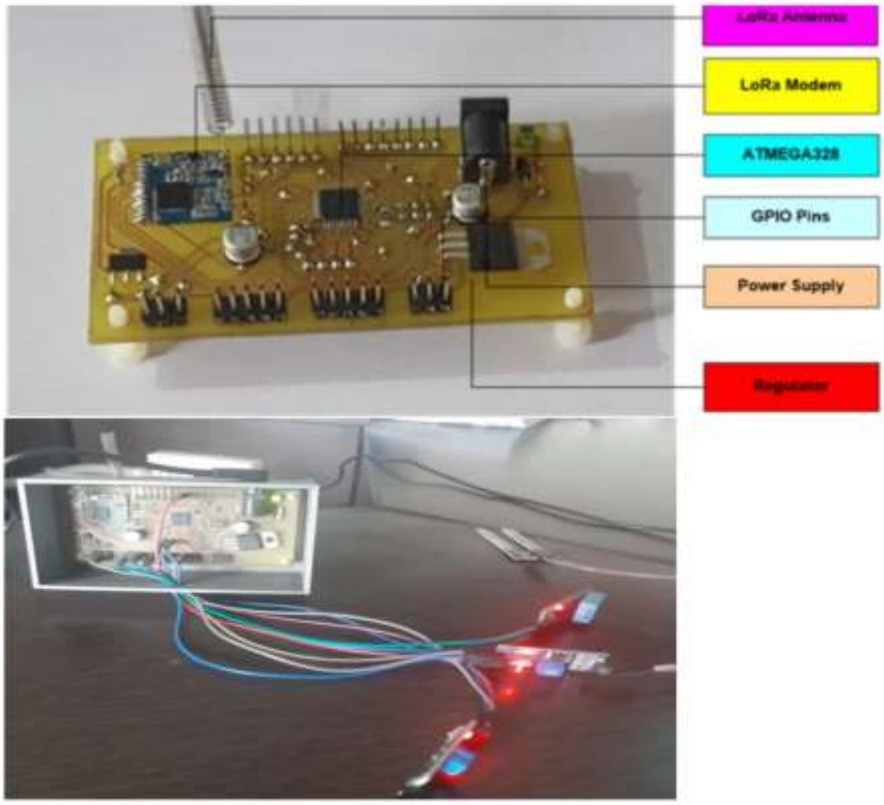


Figure. 3.7 Customized sensor mote with package

The customized sensor mote is designed and fabricated on PCB layout with necessary components and it is shown in the figure. 3.7. The LoRa modem and ATMEGA 328P controller are embedded in the customized sensor mote. The connections of the sensor mote circuit are as follows:

- The power rail pins of +12V, 5V, and 3.3V are on board to give the supply to sensors and actuators
- The Vcc, GND, and OUT pins of the soil moisture sensor are connected with +5V, GND, and A0 pins of the customized atmega328 board.

- The Vcc, GND, and OUT pins of the Fire sensor are connected with +5V, GND, and 7 pins of customized atmega328 board.
- The Vcc, GND, and OUT pins of the DHT11 sensor are connected with +5V, GND, and 2 pins of customized atmega328 board.
- The MOSI, MISO, SCK, GND, Vcc and RESET pins of the LoRA modem are connected with 11,12,13, GND, +5V and RESET pins of customized Atmega328 board.
- Onboard +12V to +5V convertor is connected to +Vcc and GND pins of the atmega328 microcontroller

3.2.2 Gateway with NUTTYFI Wi-Fi module

The circuit design of the gateway with the NUTTYFI Wi-Fi module is shown in the figure. 3.8 . As discussed ATMEGA 328 P microcontroller is also embedded in the gateway. A similar SX 1278 LoRa modem is embedding in the gateway.

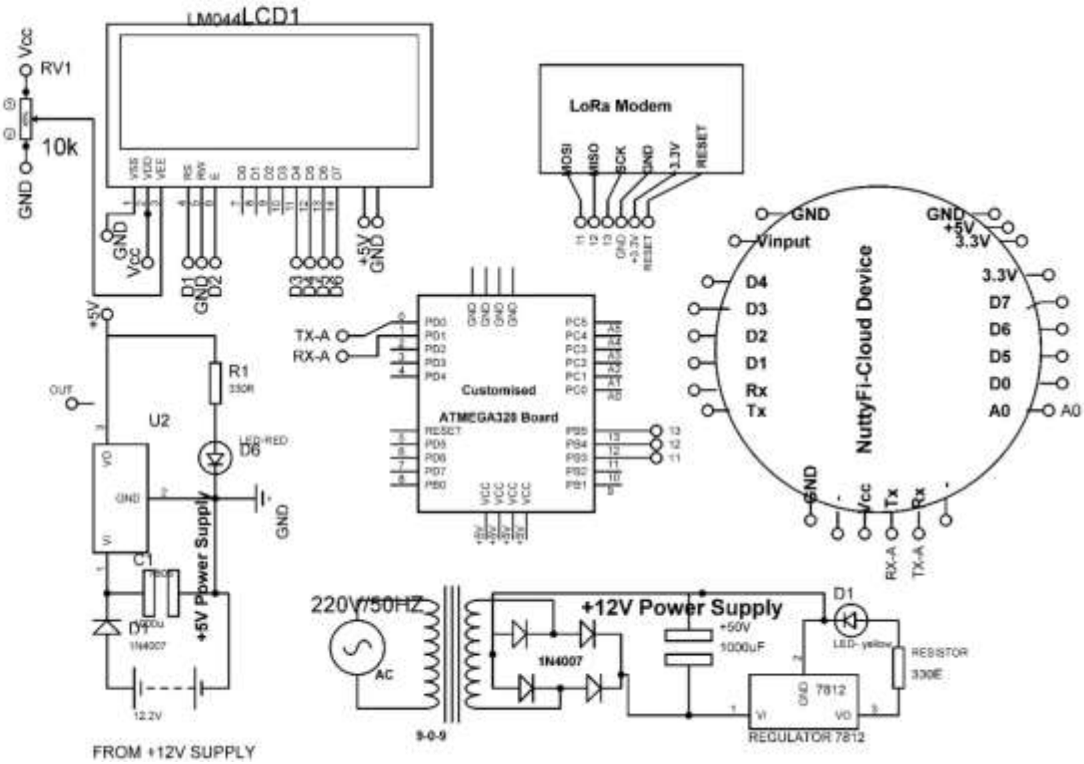


Figure. 3.8 Circuit design of the gateway

In the gateway, the LoRa modem act as a receiver, where it assists the gateway to receive the data from the sensor mote. NUTTYFI cloud device is IoT based hardware module that is based on the ESP8266 12e series. This device consists of 9 digital pins, 1 analog pins, 128kBytes memory, 4Mbytes storage. It is a 32bit Single-board microcontroller with a power voltage of 3V and 5 V. NUTTYFI cloud device is chosen based on the following advantages: Integrated support for WIFI network, reduce the size of the board, and low cost. The LM7812 regulator is embedded in the gateway for regulating for 12 Volt output.

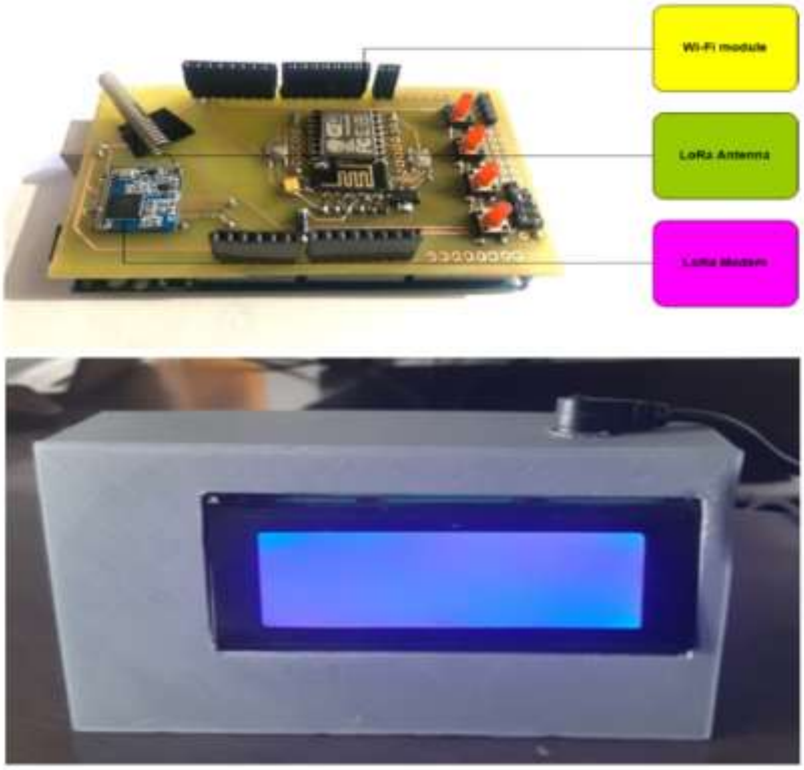


Figure. 3.9 Customized Gateway with package

LCD is embedding in the gateway to show which sensor mote the data is receiving. The customized gateway is designing and fabricating on PCB layout with necessary components and it is shown in the figure. 3.9. The LoRa modem and Wi-Fi module of the gateway are highlighted in figure 3.9 The connections of the gateway are as follows:

- The 1 and 16 pins of LCD are connected with the GND pin of the customized atmega328 board.
- The 2 and 15 pins of LCD are connected with +5V pin of customized atmega328 board.

- The 10K POT variable pin is connected with pin 3 of the customized atmega328 board to control the contrast of the LCD.
- RS, RW, and E pins of the LCD are connected with 8, GND, and 7 pins of customized atmega328 board.
- D4, D5, D6, and D7 pins of LCD are connected with 6, 5, 4, and 3 pins of customized atmega328 board.
- The MOSI, MISO, SCK, GND, Vcc and RESET pins of the LoRA modem are connected with 11,12,13, GND, +5V and RESET pins of customized Atmega328 board.
- The RX (0), TX (1), GND, and Vcc of customized atmega328 board are connected with TX, RX, GND, and +5V pins of Nuttyfi board
- Onboard +12V to +5V convertor is connected to +Vcc and GND pins of the atmega328 microcontroller.

3.2.3 Gateway with raspberry pi

The circuit design of the gateway with the NUTTYFI Wi-Fi module is shown in the figure. 3.10. As discussed ATMEGA 328 P microcontroller is also embedded in the gateway. A similar SX 1278 LoRa modem is embedding in the gateway. In the gateway, the LoRa modem act as a receiver, where it assists the gateway to receive the data from the sensor mote. Here raspberry pi interfacing with ATMEGA 328 board enables the gateway to initiate communication in between gateway and cloud server. The customized gateway is designing and fabricating on PCB layout with necessary components and it is shown in the figure. 3.7 (b). The LoRa modem and Wi-Fi module of the gateway are highlighted in figure 3.7 (b). The connections of the gateway are as follows:

- The 1 and 16 pins of LCD are connected with the GND pin of the customized atmega328 board.
- The 2 and 15 pins of LCD are connected with +5V pin of customized atmega328 board.
- The 10K POT variable pin is connected with pin 3 of the customized atmega328 board to control the contrast of the LCD.

- RS, RW, and E pins of the LCD are connected with 8, GND, and 7 pins of customized atmega328 board.
- D4, D5, D6, and D7 pins of LCD are connected with 6, 5, 4, and 3 pins of customized atmega328 board.
- The MOSI, MISO, SCK, GND, Vcc and RESET pins of the LoRA modem are connected with 11,12,13, GND, +5V and RESET pins of customized Atmega328 board.
- The RX (0), TX (1), GND, and Vcc of customized atmega328 board are connected with TX, RX, GND, and +5V pins of the raspberry pi.
- Onboard +12V to +5V convertors are interfaced with +Vcc and GND pins of the atmega328 microcontroller.
- Onboard +12V to +5V convertors are interfaced with +Vcc and GND pins of the raspberry pi.

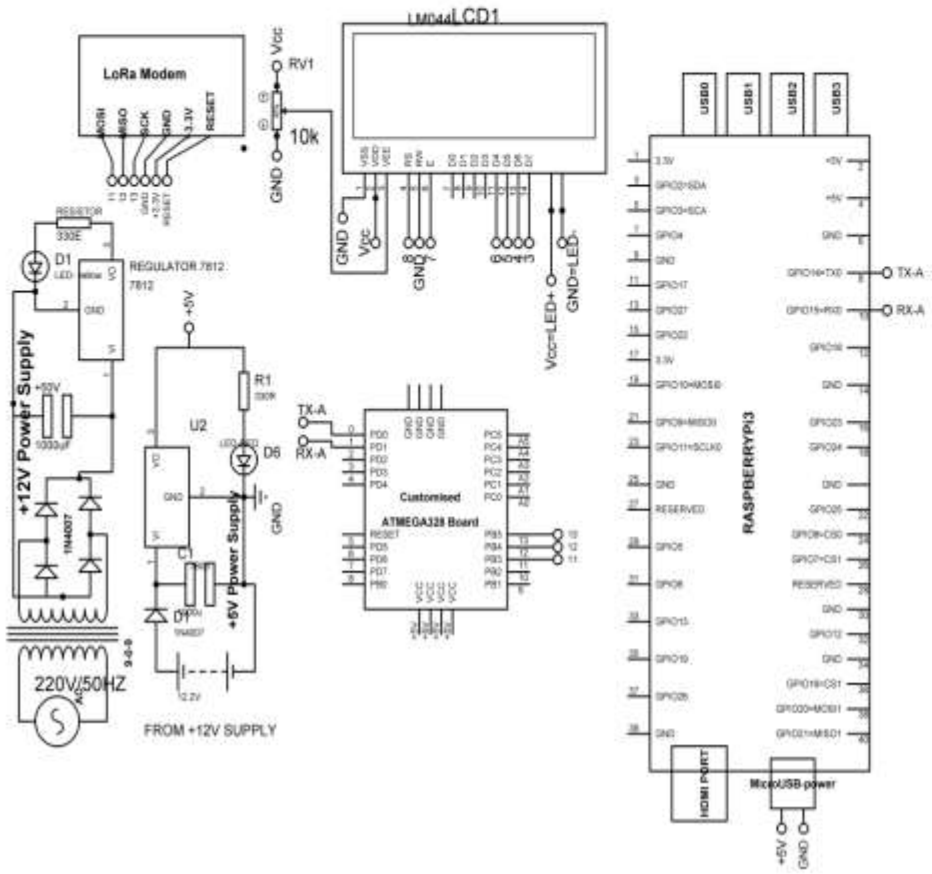


Figure. 3.10 circuit design of gateway with Raspberry pi

3.2.4 IoT based hand-held device

An IoT-based hand-held device is customized and built for delivering a portable device that will assist the farmer to monitor and supervise the agricultural field. The circuit design of IoT based hand-held device is shown in the figure. 3.11 For hand-held devices, we have considered Arduino mega which is built on the ATmega1280/2560. It consists of 16 analog input pins which can be used to read or sense any kind of peripherals having analog output, 4 serial port for communication in UART mode, 54-digital input/output pins, 16 MHz crystal oscillator, an ICSP header, reset button, a power jack, and a reset button.

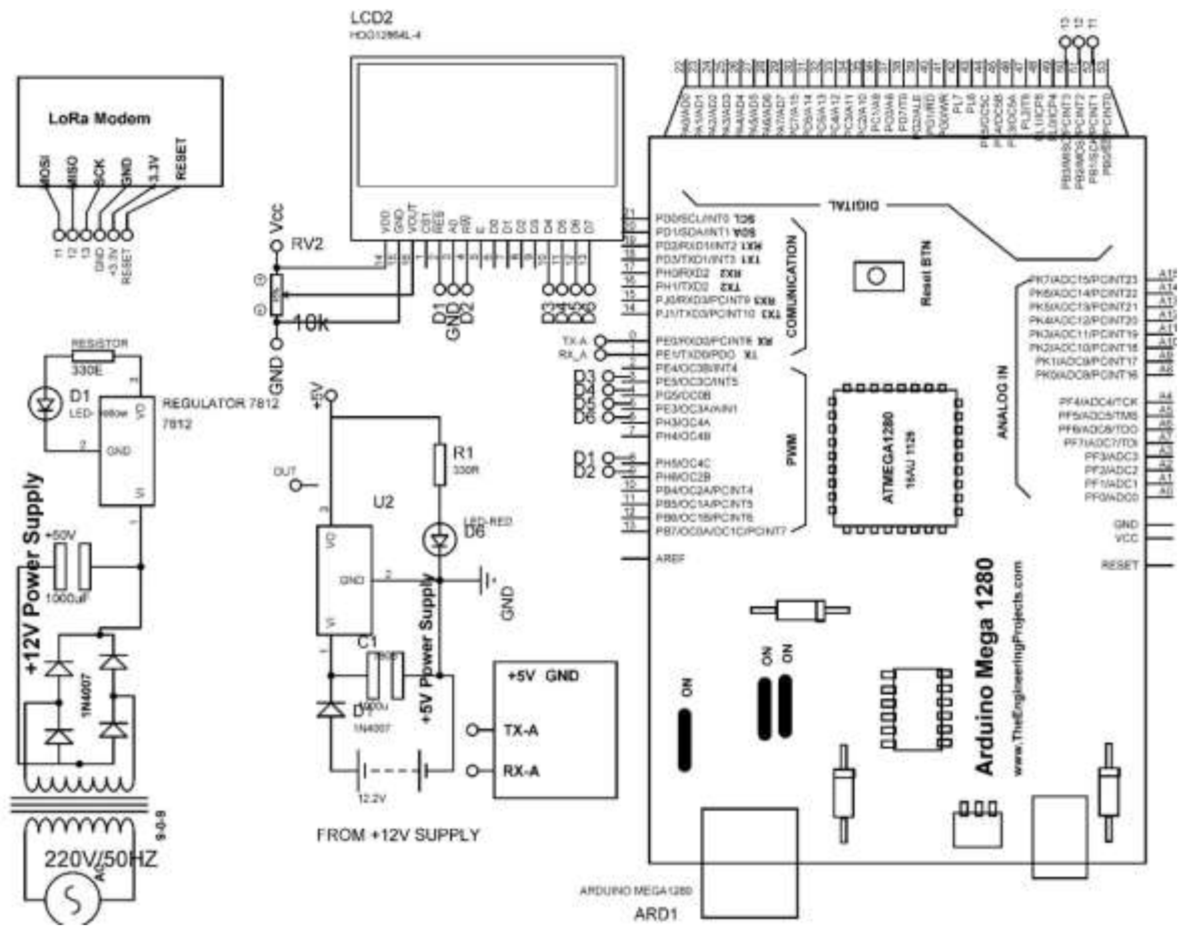


Figure. 3.11 Circuit design of IoT based hand-held device

Liquid crystal display (LCD) is embedded for visualizing the data receiving from the gateway and cloud server. LCD is comprising of 8 digital pins; 1 analog pin is built in the hand-held device. SX 1278 LoRa modem is integrated into the hand-held device for receiving the information the sensor mote. The connections of the sensor mote are as follows:

- The 1 and 16 pins of LCD are connected with the GND pin of the Arduino Mega 2560 board.
- The 2 and 15 pins of LCD are connected with the +5V pin of the Arduino Mega 2560 board.
- The 10K POT variable pin is connected with pin 3 of the Arduino Mega 2560 board to control the contrast of the LCD.

