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# Optimization of Water Resource Management: A LoRa-Based Control Framework for Multiple Pump Control Systems

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**ABSTRACT**

In the realm of water resource management, optimizing the operation of multiple water pumps plays a pivotal role in ensuring the efficient distribution and conservation of this vital resource. This research paper proposes a novel approach to address this challenge by harnessing the power of Long Range (LoRa) communication technology for controlling multiple water pumps remotely. The study begins by exploring the existing methodologies in water pump control systems and identifies their limitations, particularly in terms of scalability, range, and energy efficiency. Subsequently, it introduces the concept of LoRa technology and its applicability in the domain of multiple water pump control, highlighting its long-range communicating capability, low-power consumption, and suitability for precision agriculture. The system architecture is delineated, encompassing the integration of LoRa transceivers with each water pump, a central control unit, and a user interface for remote monitoring and management. To evaluate the efficacy of the proposed system, a series of experiments are conducted in real-world scenarios, encompassing various operational conditions and geographic locations. Performance metrics including response time and reliability are meticulously measured and analyzed. The findings of this research demonstrate significant improvements in the reliability of water pump control systems using LoRa technology.

## 1. INTRODUCTION

The water resource management is a very crucial issue specifically in the case of artificial water reservoir like water tanks. For this purpose, water pumps are used to fill the water tanks. Further, on huge campuses or on farms multiple water pumps are in place to manage the water requirements. Theses water pumps are controlled by various methods like traditional wired systems and modern wireless technologies. Along with the technology advancement, there are certain limitations of these technologies specifically in terms of scalability, range, and energy efficiency.

Traditionally the water pump control systems employed a lot of wired connections between pumps and control units. Although these systems frequently have low latency and good reliability, their substantial wiring infrastructure limits their capacity to scale. Furthermore, these systems can be prohibitively expensive to construct and maintain, particularly in large or distant areas [1].

The main driving force for creating the suggested method is to solve the problems caused by ineffective water management in existing systems. These inefficiencies lead to resource wastage, high-energy consumption, and operational inefficiencies in sectors such as agriculture, urban water distribution, and industrial systems. Existing traditional systems like SCADA rely on manual checks and lack real-time data analytics and remote monitoring capabilities, whereas, with integrated sensors and LoRa modules, the proposed system can transmit real-time data on water levels, pump status, and energy consumption, enabling intelligent automation and remote control [1]. LoRa operates on unlicensed frequency bands, significantly reducing operational costs compared to GSM or other licensed technologies. LoRa's Chirp Spread Spectrum (CSS) modulation ensures robust communication, even in environments with high interference or obstacles as compared to WAN, ZigBee, Wi-Max, etc. [2].

Radio Frequency (RF) communication systems, such as ZigBee and Bluetooth, have become more and more popular in recent years because of technological advancements. As these systems are wireless, it is easier to install and scale up or down than the wired pump control systems. Yet these systems have limitations of an operating range, specifically in the field where the distance between pumps and control units is large. Further, such systems have higher power consumption, which reduces the battery life in battery-operated devices, like sensor nodes [2].

Furthermore, advancement in cellular networks along with the Global System for Mobile Communications (GSM) [3] and General Packet Radio Service (GPRS) technologies can be used for operating and controlling water pump systems. Although these systems have a longer range than RF-based alternatives, they frequently require a cellular service subscription and may have problems with network coverage in rural or isolated locations.

Power consumption needs to be focused along with the technology development. To cope with this issue, water pump control systems can be employed with solar panels or kinetic energy harvesting, to power up the wireless sensor modules. With such technologies, sustainability can be enhanced, yet there is a challenge to meet the power requirements to operate the modules continuously, especially in weather conditions with low light or lack of optimum solar energy [4, 5].

In each technology, development faces challenges when it comes to parameters like scalability, operating range, and power efficiency. While thinking of managing the water resources, it should be sustainable and effective, apart from all other benefits. Some of the technology benefits are discussed below:

1). The use of technologies like the Internet of Things (IoT) including the use of wireless communication protocols such as NB-IoT and LoRaWAN, has significantly increased for water pump control systems [6-8]. Advantages of using these technologies are, reduces power consumption, improved scalability and longer operating range as that of the conventional wired or RF-based water pump control systems.