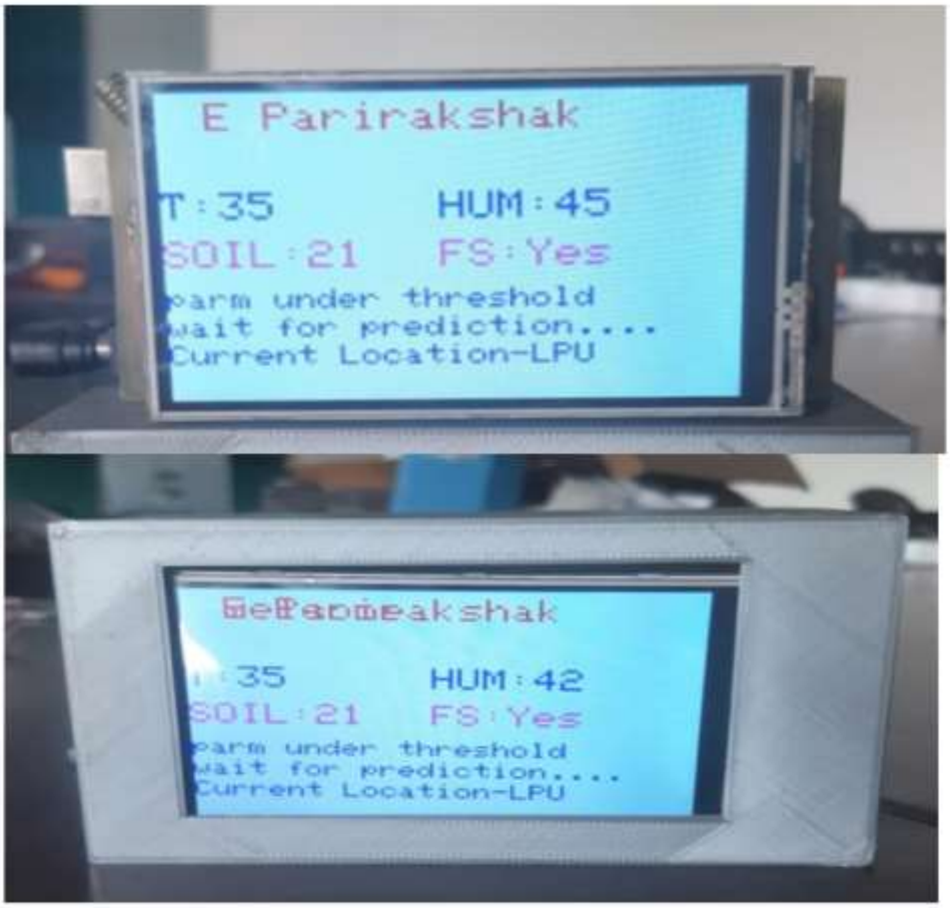


Figure. 3.12 Customized IoT based hand-held device with package

- RS, RW, and E pins of the LCD are connected with 8, GND, and 7 pins of Arduino Mega 2560 board.

- D4, D5, D6, and D7 pins of LCD are connected with 6, 5, 4, and 3 pins of Arduino Mega 2560 board.
- The MOSI, MISO, SCK, GND, Vcc and RESET pins of the LoRA modem are connected with 11,12,13, GND, +5V, and RESET pins of the Arduino Mega 2560 board.
- The RX (0), TX(1), GND, and Vcc of Arduino Mega 2560 board are connecting with TX-A, RX-A, GND, and +5V pins of the Nuttyfi board
- Onboard +12V to +5V convertor is connecting to +Vcc and GND pins of the Arduino Mega 2560 board.

After designing the circuit of a hand-held device, we have fabricated the hardware prototype on a PCB board. The customized hand-held device is shown in figure 3.12. This device is a portable one and it is having low complexity in terms of controlling. In a hand-held device, the LCDs the sensor data in color digital format. The hand-held device is well packed with an outer case and it is shown in the figure. 3.12.

3.3 Conclusion

The chapter presents the system description of LoRa based architecture for monitoring agriculture with hardware design. Here the significance of each component in the architecture is addressing with a block diagram. Moreover, in the hardware design section, the customization of sensor mote, a gateway with NUTTYFI, a gateway with the raspberry pi, and IoT-enabled hand-held device are discussed in detail. The integration of the ATMEGA 328P controller and SX 1278 LoRa module for sensor mote and gateway is also addressed in this chapter. Additionally, the gateway is embedding with controller switches that enable the farmer to control the actuators of the agricultural field through the LoRa network. IoT-enabled hand-held device is having a unique switch that assists the farmer to obtain the agricultural field data from the gateway and also the hand-held device is capable of initiating the task of prediction of the crop from the cloud server.

CHAPTER 4

FIRMWARE DEVELOPMENT

This chapter presents the customization of the operating system (OS) in the Raspberry pi enabled gateway. The customization of OS is performing on the raspberry-pi enabled gateway for eliminating the features that are not necessary for the agriculture application. The customization also assists in minimizes the execution time and enhance the reliability of the gateway. The chapter presents the step-by-step procedure of customizing the OS. For the customization of OS, embedded Linux-based YOCTO OS is utilizing in this article. For evaluating the performance of customized OS, certain parameters are defined, and it assists to validate the distinct programming languages and searching algorithms. The customized OS is delivering effective performance with merge sort algorithm

4.1Linux Kernel Architecture for gateway

We present the development of embedded Linux-based firmware for the raspberry pi installed at the gateway.   Furthermore, for Linux development, it is important to upgrade the old Linux kernel as using an old kernel can result in ill support for task scheduling, interrupt handling, resource allocation, multitasking, on-chip memory management, and simple user interfaces [142]. A variety of factors influence the porting of the Linux kernel to a target platform. The setup and compilation of the Linux kernel for the Raspberry Pi on Host Ubuntu 14.04. Cross compiler tool chains are constructed, and executable files can be ported to the target platform [143].

Linux is popular due to its lower memory footprint and customizable as per the platform. When it comes developing embedded Linux software is complex and requires a lot of effort to do it. Linux kernel plays a crucial role in organizing, scheduling multiple tasks in an OS. Since the Linux kernel supports various architectures, such as X86 and ARM, the protocols for each architecture differ. In this article, we will create an embedded Linux system for the Raspberry Pi computer, which is based on the ARM1176JFZ-S processor and the BCM2835 system on-chip. Raspbian OS is a Debian-based operating system designed for the Raspberry Pi. It includes all of the packages required for the Raspberry Pi's basic operations. The Yocto Project provides an open-source platform to design and build custom embedded firmware for the devices operated on operating systems. PiLFS is a free open-source Linux distribution suitable for the ARM architecture.

The Linux kernel architecture comprises of system calls layer, architecture-dependent and independent layer are shown in figure.4.1. The system call interface is responsible for reading and writing system instructions and socket calls. Process management manages the CPU and the active threads running inside the system. Memory management with memory allocation for the execution of the task is assigned by the kernel. The further kernel manages overall device tasks to avoid unusual breakdown of the tasks. Source code of the kernel is present in the device driver. The arch subdirectory is a package that has individual kernel codes for various platform architecture e.g. it will have different kernel codes for amd64 and different armhf, etc

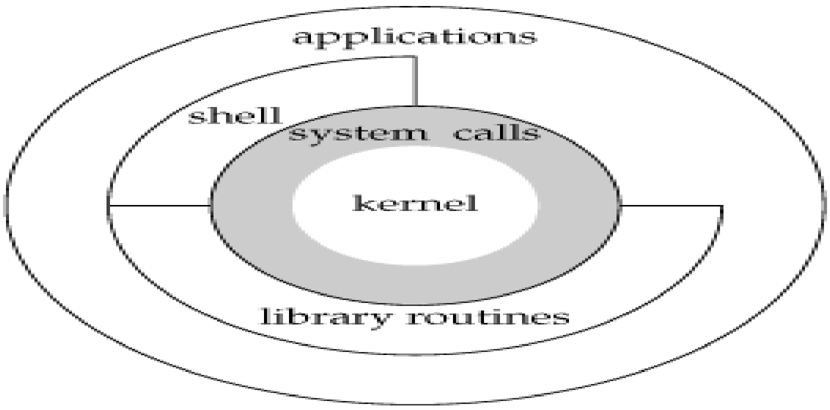


Figure 4.1 Linux kernel architecture

Cross compiler is a software-based compiling environment that enables us to compile or build our low or high-level packages for another platform to make it compatible for execution and usage on the target platform e.g. we can cross-compile a python-based package to be compatible with c based platform using cross compilers with relevant toolchains like CMake. Cross-compilation environments support Application Binary Interface (ABI) and Embedded Application Binary Interface (EABI) [144]. The ABI converts higher-level language provided by the user shell or package to machine-level language to be understood by the kernel. For different targets, Linux kernels get updated with toolchains for different applications. Figure. 4.2 shows a flow diagram for customization of Linux kernel.

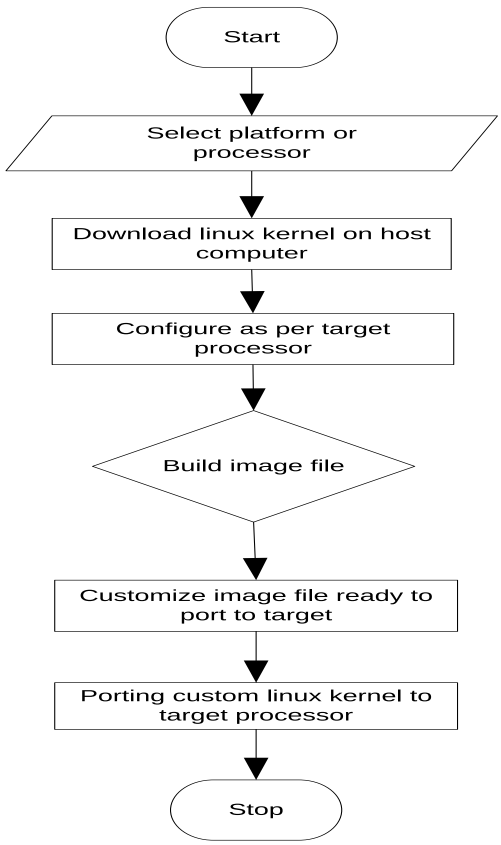


Figure 4.2 Customization procedure of Linux kernel

The Linux kernel compilation on ARM is implemented by using two methods and it is categorized as method 1 and method 2 that are discussed as follows:

Method 1:

The first step that needs to be followed is to download the latest kernel .tar file from the official website "htttps://kernel.org" by using either direct download methods or by using any of the dedicated files downloading packages like wget, curl, etc. The file is then to be extracted to a folder for example stable-img in the home directory. To optimize the process, we should utilize the current kernel named .config that can be found in /boot directory with a name starting with config- preceded by the kernel version. Copy it to the top src directory of the kernel using file explorer or by using shell commands like cp.

$ cp /boot/config- ~/* stable-img*/.config*

The updated kernel provides options that are not included in any present kernel, so we need to define a few configuration options.*$ cd ~/Linux-stable*

$ make oldconfig

Press the Enter key for every question in a random manner. After the completion of kernel configuration, the process of compiling is initiated for the Linux kernel.

$ make -j`cat /proc/cpuinfo | grep -c processor`

To build a kernel it consumes a time duration of 4-5 hours. The above command assists to build the kernel modules as well as kernel image. At present, the installation of new kernel modules and kernel images are installed.

$ sudo make modules install

The above command enables to install of the kernel image and the configuration of the new kernel is copied in the /boot directory. The command can change the configuration of the boot loader so that the boot loader (ex: GRUB) identifies the new kernel. The kernel modules are installed into /lib/modules with the naming pattern relevant to the new kernel version and the rest of the kernel headers are installed and saved into /usr/src .

Kernel system is verified after rebooting the system

$ Uname -r.

In case, if the particular Kernel version is not necessary then it can be deleted with the appropriate Kernel's config *vmlinuz*, *System.Map* and *initrd* from the /boot folder. Moreover, the kernel header is removed from */usr/src* and later on, the bootloader needs to be updated by running the following command.

"$ sudo update-grub2".

In case of rebuilding the new kernel, use the following command *"$ make mrproper" in ~/Linux-stable* for removing the old configuration and files of the kernel that is built. To compiling the custom Linux for raspberry pi on Ubuntu 14.04 host. At first, the own root directory was created and after that downloading Linux tools for Raspberry Pi.

https://github.com/raspberrypi/tools.git https://github.com/raspberrypi/linux.git cd Linux

*$ mkdir -p ~/raspberry_armtools/build/toolchain \ ~/raspberry_armtools/toolchains *

Generally, Crosstool-NG is unavailable in the standard Ubuntu. To build and install Crossstool, run the below commands

install Crosstool-NG:

$ pushd ~/raspberry_armtools/build

http://crosstoolng.org/download/crosstoolng/crosstool-ng-1.18.0.tar.bz2

$ tar xf crosstool-ng-1.18.0.tar.bz2 && cd crosstool-ng-1.18.0

The following commands are implemented for launching the menu config and use the below commands for configuring the build parameters of the toolchain :

$ pushd ~/raspberry_armtools/build/toolchain

$ ct-ng menuconfig

Toolchain customization for ARM processor:

$ ct-ng build

$ popd

If the build was successful, the toolchain will be located at

~/raspberry_armtools/toolchains/arm-unknown-Linux-gnueabihf/.

Every tool (gcc, ld, gdb, etc) is available in the bin/ directory of the toolchain with the name of the toolchain prefixed.

Method 2: Using the YOCTO project

Initially, the task of edit conf/local.conf is implemented for matching the compilation environment for presetting the target machine as Raspberry Pi, and perhaps to alter the GPU memory, by updating or adding the corresponding lines in local.conf:

BB_NUMBER_THREADS = "2"

PARALLEL_MAKE = "-j 2"

MACHINE ?= "raspberrypi"

GPU_MEM = "16"

Other system parameters such as license codecs, GPU memory, and overclocking can be accustomed as described in [145]. The path to meta-raspberrypi needs to be added to bblayers.conf file located in poky/build/conf, so that it would look like to this:

*“BBLAYERS ?= " *

/home/mahi/Yocto/poky/meta

/home/mahi/Yocto/poky/meta-Yocto

*/home/mahi/Yocto/poky/meta-Yocto-bsp *

*/home/mahi/Yocto/poky/meta-raspberrypi *

To create the image we can use the command: *$ bitbake rpi-basic-image*. On successful execution of this command, an image file will be created containing all the dependencies including SSH server support. After compilation, a file will be built and saved in *tmp/deploy/images/rpibasic-image-raspberry.rpi-sdimg*. This is a symlink to the binary image that can be copied into an SD card:

$ sudo dd.sh if=tmp/deploy/images/rpi-basicimage-raspberrypi.rpi-sdimg of=/dev/sdb bs=1M The SD boots the Raspberry Pi with the newly compiled kernel and modules. To add features or adjust the memory of the kernel, you can change the kernel configuration before building the system with the command:

$ bitbake virtual/kernel –c menuconfig.

This opens the same graphical kconfig menu that was used in the earlier compilation sections [146]. Through the menu selections, you can do similar configuration changes as were described in the previous section, “Compiling for QEMU”. The newly configured kernel should be built

4.1.1 Parameters for performance evaluation

Sorting algorithms are the best to compute the performance evaluation. This algorithm is a sequential program that is executing with a certain predefined outcome. The following are the sort algorithm namely bubble sort, merge sort, and binary search.

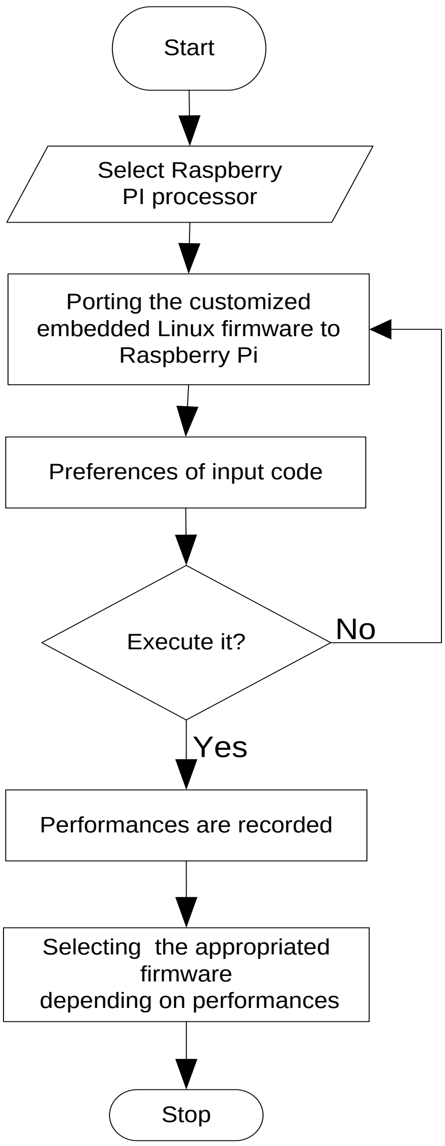


Figure. 4.3 Evaluating the performance of Embedded Linux

The code flow in an embedded firmware as shown in figure 4.3. To evaluate the time complexity and space complexity these algorithms are used. Further, the CPU clock cycles required to compute and execute the complex code are calculated. It has been found that the performance could be optimized by selecting appropriate hardware platforms, programming languages.

4.2 Evaluation of performance

In this section, the performance of the customized OS that is built on embedded Linux-based YOCTO is evaluated with other OS including Raspbian and PILES. YOCTO is an embedded Linux development platform that supports for creation of OS of IoT and embedded software that is independent of hardware architecture. The evaluation of performance has been completed on the custom kernel with YOCTO and evaluation is presented in table 4.1, table 4.2, and table 4.3.

Table 4.1. Raspbian using python

Evaluation parameters	Bubble sort	Binary Search	Merge sort
CPU	2.2×10^{18}	3.2×10^{18}	2.5×10^{18}
clock cycle	3456	3589	3678
Switching time (ms)	1245	1324	1367
Cache performance	976	976	945
Percentile performance	75	69	79

Table 4.2. PiLFS using python

Evaluation parameters	Bubble sort	Binary Search	Merge sort
CPU	2.1×10^{18}	2.9×10^{18}	2.3×10^{18}
clock cycle	1189	1201	1235
Switching time (ms)	1189	1201	1235
Cache performance	1125	1192	1232
Percentile performance	84	73	65

The evaluation parameters are present in table 4.1, 4.2 & 4.3 including CPU cycles, context switch, task clock cycle, cache hit time, and overall performance in the percentage. Additionally, searching algorithms like bubble sort, merge sort and binary search are utilizing for analyzing the performance.

Table 4.3. Yocto using python

Evaluation parameters	Bubble sort	Binary Search	Merge sort
CPU	$3.2x10^{18}$	$4.5x10^{18}$	$2.7x10^{18}$
clock cycle	4232	3954	3875
Switching time (ms)	1239	1287	1342
Cache performance	1345	1356	1189
Percentile performance	73	65	75

a) Program size: 1K

The evaluation of custom embedded firmware design is analyzing by considering a program size 1K and three basic firmware namely Python, C, and C++. The evaluation of the embedded Linux OS is calculating the time required for executing a task in terms of user time and system time. Table 4.4 presents the user time and system time required to execute a task. Figure 4.4 represents the bar graph of user time on many compilers on Yocto with program size 1k. The bar graph concludes that the C compiler is showing better performance in execution time.

The evaluation of custom embedded firmware design is analyzing by considering a program size 10K and three basic firmware namely Python, C, and C++. The evaluation of the embedded Linux OS is calculating the time required for executing the task in terms of user time and system time. Table 4.5 presents the user time and system time require for executing a task. From the table, it concludes that YOCTO OS with C++ compiler is delivering the minimum user time (0.160 milli sec (ms)) when comparing with other programming compilers.

Table 4.4. Evaluating performance of 1K size program

	User Time in ms			System Time in ms		
Firmware	Yocto	PiLFS	Raspbian	Yocto	PiLFS	Raspbian
Python	0.140	0.160	0.190	0.030	0.040	0.050
C	0.170	0.160	0.180	0.040	0.030	0.045
C++	0.160	0.100	0.150	0.025	0.025	0.035

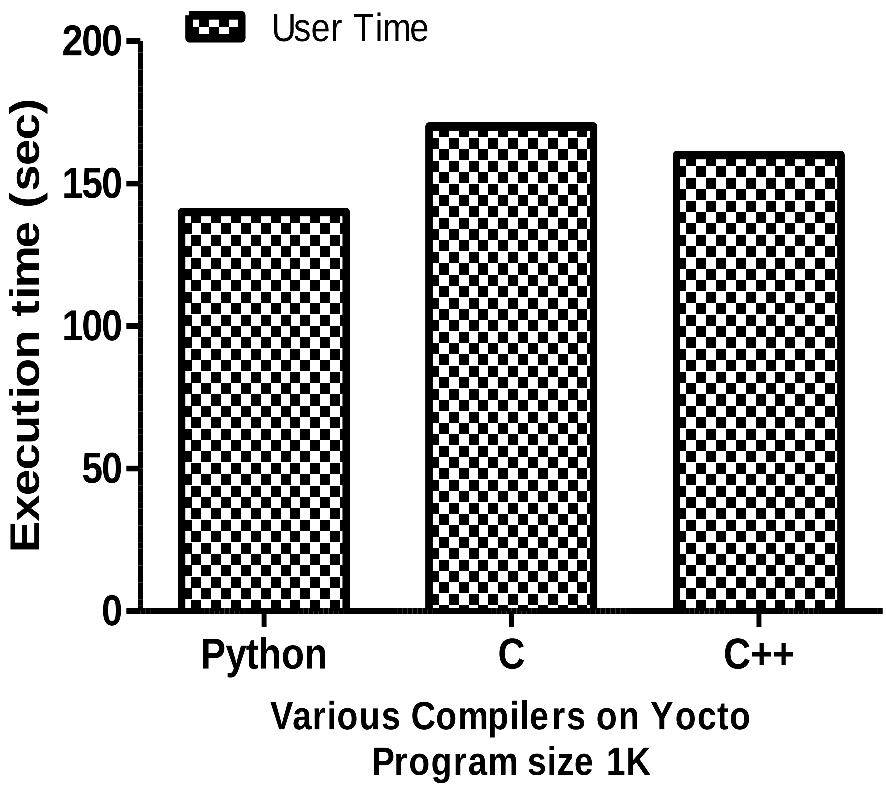


Figure. 4.4 1K program code size performance

Table 4.5. Evaluating performance of 10K size program

	Time for the user in ms			Time for the user in ms		
Firmware	Yocto	PiLFS	Raspbian	Yocto	PiLFS	Raspbian
Python	0.180	0.190	0.220	0.080	0.080	0.090
C	0.190	0.180	0.190	0.070	0.070	0.065
C++	0.160	0.170	0.180	0.065	0.055	0.045

The evaluation of custom embedded firmware design is analyzing by considering a program size 25 K and three basic firmware namely Python, C, and C++. The evaluation of the embedded Linux OS is calculating the time required for executing the task in terms of user time and system time. Table 4.6 presents the user time and system time require for executing a task. From the table, it concludes that Yocto OS with C++ compiler is delivering the minimum user time (0.150 milli sec (ms)) when comparing with other programming compilers and it is also presented in the figure. 4.5.

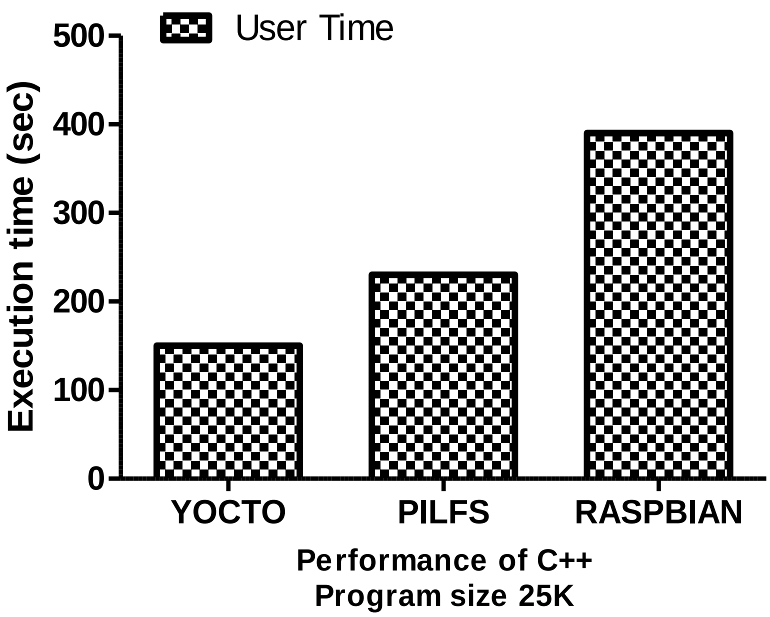


Figure. 4.5 Performance in 25KB size of code

Table. 4.6 Performance of 25 K size program

	Time for User in ms			Time for System in ms		
Firmware	Yocto	PiLFS	Raspbian	Yocto	PiLFS	Raspbian
Python	0.310	0.360	0.410	0.110	0.120	0.170
C	0.290	0.310	0.420	0.140	0.130	0.145
C++	0.150	0.230	0.390	0.120	0.115	0.130

The evaluation of custom embedded firmware design is analyzing by considering a program size 100 K and three basic firmware namely Python, C, and C++. The evaluation of the embedded Linux OS is calculating the time required for executing the task in terms of user time and system time. Table 4.7 presents the user time and system time require for executing a task. From the table, it concludes that Yocto OS with C++ compiler is delivering the minimum user time (0.650 milli sec) when comparing with other programming compilers.

Table.4.7 Evaluating performance of 100K size program

	User Time in ms			**System Time in ms**		
Firmware	**Yocto**	**PiLFS**	**Raspbian**	**Yocto**	**PiLFS**	**Raspbian**
Python	0.910	0.960	0.910	0.410	0.420	0.970
C	0.890	0.810	0.820	0.540	0.630	0.745
C++	0.650	0.730	0.790	0.380	0.515	0.530

The critical parameters are context switching time, cache heat time, CPU cycle used, and task clock cycle. As shown in Figures 4.6 and 4.7, the overall performance analysis of the custom firmware found to be superior. The observation led to the conclusion that using diverse scripting languages is showing the effect on performance in terms of CPU clock cycle consumption and context switching during task execution. The total performance seems to be effective as can be seen in figure.4.6. The conclusion obtained from this graph reveals that the customized firmware accomplishes best in terms of space and coding complexity.

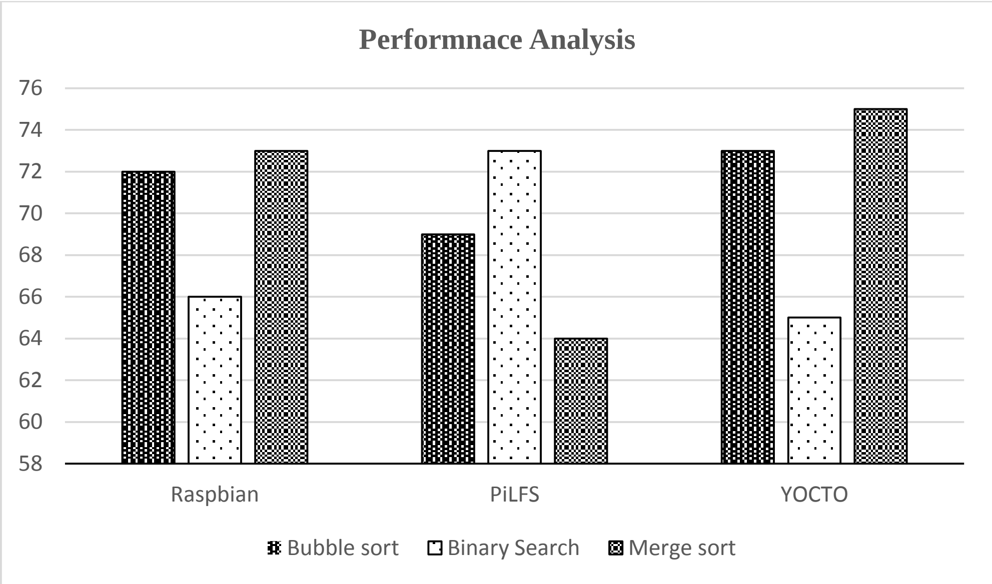


Figure.4.6 Evaluation of the performance of the distinct OS

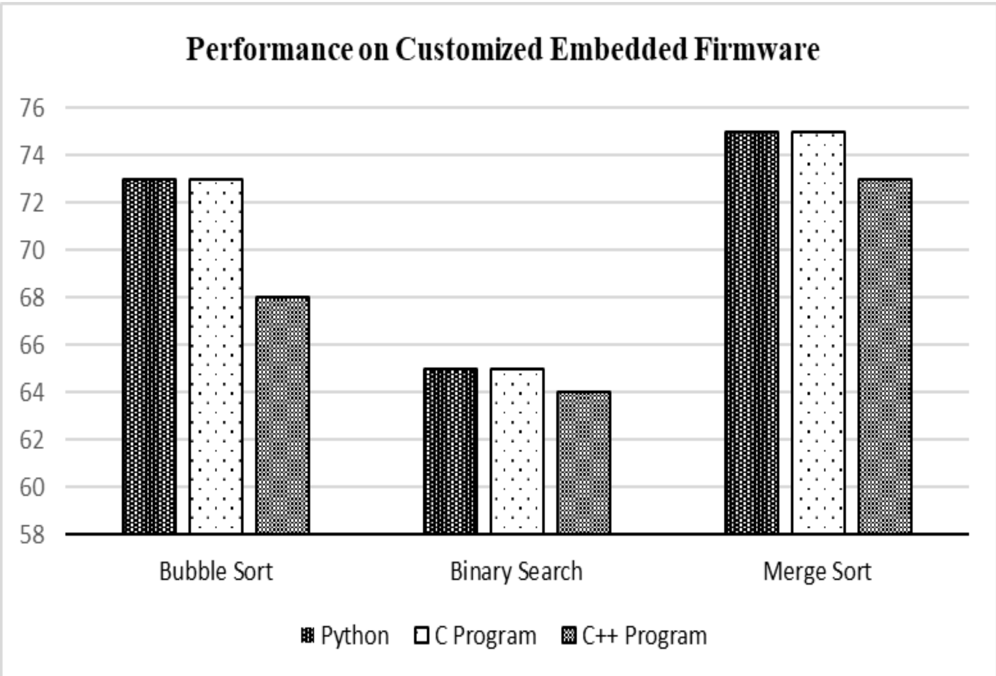


Figure.4.7 Evaluation of the performance of the distinct searching algorithm

Figure. 4.8 presents the performance of embedded firmware in terms of percentages. The customized firmware is represented in blue color in the graph. The graph concludes that the customized firmware is delivering better performance in the python firmware.

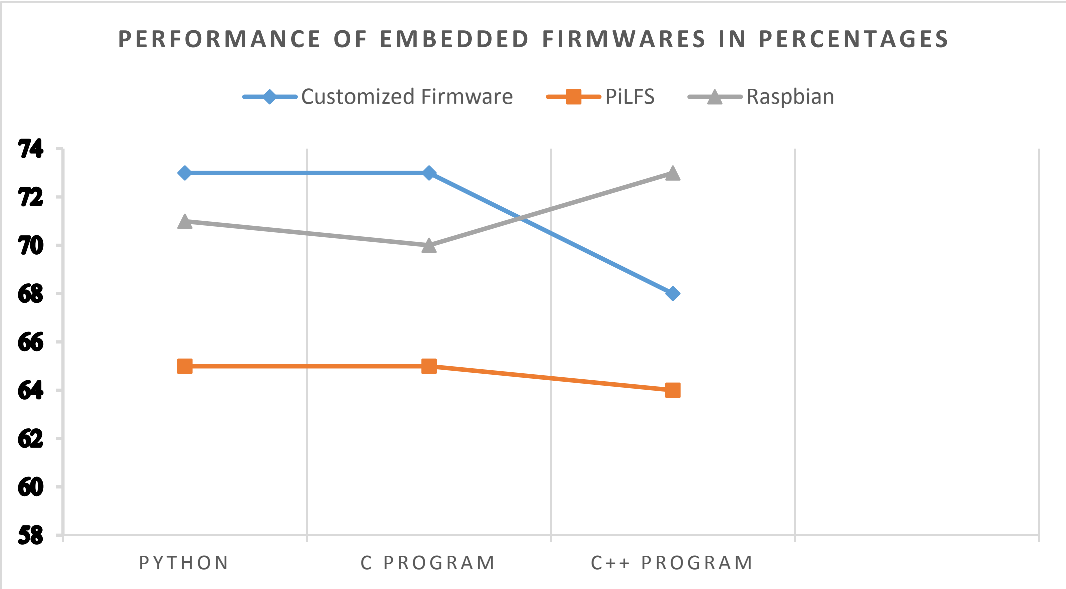


Figure.4.8 Performance evaluation of embedded firmware

4.3 Conclusion

In this chapter, we present the implementation of custom embedded firmware on the raspberry pi enabled gateway. The customization of embedded firmware enhances the performance of the gateway, as the customization enables to include of only those features that are required for the gateway. In the procedure of customization, YOCTO OS is implementing, as it is a platform for customizing the firmware that is IoT enabled. After uploading the firmware into the gateway, a performance evaluation is initiated for examining the performance of customized firmware with Raspbian and PILES OS. For examining the performance evaluation, here different sorting algorithms like the bubble sort, binary search, and merger sort have been implemented. Additionally, compilers like python, C, C++ are implemented for performance evaluation. The chapter concludes that customized firmware is delivering better performance with C++ compilers in terms of execution time.

CHAPTER 5

ESTABLISHMENT of LoRa NETWORK

In this chapter, the interlink establishment of the LoRa network in between the sensor nodes and gateway is discussing. During the establishment of interlink using LoRa, the calibration of the certain LoRa field parameters like spreading factor (SF), link budget, and receiver sensitivity are performing for extracting the relationship of these parameters on a custom-built LoRa sensor mote and gateway in MATLAB. The energy harvesting mechanism is also present in this chapter for analyzing the lifetime of the sensor mote. The MATLAB simulation concludes that hybrid range-based algorithms are more reliable, scalable to deploy in the agricultural field. An experiment is performing for evaluating the coverage of the nodes during data collection of the agricultural field.

5.1 Simulation model for LoRa network

In this section, the localization of the sensor mote, simulation of energy harvesting for evaluating for battery life of sensor mote, and MATLAB simulation for analyzing the LoRa parameters on the customized LoRa sensor mote and gateway are present.