2). By integrating AI and Predictive Analytics, the performance of water pump control systems can be optimized. With such systems, it is possible to optimize pump operation in real-time like, prediction of the maintenance requirements in advance, early detection of anomalies, by analyzing sensor data and past usage trends [9-11].

3). By adopting precision agriculture and smart irrigation systems [12-13], crop yields and water consumption can be maximized. It is achieved with the help of IoT sensor data, weather information, and soil moisture monitoring. It incorporates automated pump control functions to provide exact watering levels as per the plant requirements and environmental parameters [14].

4). The ability to monitor and control water pump systems remotely from any location with an internet connection has been made possible by the advent of cloud-based platforms. These technologies can improve total system dependability and efficiency by providing real-time insights, remote testing, and predictive maintenance capabilities [15, 16].

5). The developments in technology, data analytics [8, 17], and the growing recognition of the significance of water resource management have resulted in a trend towards the creation of more advanced, effective, and sustainable water pump control systems, which is shown in these recent endeavors.

With the proposed system development, an attempt is made to validate the advancement in the pump control system using a Master-slave module, which works on wireless technology to monitor and operate the water pump remotely. The slave unit must be placed at the field and the master unit at the remote in order to operate this setup. The master unit acts as a server and is connected to the cloud. The master unit forms a star topology with slave units. With this, the farmer can monitor and control multiple water pumps (ON or OFF position) through a specifically designed mobile application installed on his smartphone. Proposed system will be just plug and play, easy to implement and handy to use.

## 2. RELATED WORKS

The work [18] described developed low-cost and low-power WSN nodes by using ZIGBEE. To monitor agriculture farms and parameters, which are monitored by sensors like temperature sensors, humidity sensors, etc., and such data is sent to the base station using ZIGBEE protocol. ZIGBEE has a lower range that is not sufficient for the long distance communication. Santosh Kumar et.al, concentrated on creating a ZigBee-based wireless sensor network-based WSN system for precision farming. The 868MHz, 902-928MHz, and 2.4GHz frequencies are used by wireless personal area networks, which operate with the ZigBee protocol. Further, ZigBee is also utilized in WPAN, such as Wi-Fi networks, to establish low-rate WPAN (LRWPAN) to enable wireless device connections. Their research indicates that these devices in a WPAN can communicate over a distance of up to 50 meters, under typical conditions and potentially even farther under ideal conditions [18].

Săcăleanu et al. [10] addressed data compression in wireless sensor nodes and results obtained using LoRa technology are compared with ZigBee and Enhanced Shock Burst protocols. The authors discovered the ZigBee protocol-using DASMote node gathers seven attributes and sends 14 uncompressed data bytes. Energy efficiency was improved by around 20% compared to the average transmission current of 27mA for a transmission duration of 58.45ms, which was 1.59mA. The 76 parameters are gathered for Arduino nodes utilizing the Enhanced Shock Burst protocol, and 14 bytes are sent uncompressed for each parameter, allotting 2 bytes.