5.1.1 Localized algorithm simulation

Figure 5.1 depicts a flow diagram of the sensor mote localization. At first, the application defines the type of node distribution, which can be uniform or random. Further, node density is calculated to determine the number of nodes located in a square meter of area. The algorithm computes these input data and results in sensor mote distribution patterns. After establishing the communication connection between the sensor motes, it is recommended to use a hybrid range-based localization technique because it is more efficient. Localization is very crucial to determine the sensor mote target tracking, location. Here we first group the algorithms into free range based and hybrid range based. Further, we analyzed the suitable localization technique. Range free-based localization is preferred because of low power consumption. Whereas hybrid range-based localization is preferred depending on the applications. In context to agriculture, as the land is not uniform in nature hybrid range-based localization is widely preferred. IoT based most of the application required sensor mote localization as they are easy and convenient to monitor. Simulation studies are carried out to compute the localization of algorithms. Effect of the node density, data rate, and signal strength analyzed to come up with the finest algorithm for our application. Further, we have showcased a comparative analysis with the range-based and finally keeping agriculture application, range free based localization comes more suitable. Here a cluster-based sensor mote localization on the agriculture field has been illustrated on MATLAB as shown in Figure 5.2. The cluster represents senor nodes, (Point of interest) in an agriculture field as shown in the above figure. The star mark represents POIs (Yellow color *), sensor motes are represented by a blue-colored star (Blue color *). Figure 5.3 shows the centralized node deployed in an agriculture field using a hybrid protocol.

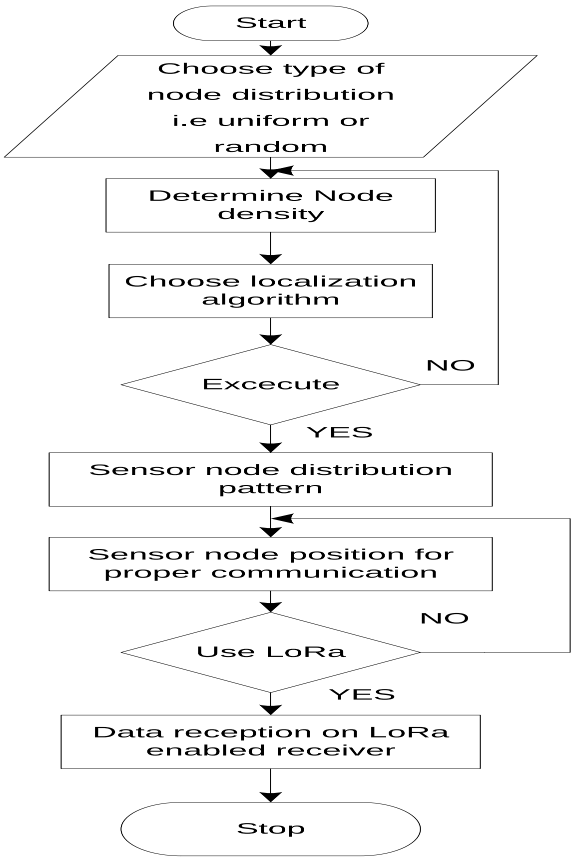


Figure. 5.1 Flow chart for execution of localization of algorithm

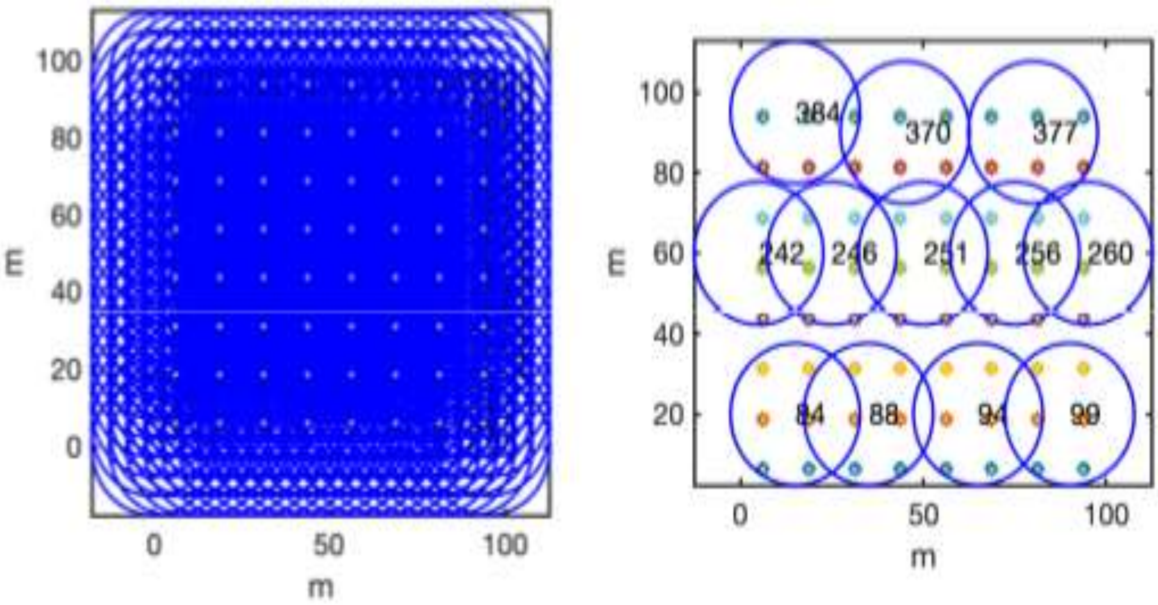


Figure 5.2. Cluster-based sensor mote localization on agriculture field

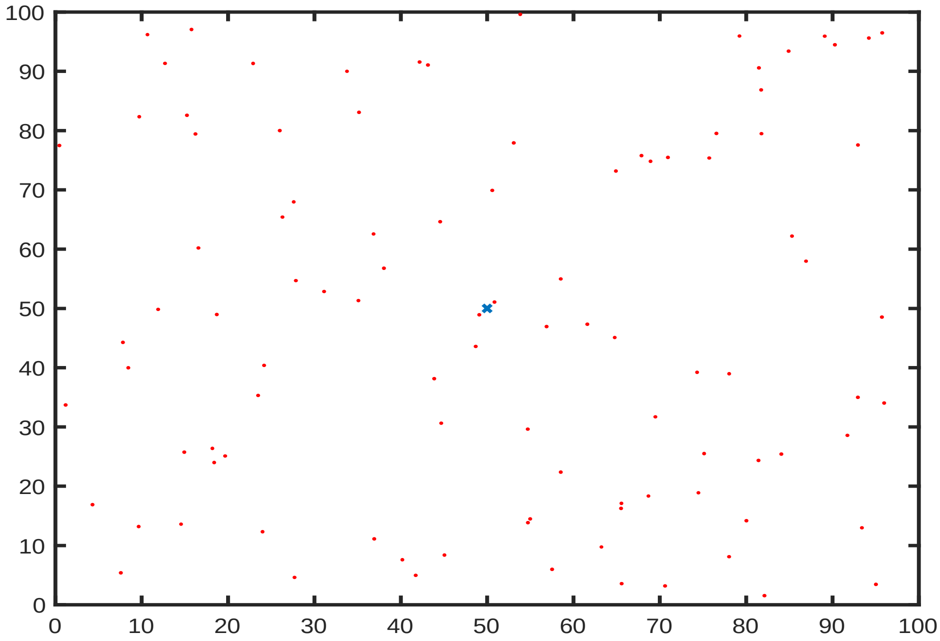


Figure. 5.3. Positioning of centralized node an agriculture field

5.1.2 Simulation of energy harvesting

Generally, in agriculture, the majority of the time the sensor motes are deployed in the outdoor environment. Moreover, the battery life of the sensor mote is challenging because the life of the battery drains due to distinct environmental conditions. So it is the optimal solution for implementing the energy harvesting for sensor motes from renewable energy sources. Energy harvesting is the better mechanism that is employed for powering the sensor motes to perform activities including sensing, preprocessing, and transferring data. The evaluation of the battery life of sensor mote using solar panels and wind turbines is performed in cisco packet tracer. Cisco packet tracer is a visualized-based simulation tool that encourages the user to implement distinct network-based simulations in it. The simulation model for evaluating the energy of the sensor mote through solar panels and wind turbine is implemented in the cisco packet tracer environment and it is shown in figure.5.4.

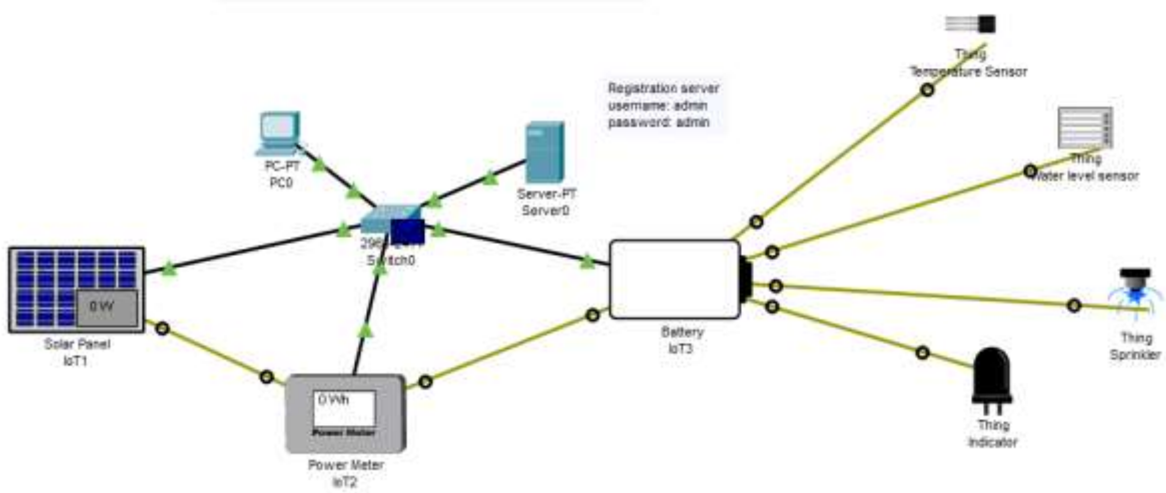


Figure. 5.4 Sensor mote communication establishment using LoRa link

A lifetime of the nodes is presented in the simulation as shown in the figure. 5.5. Data transmission from end nodes to the hub, hub to a central server, and finally at the mobile phone through cell towers. The simulation panel in the figure.5.5 presents the number of IoT devices connected to the network. Each renewable resource is connected using a power meter for calculating the power consumption. Timestamp details of the IoT devices are represented in the time column. Like IoT 2 device is connected to the network with a time of 0.129 seconds. Device IoT0, IoT1 is currently connected within 1.011 seconds. Total device connection time is mentioned as 77.660 seconds with a specific time gap or delay. Further power is transferred to the battery for storage purposes. A sample scenario of power 11 kWh in the case of turbine and 78 Watt along with 82Wh is considered.

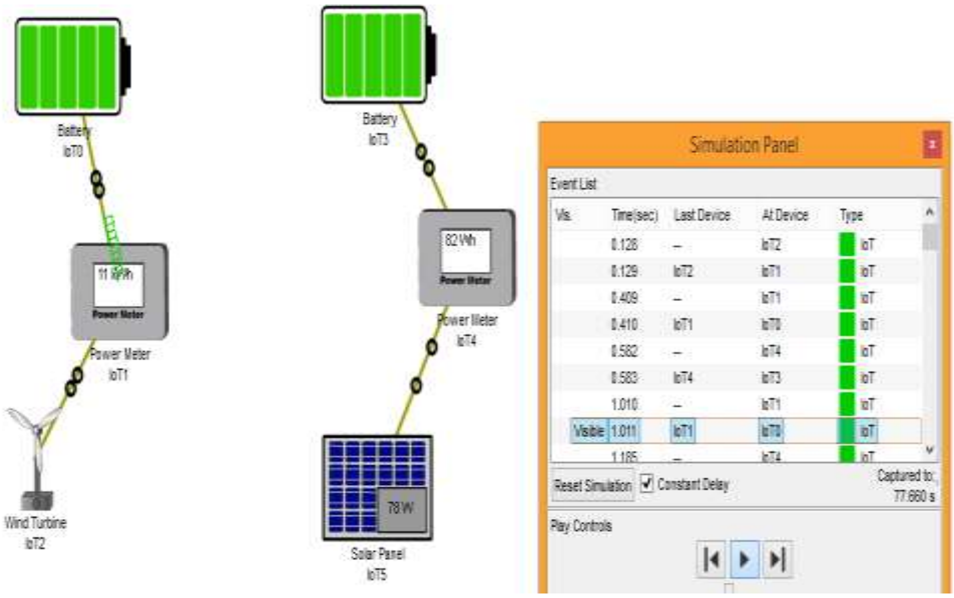


Figure. 5.5 Sensor mote Energy conservation using renewable resources

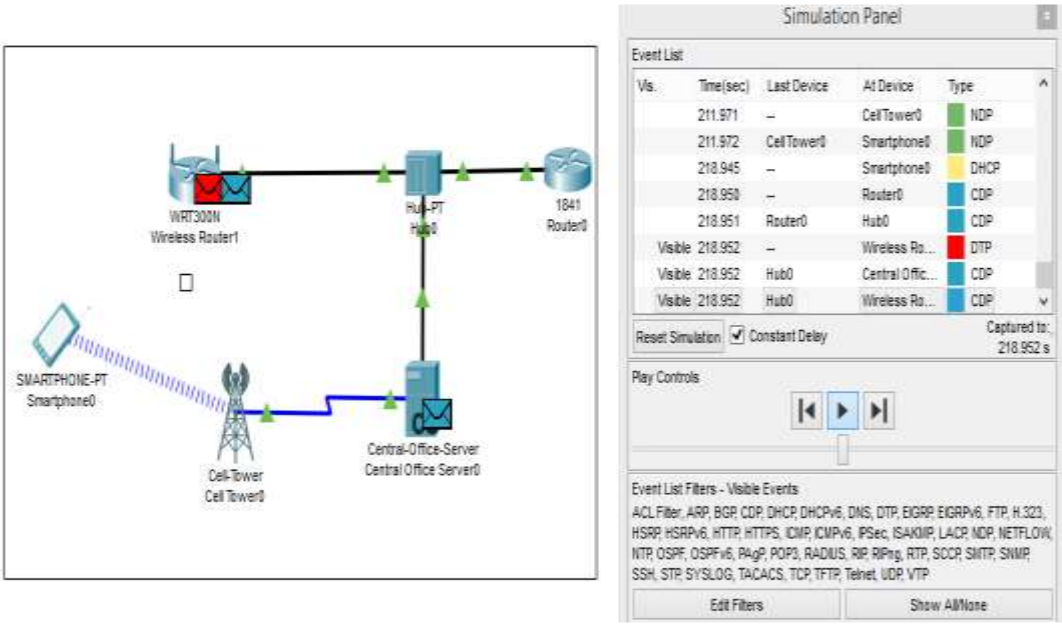


Figure.5.6 LoRa Simulation platform with simulation parameters

A LoRa based communication establishment from the sensor mote to the mobile phone is presented in the figure.5.6 The simulation model is shown in the figure.5.6, signifies the communication link established among sensor end nodes and establishes a connection with the gateway to transmit the data into the central server. In the simulation panel, the data transmission time in seconds is displayed from router to hub and hub to smartphones. The simulation signifies the on-air data transmission. Three events are mentioned with a time of 218.952 seconds, here you can see all three devices i.e wireless router, central office, and another wireless router are connected to the network at the same timestamp. It signifies, in LoRa communication the device synchronization time gap is very minute. Which is an additive advance of it. As soon as the authentication key matches the devices get synchronized and start communicating among them.

5.1.3 MATLAB Simulation for LoRa

The MATLAB simulation platform is considered in this study for characterizing the behavior of the LoRaWAN network. A simulation model is developed in MATLAB for evaluating the effects of various parameters such as SNR, Bitrate, and SF. A sample LoRa testbed is developed on the MATLAB simulation platform. The simulation was implemented by considering the following features including a network with 10 to 100 nodes, 1 gateway, and 1 network server. The nodes were distributed both randomly and uniformly with a minimum period of 100s. SF, transmission power, and gateway transmission power were defined as per the protocol. SNR value is determined from the simulation result. We have classified the simulation into cases as follows:

Table.5.1 Adaptive data rate of LoRa

SF	Chirps	SNR	ToA	Data rate
7	128	-8.5	122 ms	6345 bps
8	256	-11	189 ms	4425 bps
9	512	-15.48	235 ms	2118bps
10	1024	-18.5	381 ms	1233bps
11	2048	-15.48	235 ms	2118bps
12	4096	-18.5	381 ms	1233bps

Case. I:

Lora trades the transmission and reception data rate for sensitivity within given channel bandwidth. As shown in Table.5.1, LoRa implements an adaptive data rate by the utilization of orthogonal SFs. This allows the user to minimize the power consumption and optimize the network performance for a given bandwidth. At the receiver end, keeping mode of operation downlink, gate power at 27dB, node sensitivity maintained at -124 dBm, operating frequency as 868 MHz, antenna gain at 10 dB, and node antenna gain & node noise at 30 dB. After performing the simulation and the obtained results are presented in table.5.2. The result concludes that a change in antenna height from 1 to 7 meters is showing significant changes in the coverage area.

Keeping the following parameters like frequency of 868MHz, Node sensitivity at -124 dBm, Gateway node power 10 dB, and the Antenna gain of 27 dB, a relationship between the height of gateway and node with range are plotted in figure 5.7. Experimental data shown in Table 5.2 give a brief idea of a correlation between the height of Gateway, the height of end nodes, and the range.

Table. 5.2 Range and link budget at node sensitivity -124 dBm

Mode	Gateway Height in meter	End Node Height in meter	Link Budget dBm	Range in meter
Down Link	1	1	159	932
Down Link	2	1	159	1318
Down Link	3	1	159	1614
Down Link	4	1	159	1683
Down Link	5	1	159	2083
Down Link	6	1	159	2282
Down Link	7	1	159	2465

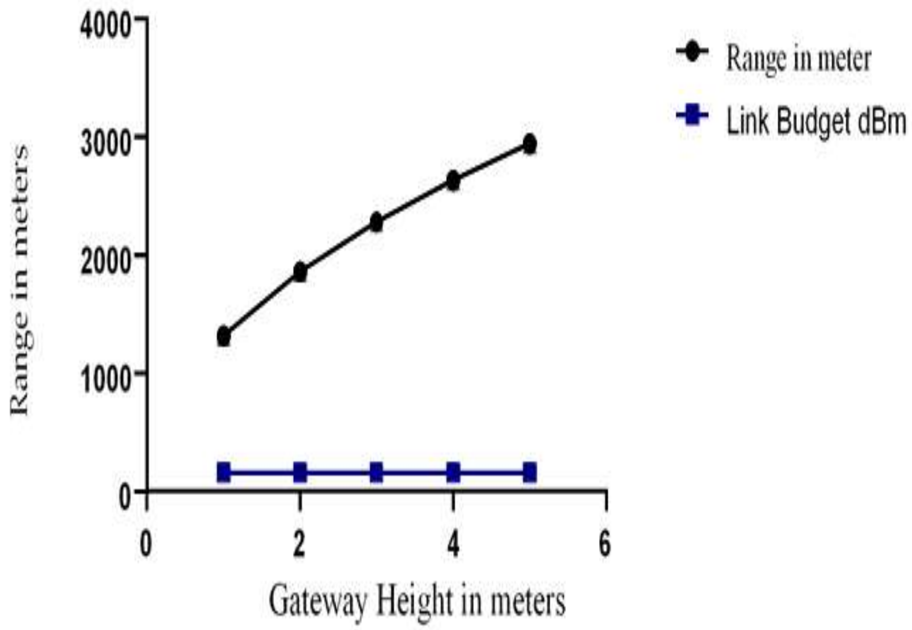


Figure.5.7 Gateway Height versus range in meter

During data reception at the receiver, the data have been interpreted; the model in the table signifies the downlink. The graph gives a conclusion that a constant link budget of 159 dBm range is directly proportional to the height of the end node and gateway. So, it is considered to be for more range coverage the end nodes are mounted on cylindrical bars as shown in figure.5.7.

Case II

The establishment of the LoRa communication link significantly depends on Gateway height as well as End node heights. Experimental data present in the table.5.3. Here the node sensitivity is considered as -124 dBm, the operating frequency is 868 MHz, and observed that the signal coverage area changes along with the variation in heights of Gateway and End node. End node height is 2 meters from the ground, if we are adjusting the gateway height from 1 meter to 5 meters the coverage area and signal strength changes drastically from 1319 meter to 2946 meter. This signifies that keeping all the parameters at a certain value will enhance the link budget strength increases as there is minimum interference.

Table 5.3 Range and link budget at node sensitivity -124 dBm

Mode	Gateway Height in meter	End Node Height in meter	Link Budget dBm	Range in meter
Down Link	1	2	159	1319
Down Link	2	2	159	1863
Down Link	3	2	159	2282
Down Link	4	2	159	2635
Down Link	5	2	159	2946

The establishment of the LoRa communication link significantly depends on Gateway height as well as End node heights. Experimental data is showcased in the above table, Keeping Node sensitivity at -124 dBm, operating frequency at 868 MHz, signal coverage area changes concerning the variation of heights of Gateway and End node. At the End node height of 2 meters, if we change the Gateway height from 1 meter to 5 meters the coverage area and signal strength changes drastically from 1319 meter to 2946 meter. This signifies that keeping all the parameters at a certain value, link budget strength increases as there is less interference.

Case III:

In this case, the following parameters are considered as node sensitivity changes to -137 dBm, operating frequency at 433MHz. Now changing the value of Gateway height significantly impact on range. Keeping a link budget of 151 dBm, it is observed that SNR decreases as there is a low possibility of interference**.** The mode of operation during the experiment is downlink i.e data received at the receiver side. During experimenting, it is observed that at a fixed node sensitivity -137 dBm, antenna gain of 10 dB, the custom build sensor mote is varying the value of link budget in dB along with a change in the wide-area range coverage at 433 MHz frequency is shown in table.5.4 and figure.5.8. In Figure.5.8, a relationship between antenna gain, link budget, and range has been plotted. The blue line graph shows increasing antenna gain concerning the range, whereas the red line shows increasing the range in response to the link budget in LoRa. Keeping all the parameters remains the same, antenna height is directly proportional to the coverage range. It signifies that deploying the LoRa receiver at a certain height could enable a strong communication link.

Table.5.4 Range and link budget at node sensitivity of -137 dBm

Mode	Gateway Height in meter	End Node Height in meter	Link Budget dBm	Range in meter
Down Link	1	1	151	1681
Down Link	2	1	151	2377
Down Link	3	1	151	2911
Down Link	4	1	151	3362
Down Link	5	1	151	3758

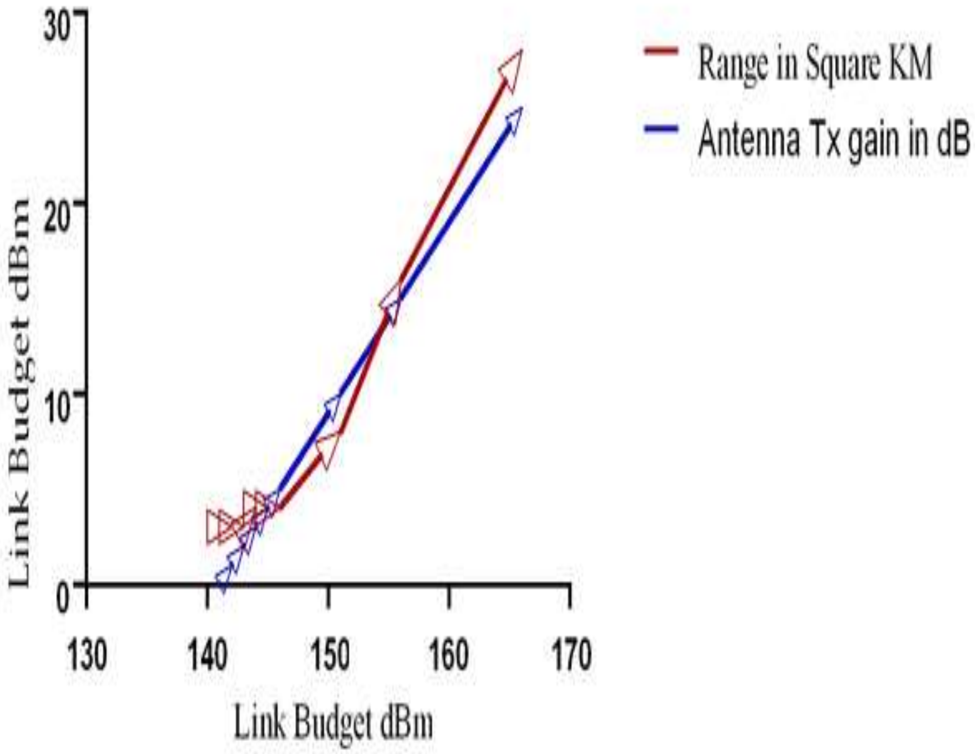


Figure. 5.8. Link budget variation with Range

Case IV:

Transmission signal strength is optimized by setting the antenna gain from 1 dB to 25 dB. Here the transmission range and link budget of the LoRa transmitter module are evaluated along with a change in antenna gain. The mode of operation is uplink and it is presented in table.5.5. Antenna gain is changed through writing the code in MATLAB for interpreting the signal strength at 433MHz frequency. Keeping Gateway noise at 10 dB, node sensitivity at -137 dBm, it has been observed that the link budget getting to increase from 141 dBm to 166 dBm. Hence, it is concluded that by changing antenna gain we can get a better coverage area. So, it is preferred to use an antenna with high gain.

Table. 5.5 Link Budget in dBm from 141 dBm to 164 Bm for Transmitter LoRa module

Mode	**Antenna Tx gain (dB)**	**Link Budget (dBm)**	**Range (meter)**	**Range (Square KM)**
Up Link	0	141	945	3
Up Link	1	142	1001	3
Up Link	2	143	1061	3
Up Link	3	144	1123	4
Up Link	4	145	1190	4
Up Link	5	146	1260	4
Up Link	10	151	1681	8
Up Link	15	156	2241	16
Up Link	25	166	3986	28

Experimental parameters are presented in the table. 5.6, signifies the importance of node sensitivity. We have used a helical antenna for the design of the custom sensor mote and gateway. Keeping uplink frequency at 433 MHz, by changing node sensitivity from -124 dBm to -130 dBm sensor coverage distance increased from 945 meters to 3986 meters. The data from a table.5.6 concludes that change in node sensitivity is directly proportional to the range.

Table.5.6 Node sensitivity ranging in between -124 dBm to 132 dBm

Mode	Frequency	Node Sensitivity (dBm)	Range (meter)	Range (Square KM)
Up Link	433	-124	945	3
Up Link	433	-125	1001	3
Up Link	433	-126	1061	3
Up Link	433	-127	1123	4
Up Link	433	-128	1190	4
Up Link	433	-129	1260	4
Up Link	433	-130	1681	8
Up Link	433	-131	2241	16
Up Link	433	-132	3986	28

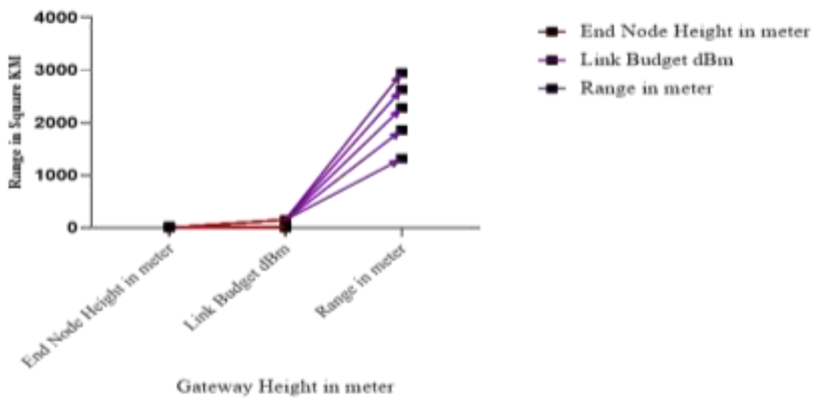
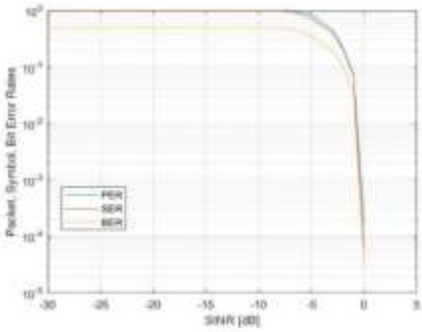
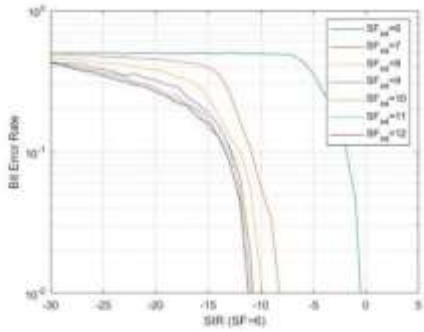


Figure.5.9. Link budget variation with Range

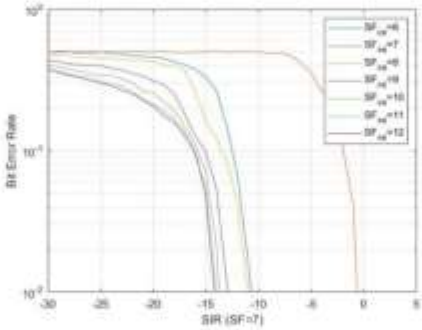
With the change in the height of the gateway and sensor mote, the range is also varied. The variation in the height of both gateway and end node changes the range significantly during downlink mode at the receiver. In figure.5.9, the red triangle denotes the data rate, black downward triangles signify the bit rate. Figure. 5.10 (a), (b) shown the relation among bit error rate, packet error rate, and symbol error rate concerning the spreading factor. As the spreading rate increases, there is an increase in the bit error rate. Changing the spreading factor from 7 to 12, the bit error is minimum at SF=6. So there is a loss of data packets. In concern to that, it is preferred



a)



b)



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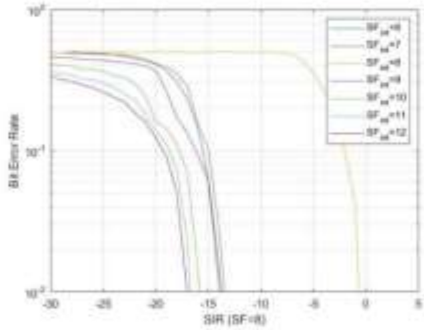

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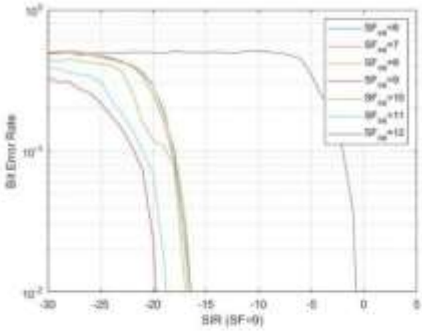
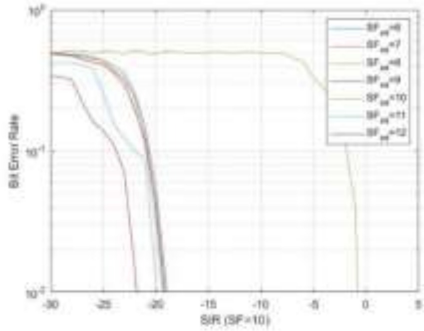
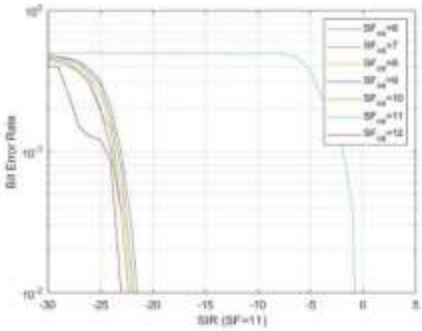


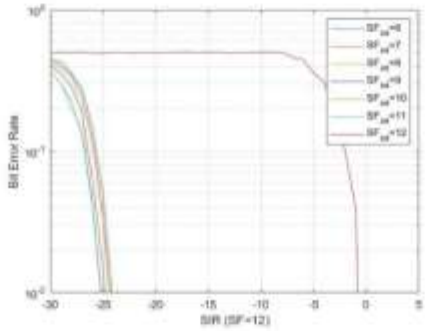
e)



f)



g)



i)

Figure. 5.10. (a) PER, SER, and BER about the Signal to Noise ratio and figure. 5.10 (b-i) presents BER to SF = 6-12 to send the data with Spreading factor so that bitt error and packet error rate can be minimized. Keeping this in conclusion, it is preferred to keep the SF value minimum to minimize the bit rate error. To keep minimum collision among data packets less value SF is preferred. After computing all communication essential parameters of LoRa, it is found that increasing SNR affects the PER, SER, and BER. At -30 dB of SNR, the BER is almost 1, which is not considered, and also observed a decrease in the value of SINR to 0 dB, the error rate decreases. A comparative graphical diagram was obtained with its plots as a signal to noise ratio (SNR) and bit error. During the experiment, the value of the spreading factor was gradually changed from six to twelve. The response graph is drawn to visualize and analyze the bit error during the transmission of data packets from end nodes to the gateway.

5.2 Experimental setup for data collection

This section covers the deployment of sensor motes, gateway, and hand-held devices in a real-time environment. The evaluation of LoRa coverage is performing by deploying the sensor motes and gateway in a real-time environment and it is shown in figure.5.11. The serial communication initiation in between the sensor mote ‘1’and sensor mote ‘2’ is present in figure.5.12. The RSSI value and SNR value of the two sensor motes during the serial communication are shown in figure.5.12. To validate the distance coverage of the nodes, we have performed validation with two distinct communication namely single-hop and multi-hop communication. The experimental data of single-hop communication are recorded, and it is available in the table.5.7. The experimental data presents the variation in the range of distance in the meter of single-hop communication at the sensitivity of −137 dBm. The result present in the table. 5.7 are obtained by maintaining antenna gain of 10 dB, gate power in 27 dB, and node noise at 30 dB. The established single-hop communication link represents that the distance coverage increases with node sensitivity. In multi-hop communication distance, the two sensor motes are positioned in the agriculture field for distance validation. The experimental data of multi-hop communication are recorded in table.5.7. The experimental data concludes that there is a variation in range for multi-hop communication concerning the sensitivity of nodes ranging from −124 to 132 dBm.