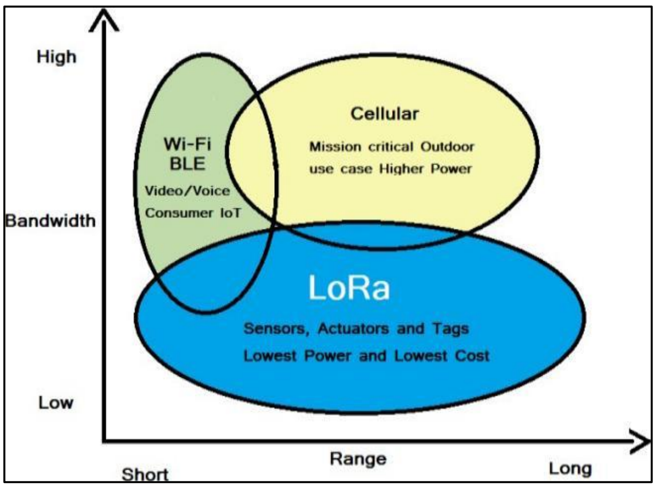



**Figure 1.** Comparisons of WSN technologies [7]

LoRa technology facilitates bidirectional transmission of data over extensive distances, with typical ranges spanning up to 15 to 20 kilometers, and operational longevity of up to one year on a single battery charge [19, 20]. The frequency range that is assigned to LoRa in India is 865 MHz-867MHz. Conversely, Bluetooth-Low-Energy/BLE operates on less power consumption having trade-off with limited range capabilities. However, LoRa technology enables long-distance communication without relying on an internet connection, thereby circumventing the constraints associated with Wi-Fi and BLE communication protocols.

Figure 1 provides a range versus bandwidth for different WSN technologies. It shows that LoRa can cover maximum range in trade off with the bandwidth [21].

By utilizing LoRa technology, we can transmit data from areas with poor internet connectivity to regions with better connectivity, effectively addressing network issues. This approach also allows us to maintain a database of frequently collected data, which can aid in making informed decisions for optimal fertilizer application and disease management, ultimately promoting better onion growth. To conserve power and extend the operational life of a sensor node on a single rechargeable cell, many people rely on microcontroller sleep or power-down modes. However, these modes are often inefficient, as they still consume power in mW. Instead, we can use the TPL5110 nano power timer, which delivers power to the system only during its operation and conserves energy by consuming power in microwatts during the preset delay. This enables each sensor node to function for extended periods on a single rechargeable cell. Additionally, we can integrate remote farm monitoring and irrigation pump control into a unified system, allowing for remote management from any location.

Following are the key features of LoRa, which attract users to use it for multiple applications,

- For the IoT and Machine-to-Machine (M2M) communication, LoRa is a form of wireless communication designed to operate at low power wide area networks [22].

- The extended life of the LoRa is one of its preferred benefits. IoT devices are generally made to minimize the frequent need for battery replacements. Thus, LoRa must be powered up with an extended battery life.

- Transmission distance up to ten kilometers is supported by LoRa technology. In spite of having an intuitive architecture, LoRa cut down the overall network cost.

- The capabilities of LoRa technology extended beyond the private network. In addition, it offers public networks. LoRa is widely used as an ideal option, irrespective of the present state of development.

The work [6] proposed and designed an IoT-based system for precision agriculture applications which employs a variety of hardware, viz. humidity sensor, temperature sensor, moisture sensor, microcontroller, Wi-Fi module, a mobile application, and a cloud platform. This system is capable of sensing data & simultaneously sending data to the thing speak cloud, which the users may access via a dedicated mobile application.

The work [20] depicted, introduced an innovative approach to precision farming employing a wireless sensor network (WSN). Their study explores various network topologies designed for smart farming applications. The evolution and implementation of wireless sensor networking have reshaped conventional network structures, with emphasis placed on assessing different topologies such as Bus, Star, Ring, and Grid to evaluate communication delays. Their findings indicate that the star topology experiences significantly lower delays compared to the bus, grid, and ring topologies. According to their investigations, the average network delay across the four scenarios was recorded as 45ms: star topology, 71ms: grid topology, 81ms: bus topology, and 98ms: ring topology. Notably, the star-topology exhibited a notable decrease in delay of approximately 50%.

While discussing with the farmers from rural areas it is seen that there is a need to develop a pump control system that can reduce human efforts, monitor the water level of multiple water tanks in real-time, control the ware pump with respect to the water level and thereby reducing water wastage and hence save the electricity. Electricity and network range are the main issues for technology adoption in the rural area. Section 2.1 explores the proposed system's architecture.

### 2.1 System architecture of proposed pump control system

Figure 2 shows the System Architecture of the proposed pump control system. In this system, the mobile user is connected to the LoRa server using the Internet and cloud. To connect the master LoRa to the cloud, the Node MCU ESP8266 Module is used. This module is serially connected to the ATmega328P Microcontroller, LoRa Trans Receiver Module XL1278-SMT 433MHz and is further connected to a Central Control Unit. This unit serves as the main interface for monitoring and controlling the multiple pumps [23]. It typically consists of a microcontroller with LoRa communication capabilities. Each water pump is equipped with a LoRa transceiver module capable of wirelessly communicating with the central control unit. The water pump will operate automatically by sensing the water level of the respective water tank.