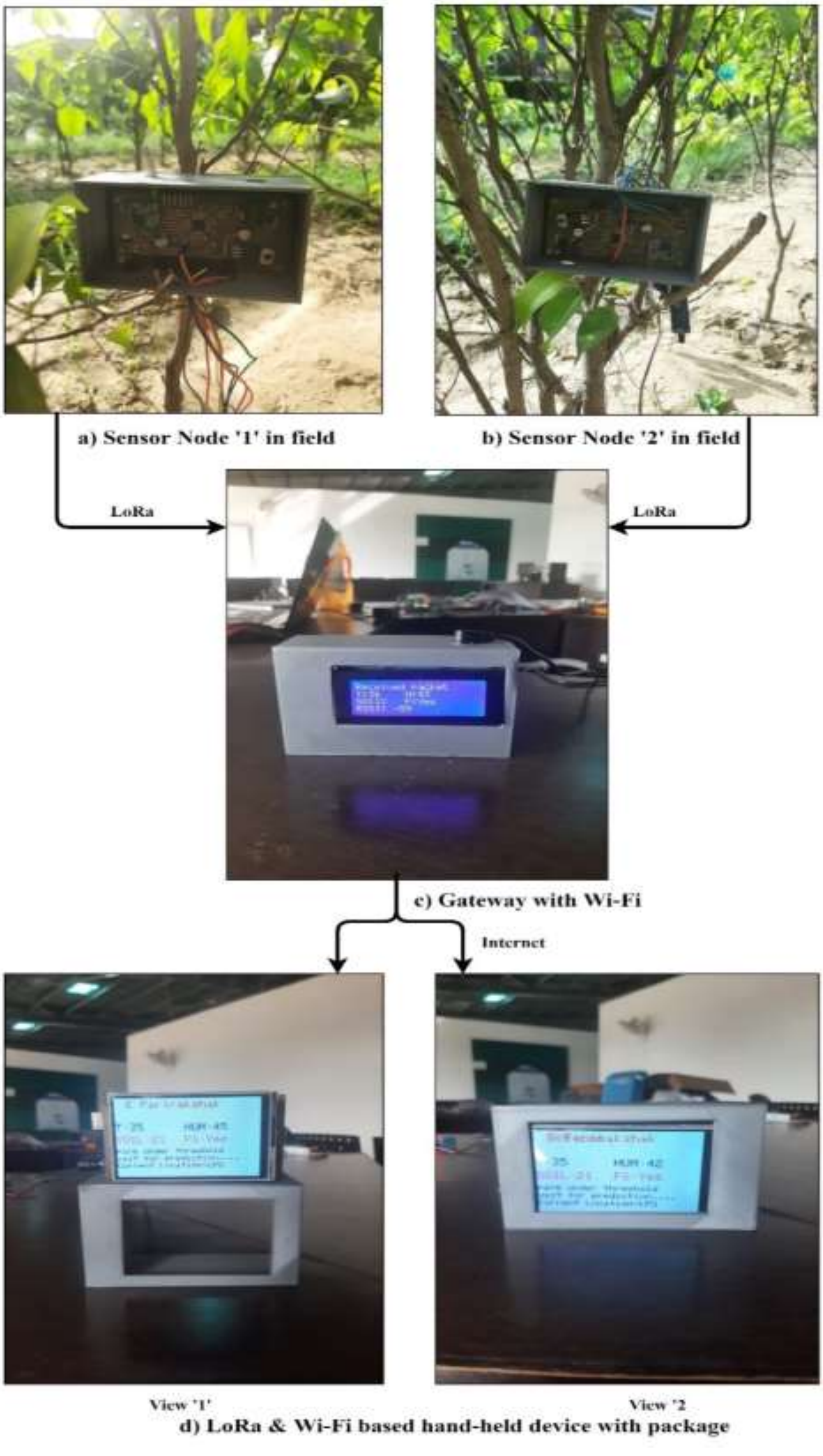


Figure. 5.11 Experimental setup

As shown in the table. 5.7, the variation in node sensitivity is directly proportional to the area coverage of the transmission. Then some software-based optimization using onboard algorithms was used to minimize the latency and also maintaining the bit rate.

```
Received from: 0xbb
Sent to: 0xff
Message ID: 42
Message length: 12
Message: hello World!
RSSI: -33
Snr: 9.75
```

Data received from transmitter A

```
Received from: 0xcc
Sent to: 0xff
Message ID: 44
Message length: 9
Message: he World!
RSSI: -31
Snr: 9.25
```

Data received from transmitter B

Figure.5.12 Serial communication of transmission and reception of sensor mote

Table.5.7. Experimental data of single-hop communication for validation of distance

Mode	**Frequency (MHz)**	**Node Sensitivity (dBm)**	**Link Budget (dBm)**	**Range (metre)**
Uplink	433	−124	151	1,687
Uplink	433	−125	151	2,437
Uplink	433	−126	151	2,985
Uplink	433	−127	151	3,432
Uplink	433	−128	151	3,842

Table.5.8 Experimental data of multiple-hop communication for validation of distance

Mode	**Frequency (MHz)**	**Node Sensitivity (dBm)**	**Link Budget (dBm)**	**Range (metre)**
Uplink	433	−124	151	945
Uplink	433	−125	151	1,001
Uplink	433	−126	151	1,061
Uplink	433	−127	151	1,123
Uplink	433	−128	151	1,190
Uplink	433	−129	151	1,260
Uplink	433	−130	151	1,681
Uplink	433	−131	151	2,241
Uplink	433	−132	151	3,986

Table.5.9 Building material causing losses during LoRa communication

Medium	**Loss (dB)**
Material made of Glass 0.25^{00}	0.8
Brick (3.5^{00})	3.5
Brick 7^{00}	5
Concrete 4^{00} 102 mm	12
Brick based concrete (7.5^{00})	17
Reinforced concrete 3.5^{00}	27

Figure.5.14 presents the optimization of performance in both single-hop and multi-hop communication with obstacles. During transmission, the data packet is affected by obstacles in its way. The bit rate of the transmitted signal gets obstruct by the various mediums, as mentioned in table 5.9. The maximum throughput is achieved with medium-like materials of glass. The losses increase exponentially as the medium becomes difficult enough to enable data transmission. The medium is stored, ranging

from glass to reinforcement concrete. The main cause of signal losses is due to the obstacles in the way of transmission, as shown in figure.5.13. The signal strength is greatly influenced by the hardness of the surface. Sensor motes and gateways could be placed on vertical pillars or bars to reduce signal losses. Sensor motes positioning that is appropriate eliminates signal losses. Signal losses vary from 3 to 27 dB based on obstacle type.

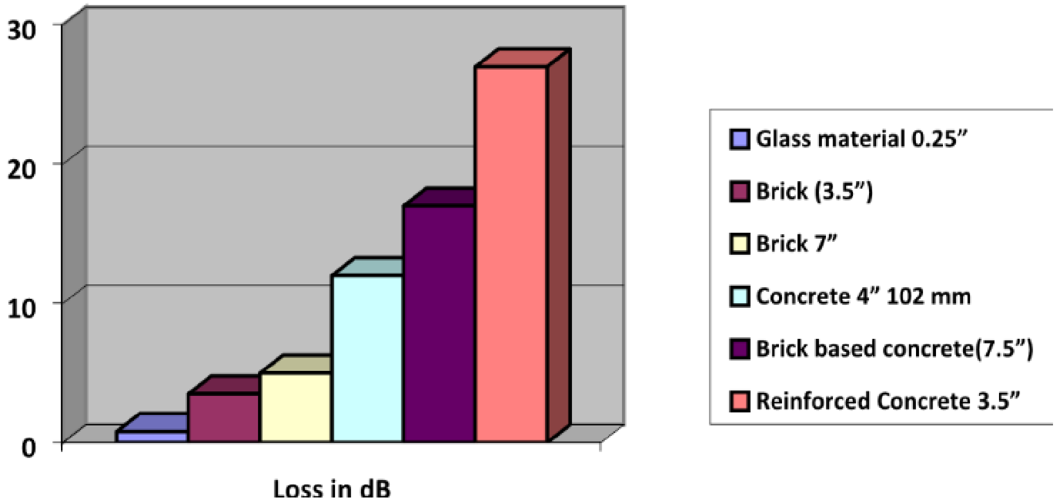


Figure.5.13 Losses during data transmission through an obstacle

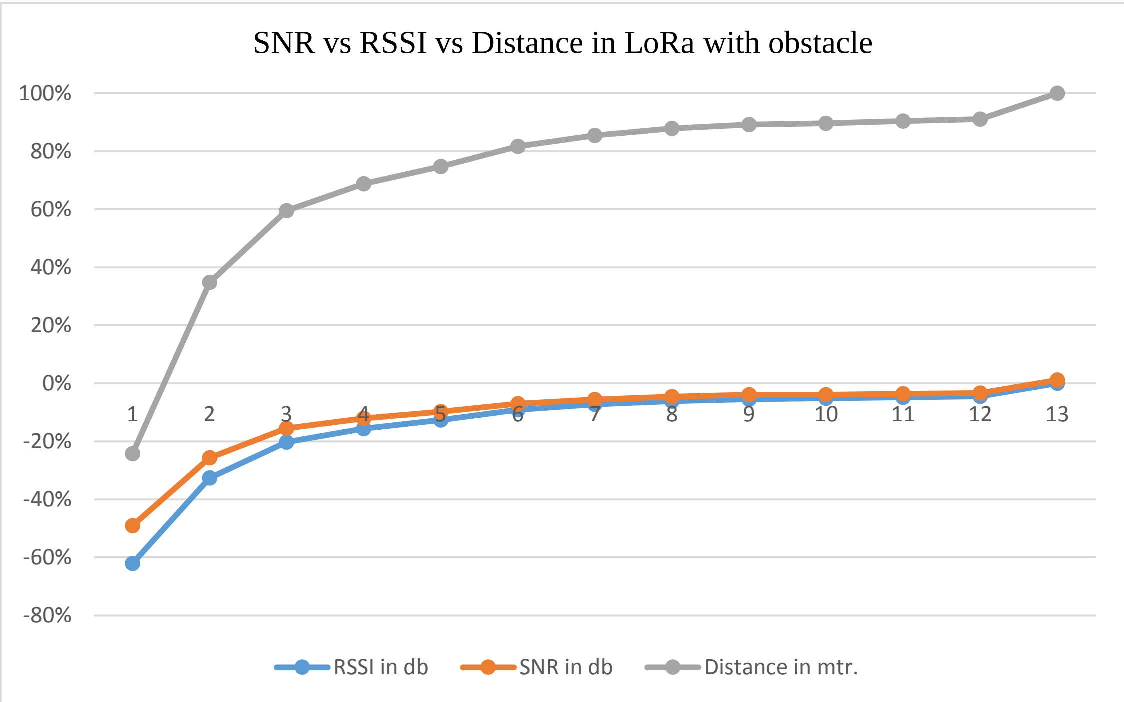


Figure.5.14 SNR vs RSSI vs Distance for LoRa with obstacle

It has been concluded that the distance is inversely proportional to SNR where the increase in the distance leads to a decrease in SNR strength In figure.5.14, the red line is SNR the blue line is RSSI, and the grey line is distance, and the distance coverage of sensor mote increases with SNR. Figure.5.15 presents visualize that the increase in the distance leads to decreasing in RSSI value and due to the large area the signal strength becomes weak.

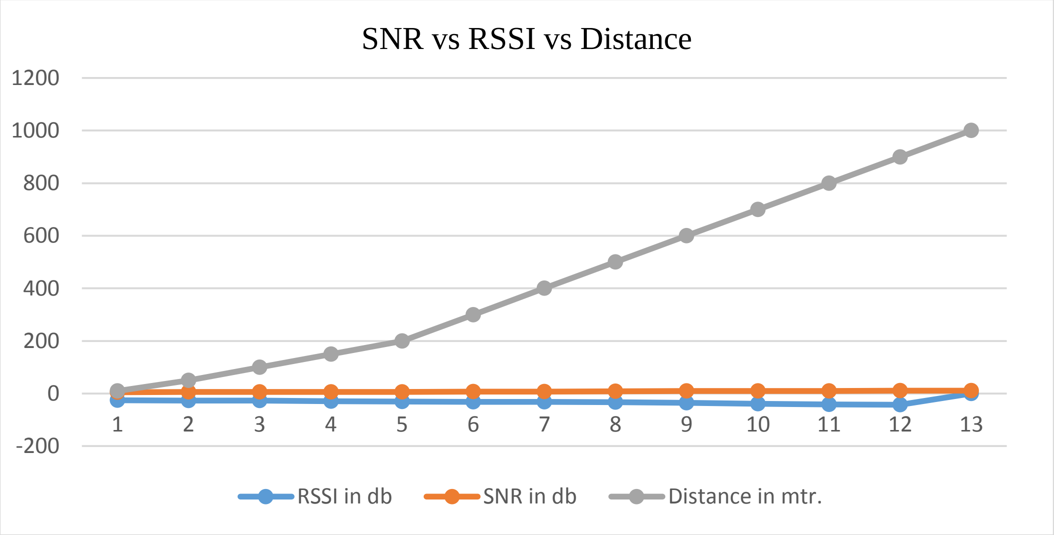


Figure. 5.15 SNR vs RSSI vs Distance for LoRa without obstacle

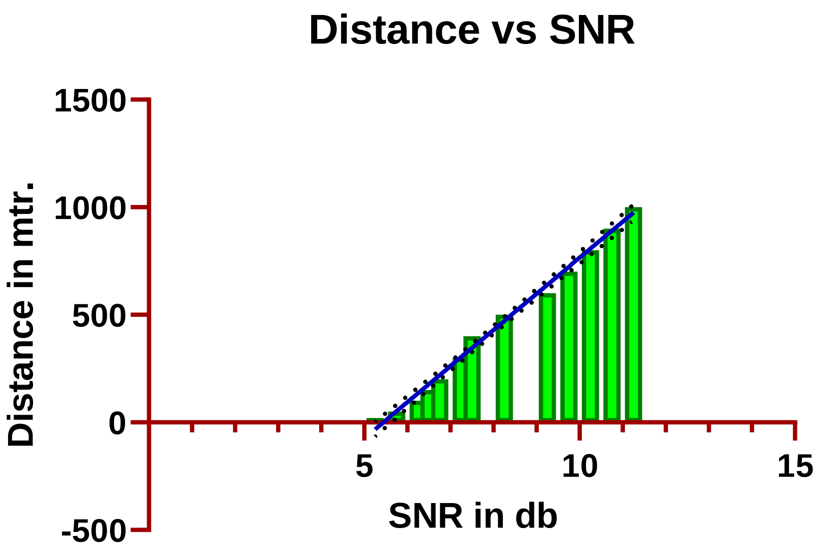


Figure. 5.16 Distance vs SNR

The SNR and distance also measuring by changing the payload size to 20 bytes. Further, the distance validation of the experimental setup is illustrating in the figure. 5.16, where it is concluding that the SNR value is varying along with a change in payload size. Figure. 5.17 illustrates the gateway that is capable of receiving the sensor data via LoRa communication and communicating to the cloud server. This gateway is positioned at the location where the internet connectivity is stable. This gateway assists the farmers to control the actuators of the agricultural field through LoRa communication. As you can see, the received data from sensor mote including temperature, humidity, and RSSI are visualizing on LCD. The gateway receiving the data from sensor mote installed at a range of 1.5 km to 2 km. Effective data reception is achieved during experimental for a range of 1.5km.

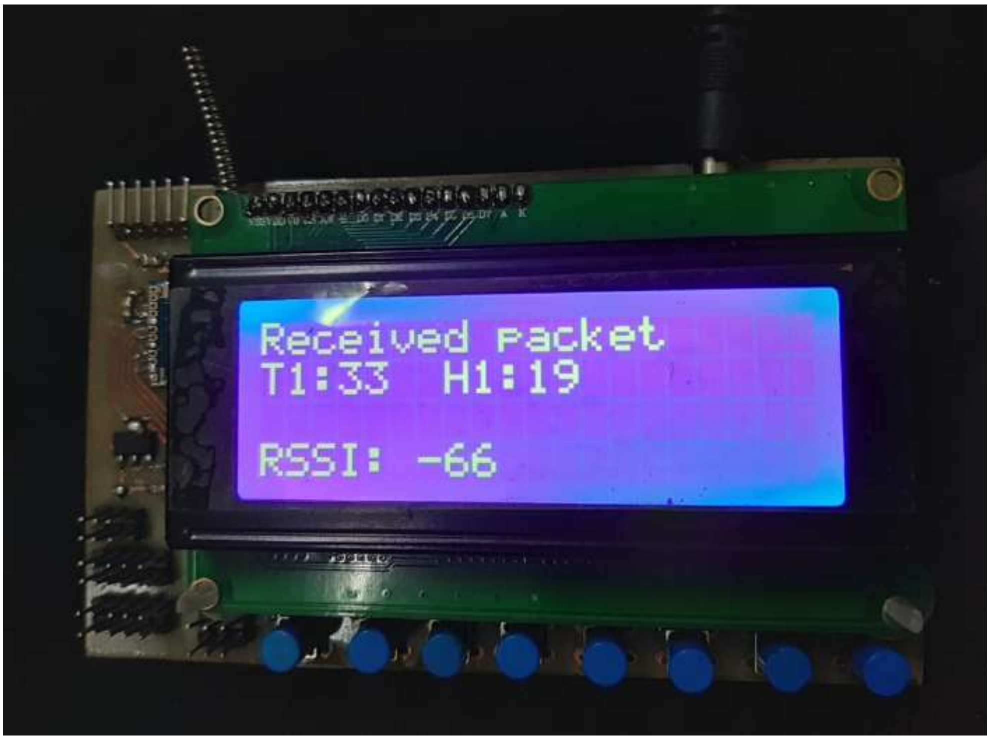


Figure. 5.17 Gateway receiving the data

5.2.1 Data acquisition from field sensor motes

In this section, the results of sensor motes are deployed in the agricultural field for obtaining the sensory data of parameters like temperature, soil pH, humidity, rain level, wind, soil type, rain, and NPK. The sensory data of those parameters are recorded and plotted in the graph which is shown in the figure. 5.18. The orange line represents the wheat field and the blue line represents the rice crop in the graph.