An ultrasonic sensor is used to sense the water level along each LoRa module will transmit the signal from the master controller (server) to Slave1 and Slave 2 respectively for controlling the distinctly located water pumps. The slave node will collect the water level of the respective water body, using a float sensor. Master and slave nodes will have the same architecture, except for the installation of the Node MCU esp8266 module.

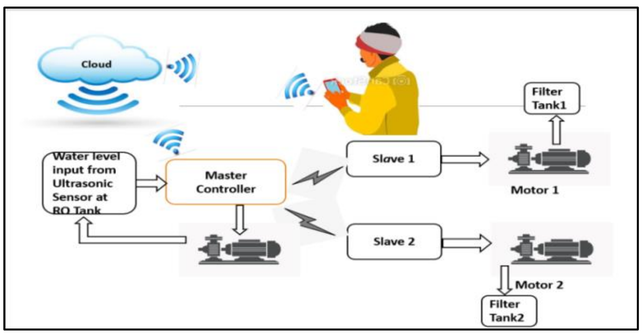



**Figure 2.** System architecture of the proposed system

Each node with the LoRa Module is assigned a unique identification code. The nodes are connected in the star topology where the central control unit acts as a gateway, communicating directly with each pump node. This topology simplifies network management and enables efficient communication between the control unit and individual pump nodes. Each node communicates with the master using the LoRaWAN (Long Range Wide Area Network) protocols. It describes the exchange of data between central network servers (control units) and end-devices (pump-nodes). In addition, LoRaWAN offers safe encryption, adaptable data rate, and bi-directional communication; it is best suited for controlling multiple water pumps. Each pump node receives instructions and configuration parameters from the master node and the master-slave starts communicating with each other. It includes parameters like, operating schedules, threshold values for sensor data, and directions for activating and deactivating pumps.

Periodically, pump nodes gather sensor data and send it via LoRa communication to the master unit. Pump nodes start gathering the sensor data and transmit it through the LoRa communication to the master node. The central control unit verifies successful transmission and begins processing the data it receives from the pump nodes. The control unit may transmit control commands back to the pump nodes to modify pump operation parameters, such as flow rate or on/off status, based on the data analysis and control algorithms.

Figure 3 shows the typical architecture of an LPWAN where LPWAN sensors/end-nodes, gather various measured values, and transmits them to the gateway. Subsequently, gateway forwards the data to an internet cloud service, where clients can access and utilize the collected data. The long-range capability with a single base-station capable of covering extensive areas is the major benefit of using LoRa, although the actual range is subject to environmental factors and obstacles [24].

The data flows from the sensor node to the application server is termed uplink communication. The sensor node collects water level, and pressure data and transmits it to the nearest gateway. Such LoRa signals are then forwarded to the network server via IP-based backhaul. If multiple gateways receive the same messages, then such duplicate signals are removed. The processed data is forwarded to the application layer for storage or further analysis.

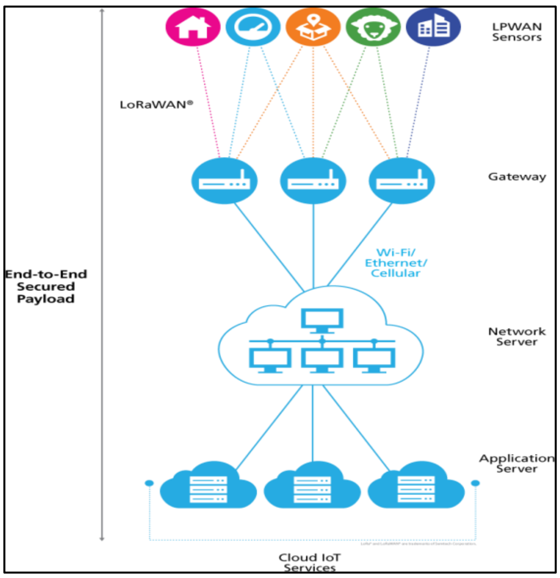



**Figure 3.** Typical architecture of LoRaWAN [24]

The dataflow from application server to sensor node is termed as downlink communication. The application server sends a control command to turn ON the pump to the network server. The network server schedules the command and sends it to the appropriate gateway, which then transmits the downlink command using LoRa to the specific end device.