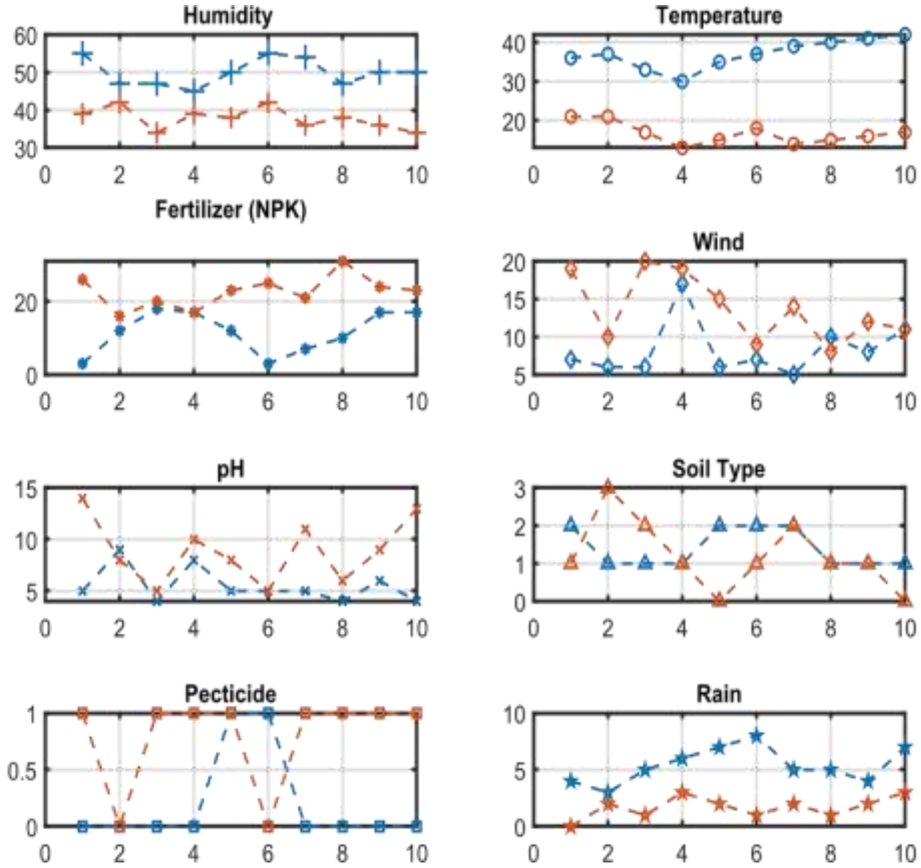


Figure.5.18 LoRa sensor mote (for rice & wheat)

The battery lifetime of the customized sensor mote is addressing. This analysis is performing for justifying the statement that, the customized sensor mote is low power. Table.5.19 presents an analysis of distinct battery types for the customized sensor mote. The distinct battery types are Lead-acid, MnO2Li, Poly carbon, MnO2, NiCd, NiMH, and Li-ion. From the table.5.10 it is concluded that integrating a Li-on battery boosts the battery life of the sensor motes. Lora power consumption is minimizing by standardizing the critical parameters including, better circuitry, optimized firmware, and configuration of transmission and receiver modules. In certain cases, the payload size directly impacts power consumption, where the power consumption increases due to an increase in payload size. In this study, the static parameters are collecting from the agricultural field for a period of 1 to 2 hours, for the same the sensor mote configures in sleep mode for conserving battery power.

Table.5.10 Battery capacity of IoT testbed

Type	**Rated Voltage (V)**	**Capacity, (mAh)**	**Temp. Range (C°)**	**Cycling Capacity**	**Specific Energy, (Wh/kg)**
Lead acid	2	1.3	−20 to 60	500–1,000	30–50
MnO_2Li	3	0.0.3–5	−20 to 60	1,000–2,000	280
Poly carbon	3	0.025–5	−20 to 60	-	100–250
MnO_2	1.65	−.617	−20 to 60	-	300–610
NiCd	1.2	1.1	−40 to 70	10,000–20,000	50–60
NiMH	1.2	2.5	−20 to 40	1,000–20,000	60–70
Li-ion	3.6	0.74	−30 to 45	1,000–100,000	75–200

5.3 Conclusion

This chapter provides details regarding the interlink establishment of the LoRa network between sensor mote and gateway. During the establishment of interlink, a simulation is performing for analyzing the network behavior LoRa network in terms of range, battery lifetime by varying the link budget. An energy harvesting simulation for the sensor motes implementing in cisco packet tracer for checking the battery life with solar power and wind turbine. During experimenting, it is observing that at a fixed node sensitivity of -137 dBm, the antenna gain of 10 dB the custom build LoRa module is a having variation in the wide-area range coverage concerning change in link budget. In battery capacity analysis it is identified that Li-ion batteries are optimal for the sensor mote. As a conclusion, it is also found that the higher the spreading factor higher the data speed and less area coverage, and vice versa. So, it is important to set the value of SF during modulation.

CHAPTER 6

TESTING AND VALIDATION

The chapter presents the testing and validation of customized hand-held devices for agriculture. The sensor data obtaining from the sensor mote is receiving in the hand-held device. The hand-held device communicates the sensor data of the agricultural field to the cloud server. The sensor data available in the cloud server are useful for prediction purpose, that indeed assists the farmers for enhancing the yield of the crop. To apply prediction on sensor data, the machine learning techniques are highly providing better performance. The significance of machine learning algorithms specifically to agriculture is presenting in this chapter.

6.1 Machine learning for prediction of suitable crop

The sensor data obtaining from the sensor motes of the agricultural field encourages to implementation of machine learning (ML) for optimizing the yielding of the crop. The sensor data is communicating to the customized cloud server through the gateway that is based on SX 1278 LoRa and Wi-Fi. The powerful ML algorithms are used to analyze the data collected from sensor motes over some time. To apply ML algorithms for the sensor data, we have considered temperature and humidity as the parameters. Figure. 6.1 provides the heat map of the data collected from the sensor mote of LoRa. The sensor data regarding temperature and humidity are recorded and represented in the heat map. Figure. 6.2 presents the temperature and humidity data utilized for building a real-time data set. Identifying the right hyperplane in figure 6.3 using a regressive classifying technique. The hyperplane separate data into two cluster by eliminating data overfitting and underfitting which has been shown figure 6.4. If the data is nonlinear, SVM uses kernel trick where data gets divided into 3-dimensional view. Kernel tricking helps the algorithm to identify the right hyper-plane with minimizing error. Further, a confusion matric is calculated to calculate the mean square error concerning the training data and testing data.

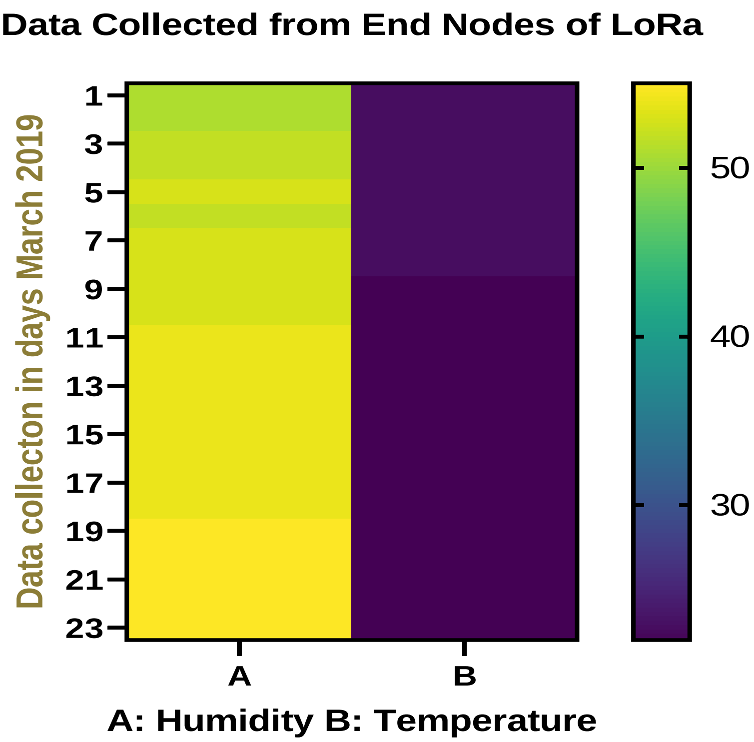


Figure 6.1 Heat map of temperature and humidity recorded from sensor mote

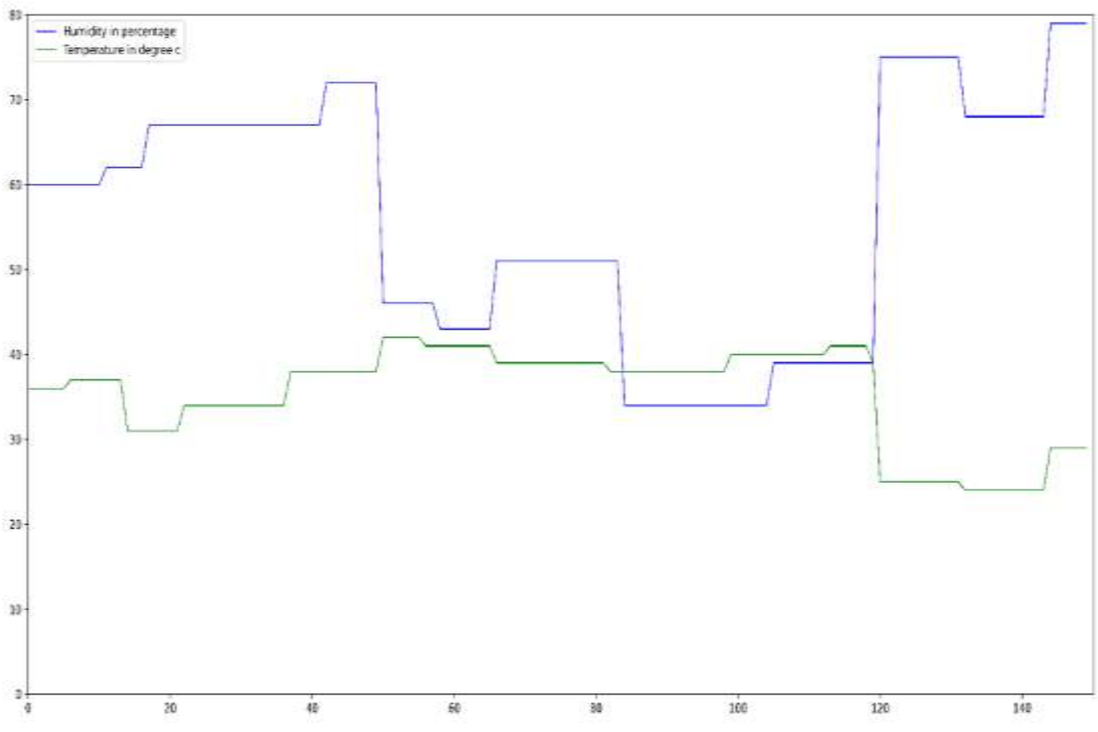


Figure 6.2 Parameter to be analyzed (temperature, humidity) from real-time dataset

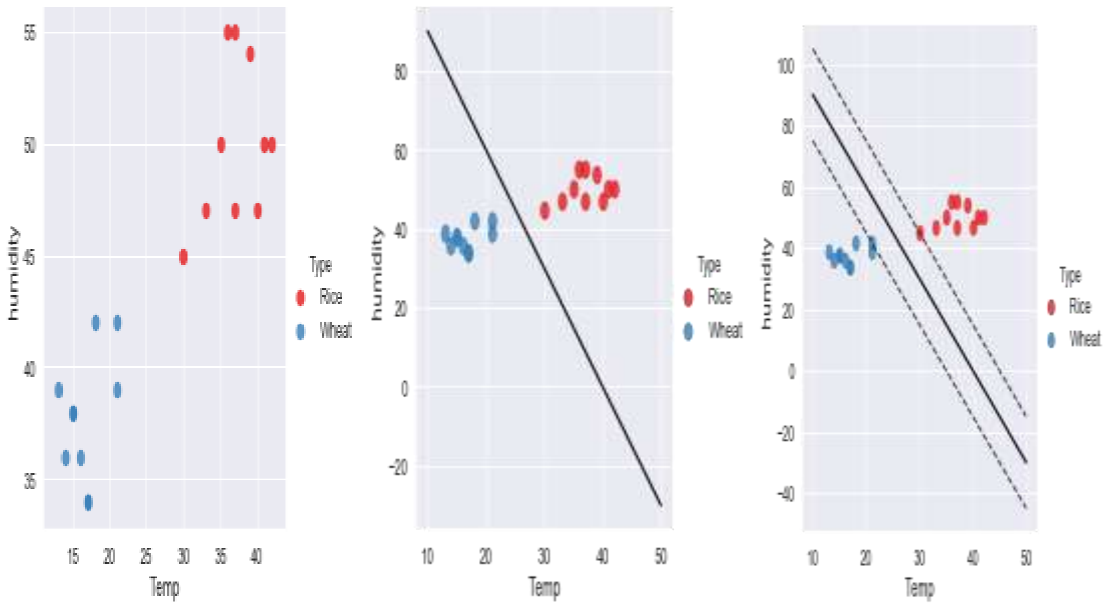


Figure 6.3 Machine learning algorithm on collected data from sensor mote for prediction of suitable crop species.

According to the figures and tables above, applications of machine learning models are very diverse, including applications related to predicting the yield (20 percent), disease detection (22 percent), and crop control (61 percent), This distribution pattern in applications illustrates the data-intensive applications within the crop and the comparatively higher use of photographs (hyperspectral, spectral, NIR, etc.). A mature and complex scientific discipline as data science lays the groundwork for the establishment of applications related to a different type of crop management services because, it is very likely that, machine learning-based forecasts can be obtained without the requirement for data fusion from external sources. In comparison, when data acquisitions are concerned, often at the level of big data, the number of machine learning (ML) implementations is lower, owing to the hyped effort required for the analysis of the gathered data rather than the machine learning models. This fact helps to understand the nearly equal distribution of machine learning (ML) applications in managing soil parameters (10%), water distribution managing (10%), and livestock management (19%). The study also shows that the majority of the studies used artificial neural networks and support vector machine, machine learning models. More specifically, artificial neural networks were used most favorably in applications related to crop, water, and soil management, while support vector machine algorithms were used more for livestock management. The accuracy of the model is showcased in figure.6.7. Figure 6.5 presents training loss vs validation loss and figure 6.6 presents model loss during training and testing.

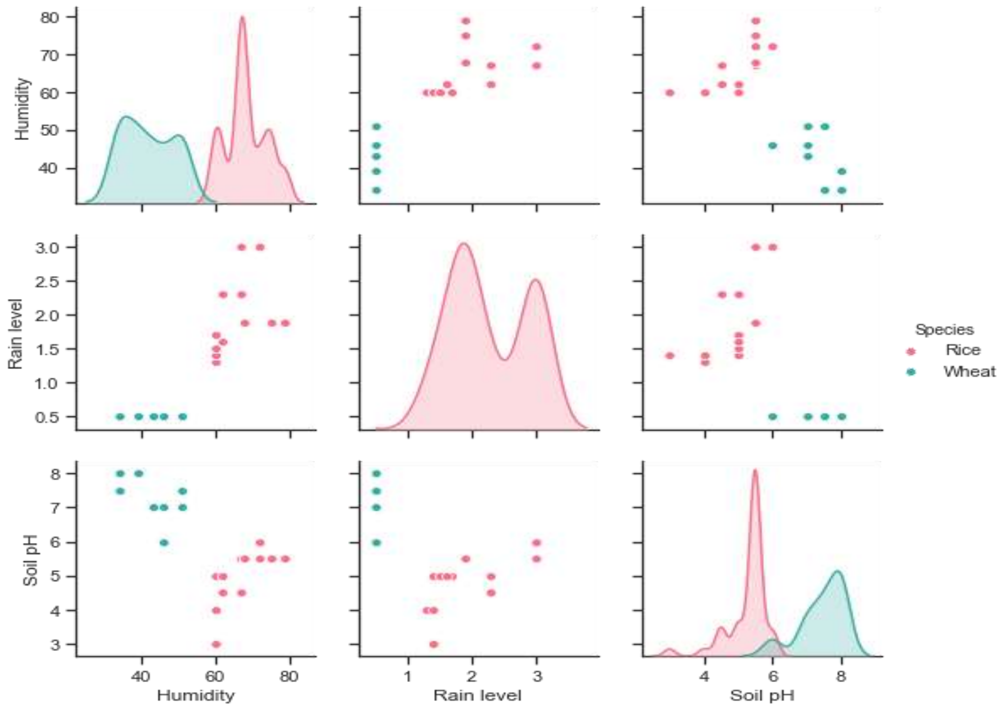


Figure 6.4 Machine learning algorithm on collected data from sensor mote for prediction of suitable crop species RICE and WHEAT