### 2.2 Mathematical modeling

The communication between the slave and master nodes is illustrated with the mathematical modelling. The mathematical modeling describes the interaction between sensors, water pumps, and a control strategy, including internal states, measurements, and optimization for control commands.

Let N = number of water pumps to be controlled at discrete time t;

Let $u_i(t)$ be the control-command for pump $i$ at time $t$, responsible for the operating parameters or ON/OFF status of the water-pump.

Let $y_i(t)$ be the measured parameter (temperature, pressure, or water level) by the sensor data installed at respective pump $i$ at time t.

Let $x_i(t)$ be the internal state of water pump $i$ at time $t$, the function of variables (like energy consumption and error status) of the water pump.

Let $i$ be the dynamics of the water pump and can be represented by a discrete-time state-space model:

$$x_i(t+1) = f_i\left(x_i(t), u_i(t)\right) \tag{1}$$

Eq. (1) is a state transition equation, which models how the internal state $x_i\,(t)$ of pump $i$ evolves over time. This is a specific example of a water pump. In Eq. (1), function $f_i()$ is used to capture the evolution of the internal state of the individual water pump at its current state and control command. It denotes the state transition function for water pump $i$.

Eq. (2) describes the internal states of water pump $y_i(t)$, where the sensor data at time ‘t’ are collected:

$$y_i(t) = g_i\left(x_i(t)\right) \tag{2}$$

In the above equation, the sensor measurement function of water pump $i$ is given by $g_i()$, which maps the sensor’s data with the internal conditions of the water pump. This sensor measurement equation measures water pressure, temperature, or energy consumption ($y_i\,(t)$).

A control strategy determines the control commands $u_i(t)$ for each pump based on sensor data, system constraints, and control objectives. This can be expressed as an optimization problem, in which the control instructions are selected in order to minimize an objective function subject to constraints on u($t$) and x($t$) and is given by Eq. (3):

$$\min_{\mathrm{u}(t)} J(\mathrm{u}(t)) \tag{3}$$

In Eq. (3), u($t$) = [$u_1(t)$, $u_2(t)$, ..., $u_N(t)$] which represents the vector of control commands for all pumps, x($t$) = [$x_1(t)$, $x_2(t)$, ..., $x_N(t)$] gives vector of internal states for all pumps, and $J(\cdot)$ is the objective function to be optimized. The objective of this equation is to minimize energy consumption and maximize pump efficiency. By solving this optimization problem, the control strategy can efficiently determined at each time.

## 3. METHODOLOGY FOR SYSTEM DEVELOPMENT

Long Range (LoRa) is a wireless communication technology that enables long-range, low-power, and low-data-rate communication. It is the physical layer (PHY) protocol used in LoRa Wide Area Network (LoRaWAN) and operates on the unlicensed ISM bands (e.g., 868 MHz in Europe, 915 MHz in North America, and 433 MHz in some regions). LoRa employs Chirp Spread Spectrum (CSS) [25] modulation, where data is encoded using chirps-signals that increase or decrease in frequency over time. Chirps are highly resistant to noise and interference, making LoRa suitable for noisy environments. CSS allows a trade-off between data rate and range by varying the Spreading Factor (SF). The SF determines the amount of signal spread over time. Due to these features, LoRa excels making it ideal for IoT-based water management systems.

Figure 4 illustrates the methodology to develop the proposed system.

Using a Lora technology, a wireless network is formed, it consists of a transmitter and two receivers. The system is divided into two LoRa module sections, one is the slave and another is the master. One transmitter and two receivers are used are located in the field area. Both slave and master sides act as transceiver. On the slave side, the three-phase motor is connected to the controller through a relay circuit, and on the master, side controller is connected through mobile application.