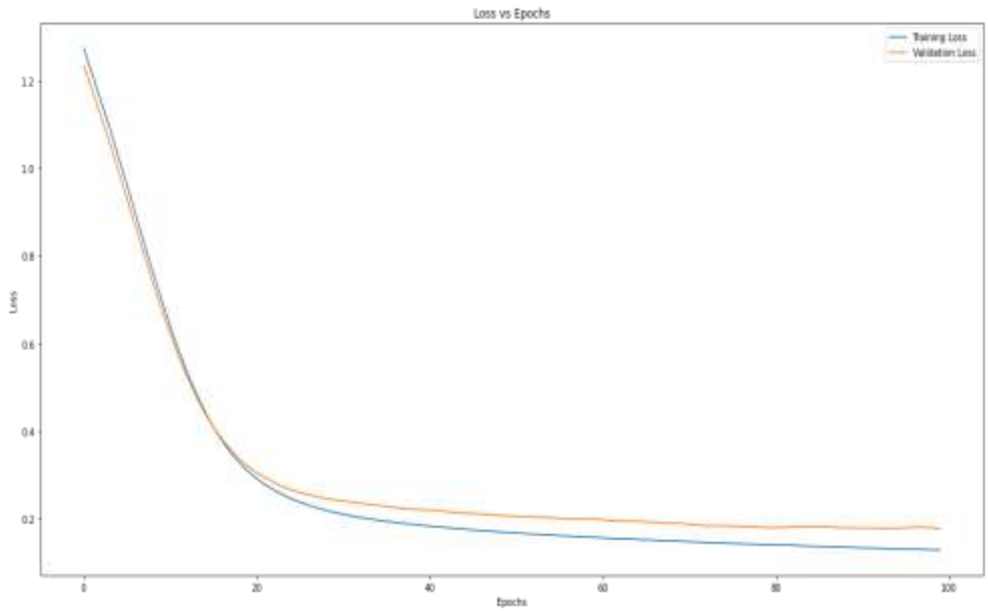


Figure 6.5 Training loss vs validation loss

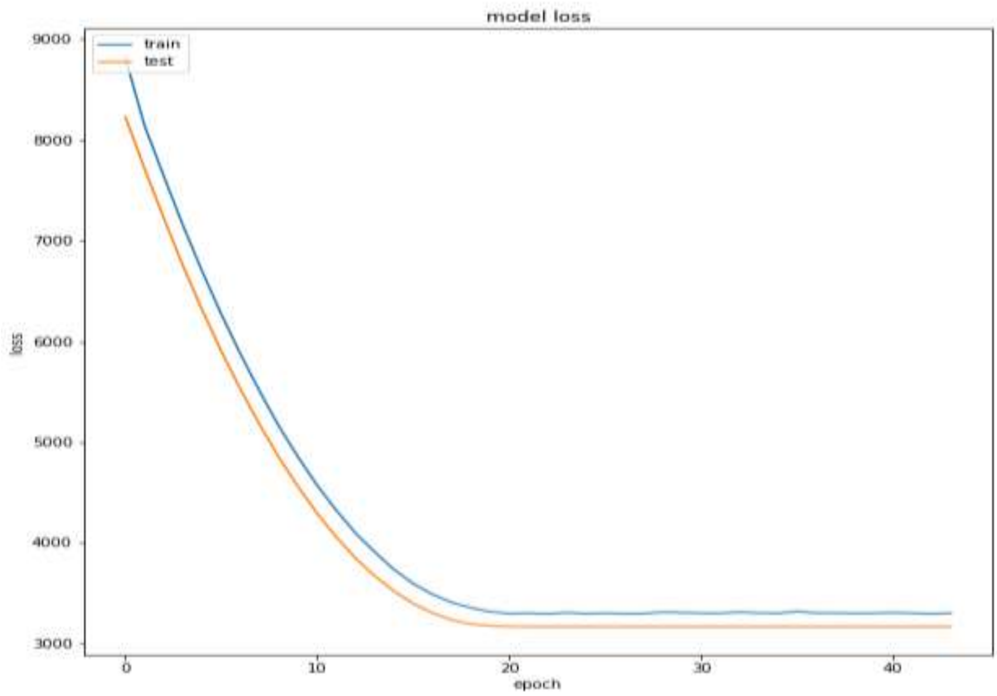


Figure 6.6 Model loss of training and testing

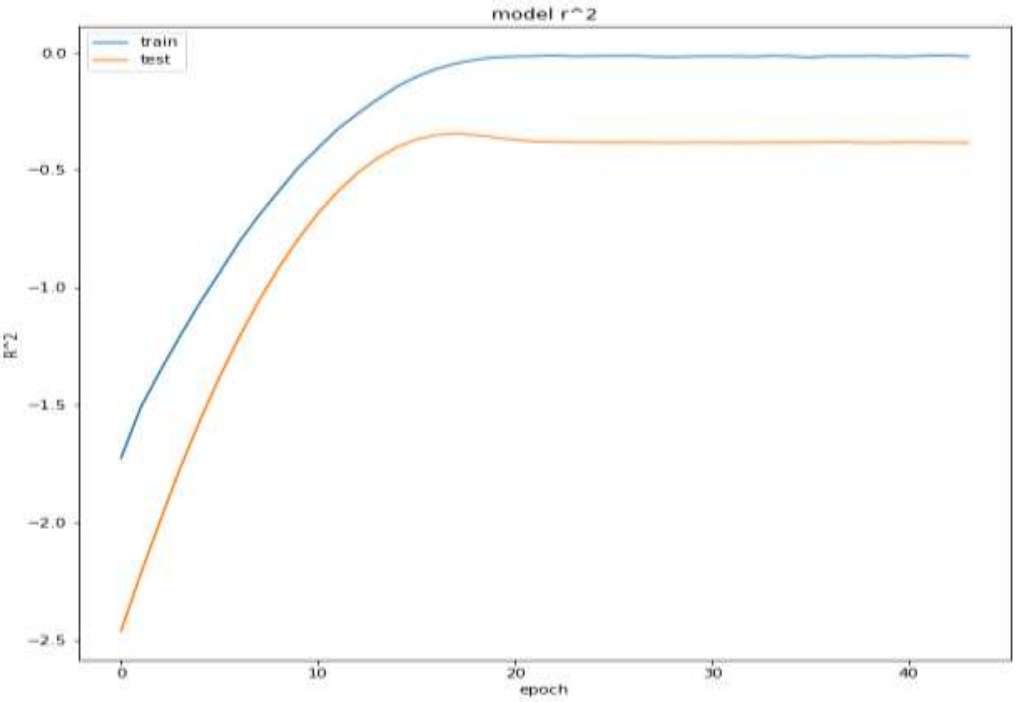


Figure 6.7 Accuracy of training and testing

6.2 Conclusion

This chapter concludes with testing and validating the IoT-based hand-held device for farmers. An IoT-based hand-held device is receiving and communicating the sensor data of the agricultural field through LoRa and Wi-Fi. A hand-held device is embedding with two different switches in it, where the farmer can request the sensor data of the agricultural field through a gateway when the internet connection is poor. If the internet connection is stable, then the hand-held device requests the sensor data from the cloud server. Another switch in the hand-held device enables the farmer to obtain prediction results regarding the cultivation of suitable crops for the next season. The sensor data available in the cloud server is utilizing for the prediction of suitable crops using ML algorithms. Advance ML algorithms are applying for extracting meaningful insights from the raw data collected from the agricultural land. A set of algorithms, including supervised, unsupervised, and ensemble techniques are preferred. Depending on the input parameters suitable crop suggestions are achieved. For example for a state like Punjab where temperature lies from 37 to 45 degrees Celsius with 30 to 55% humidity, Wheat is the preferred crop. As per geographical location, weathers condition and seasons also have a great impact on it. Monitoring the dynamic parameters at the farming is the advantage to tale early preventions to protect from harsh conditions.

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

The chapter presents the significant outcomes of the study with novelty and future directions. Here we present the outcome of each objective with publications.

7.1 Major Outcome

The aim of the research to implement an intelligent mote for agriculture application, for achieving it, the research categorizes it into four objectives. The outcome of the four objectives is presenting here with features and publications.

7.1.1 Objective 1: To design customized intelligent mote

The customization of the intelligent mote is implementing for reducing the system complexity. The customization of the intelligent mote is available in the chapter. 3 with the title “Hardware Description”. Chapter 3 presents the significance of the customization including the selection of appropriate components for the agriculture application.

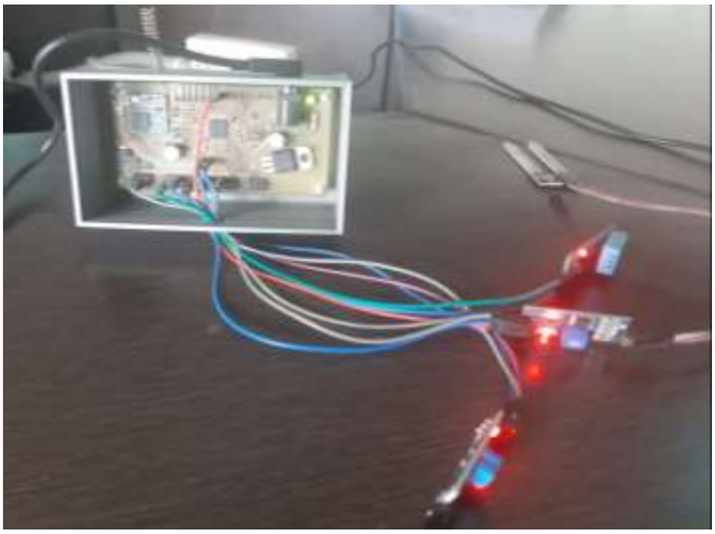


Figure. 7.1. Sensor mote with packing

The development of customized sensor mote and gateway is achieving with ATMEGA 328P microcontroller and SX1276 LoRa modem and it is shown in the figure. 7.1 and 7.2. The sensor mote consists of multiple power trails like 12V, 5V, and 3.3 V for meeting the appropriate power supply to the components that are interfacing. The hand-held device is developing based on ATMEGA 1280 and SX1276 LoRa modem and is embedding with a graphical liquid crystal display also. Additionally, the gateway and IoT-based hand-held device is integrating with NUTTFY ESP 8266 modem for transmitting the data to the cloud server. SX 1278 LoRa module is integrating into the sensor mote, gateway, and hand-held device for enhancing interconnectivity during transmission of agriculture data.

Figure. 7.2. Gateway with packing

7.1.2 Objective 2: To implement firmware on the intelligent mote.

In this objective, custom firmware is implementing on the gateway for enhancing the reliability of the device. This objective is present in chapter. 4 with the title *Firmware Development*, where the significance of implementing the firmware using LINUX is addressing with performance evaluation. The performance evaluation is conducting on the distinct operating system (OS) namely Raspbian, PILES, and Yocto project. Moreover, distinct searching algorithms like the bubble sort, binary search, and merge sort and also with distinct programming languages namely C, C++, and python. The following are evaluation parameters that are considering for evaluating the performance of the firmware and parameters are CPU cycles, context switch time in milliseconds, task clock cycle, cache hit time in milliseconds, overall performance parameters in percentage. Of all the OS, the customized firmware based on the YOCTO OS shows effective performance with distinct searching algorithms and programming languages.

7.1.3 Objective 3: To establish an inter-mote network using LoRa.

This objective is about the establishment of the LoRa network in between the sensor mote and gateway. This objective is present in the chapter.5 with the title "*Establishment Interlink Using LoRa*" During the establishment of interlink using LoRa, the calibration of the certain LoRa field parameters like link budget, spreading factor, and receiver sensitivity are done for extracting the interrelations between all the relevant parameters from a dedicatedly built LoRa network and gateway in MATLAB simulation. Moreover, energy harvesting simulation for sensor mote is also implementing for evaluating battery lifetime of sensor mote using solar and wind turbine. The MATLAB simulation concludes that the reliability of localization algorithms made up of hybrid range-based are observed to be more reliable, effective, and scalable in the relevant applications including agriculture. A real-time experimental setup is established for evaluating the performance of the LoRa network in real-time.

7.1.4 Objective 4: Information-based handheld controlling device for the farmer.

This objective is about the development of a hand-held device that assists the farmers to visualize the information of the agricultural field from any remote location. This objective is available in chapter '6' with the title "Testing and Validation. The customization of the hand-held device is already presented in chapter '3'. Figure 7.3 presents the hand-held device with packing. The hand-held device integrates with ATMEGA 1280/2560 controller, SX 1278 LoRa module, and NUTTYFI Wi-Fi module for receiving the information from the agricultural field either through a local network or else by internet and thereby logging the data into a cloud server. The hand-held device is receiving the sensor data of the agricultural field and it is visualizing in the graphical LCD as shown in the figure. 7.3.

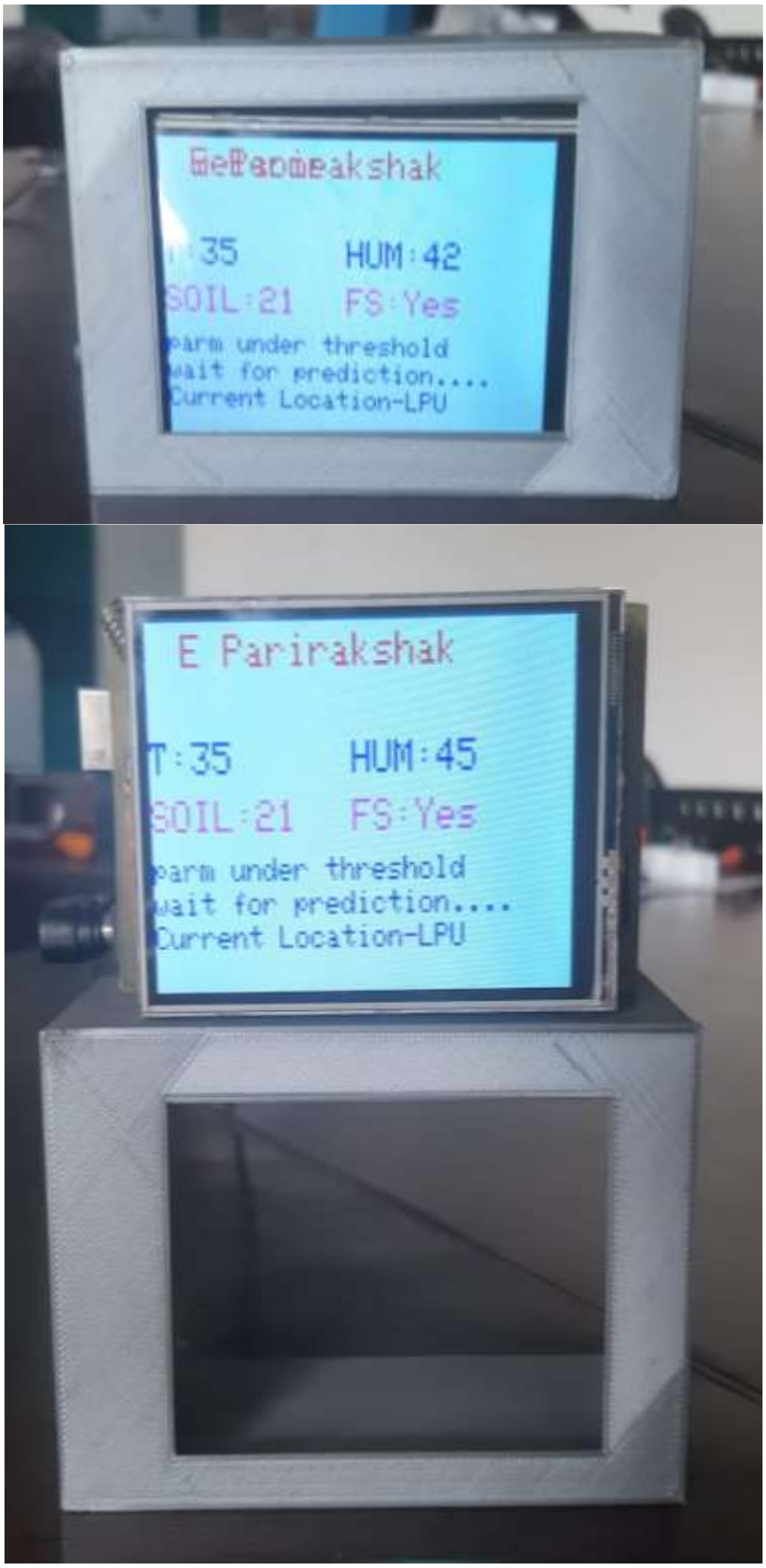


Figure.7.3 Customized hand-held device with graphical LCD and packing

The hand-held device is transmitting the sensor data to the cloud server via the NUTTYFI Wi-Fi module. The sensor data available in the cloud server is utilizing to predict the suitable crops for enhancing crop productivity. Machine learning (ML) algorithms are utilizing for the prediction of the sensor data available in the cloud server. Temperature and humidity parameters are considering for applying the ML algorithms. In ML algorithms, a support vector machine (SVM) based algorithm is applying for the prediction of suitable crops like rice and wheat.

7.2 Novelty: The novelty of the research is as follows:

a. Machine Learning is applied to sensor data obtained by sensor mote for predicting suitable crops like wheat and rice.
b. Long Range and Wi-Fi enabled hand-held device to the farmers for monitoring of agricultural field.

7.3 Future work

The present research work is having opportunities that can be enhanced in future work for delivering effective and reliable solutions in agriculture. The following are the future work of the current research and it is as follows:

Hand-held device: The present hand-held device is providing the sensor data with and without an internet connection. The device is also able to provide the prediction results based on request. For future work, the hand-held device needs to be integrated with the machine learning-based chips and edge computing technology for obtaining the prediction results at the hand-held device.

Energy harvesting for sensor mote: Generally, the sensor mote locating in the agricultural field are facing the issue of energy because it is powering with battery. In future work, energy harvesting resources like solar and wind turbine will be for enhancing the electrical power infrastructure and better power management to the sensor mote.

A deep learning algorithm for prediction: The predictive analysis assists the farmers to cultivate suitable crops for meeting the food demand and enhancing productivity with minimum resources. In the future, the powerful deep learning (DL) algorithm will be implemented for obtaining better results.

Publications

1. **A cost- effective LoRa- based customized device for agriculture field monitoring and precision farming on IoT platform**" in "International Journal of Communication Systems (Wiley) [SCI with Impact Factor: 1.319].
2. **A Reliable Approach To Customizing Linux Kernel Using Custom Build Tool-Chain For Arm Architecture And Application To Agriculture** is published in "International Journal Of Electrical & Computer Engineering" [Scopus with SJR: 0.322].
3. **Performance Analysis Of Various Embedded Linux Firmwares For Arm Architecture Based IoT Devices** is published in "International Conference on Intelligent Computing and Smart Communication 2019" [Scopus].
4. **Lora-LBO: An Experimental Analysis of LoRa Link Budget Optimization in Custom Build IoT Test Bed for Agriculture 4.0** is published Agronomy (MDPI) [SCI Journal with an impact factor**:** 2.603].
5. **A Machine Learning Approach of Data Mining in Agriculture 4.0** is published in "International Journal on Emerging Technologies" [Scopus with SJR: 0.12].
6. **Spade To Spoon: An IoT-Based End To End Solution For Farmer Using Machine Learning In Precision Agriculture** is accepted and presented in "2nd Global Conference On Artificial Intelligence And Applications (Gcaia 2020) Jaipur, Rajasthan (Springer Conference Proceedings)"[Scopus].
7. **A Machine Learning Approach For Optimization Lora Scalability On Simulation Platform"** is accepted and published in "International Conference On "Fourth Industrial Revolution Based Technology And Practices (Icfirtp-2020)" [Scopus].
8. The patent titled "**E-parirakshak: INTERNET OF THINGS ENABLED HANDHELD DEVICE FOR FARMER TO MONITOR AGRICULTURE FIELD"** filed on 2nd March 2019 and published on 27 September 2019, application number: 201911008276.

9. **An IoT Enabled Integrated Framework For Solar Energy Harvesting In Wireless Sensor motes Over LoRa** is a published book with the title: Energy Harvesting Technologies for Powering WPAN and IoT Devices for Industry 4.0 Up-Gradation [Scopus].
10. **LoRaWAN: A Communication Protocol For IoT Agriculture Application**s published in the book with the title: LoRA and IoT Networks for Applications in Industry 4.0 [Scopus].

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