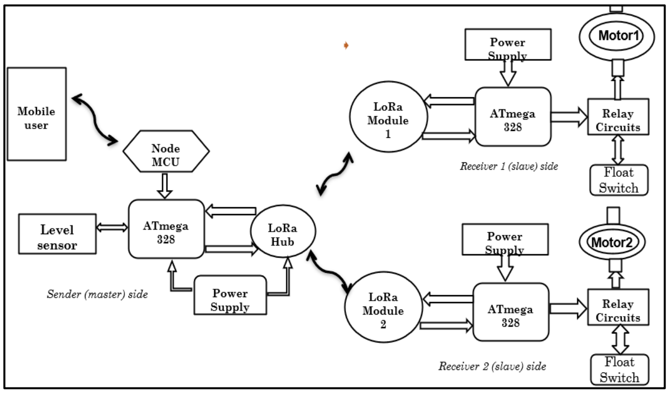



**Figure 4.** Schematic view of the proposed system

## 4. EXPERIMENTATION

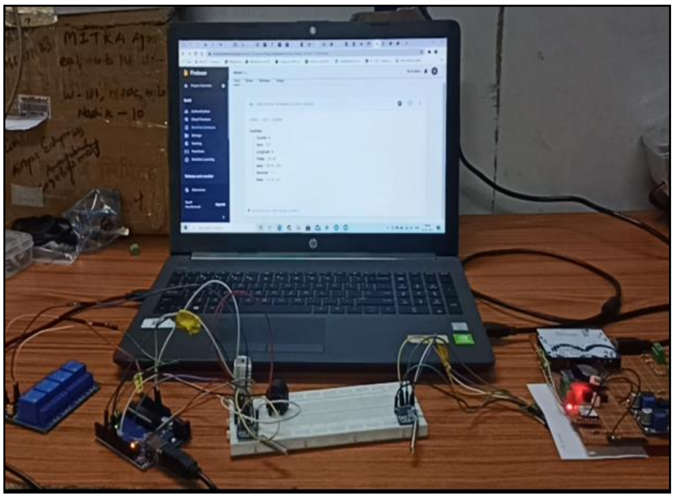
The experimental setup of the proposed system is as shown in Figure 5(a). After initial testing of the intended working principle. In the hardware set-up, the Mobile user is connected to the LoRa server using the Internet and cloud (IoT) [22]. The Node-MCU ESP8266 Module is used to connect the master LoRa to the cloud which is serially connected to ATmega328P Microcontroller. LoRa Trans-receiver Module XL1278-SMT 433Mhz is connected to the microcontroller. An ultrasonic level-sensor is used to know the status of the water level of the water tank. The water tank motor operates in synchronization with the readings of the ultrasonic sensor. Slave Nodes (Atmega 325) are programmed using C/C++ with AVR libraries to read level sensor and float switch, control relays for pump operation, and send sensor readings data/pump status to the master node via LoRa. Also, the NodeMCU is programmed using Arduino IDE with ESP8266 libraries.

The modules are installed on the water controlled located at respective tanks. The performance of the system is monitored in real-time through the mobile application specifically developed for monitoring purposes, as shown in Figure 5(b).

The role of the master transceiver is to control the motors of the receiver side and take the feedback from them i.e., whether they turn ON or OFF which can be remotely monitor it on the mobile App.

LoRa module is used to transmit the signal from the master controller (server) to slave1 and slave2 respectively. Using a float sensor, the receiver on the slave side first determines whether water is present in the well or not. If water is present, the sensor will function as a "close switch," meaning 1, and if not, it will function as an "open switch," meaning 0. If a user wishes to turn on the Tank 1 motor, the Tank 1 slave will receive the signal, check the sensor condition, and execute the operation appropriately.

LoRa module is used to transmit the signal from the master controller (server) to slave1 and slave2 respectively; a unique identity-code is assigned to each LoRa module, this is due to the same operating 433MHz is available for all LoRa modules [23, 24].



(a) Implementation

(b) Testing of the Proposed System

**Figure 5.** Implementation and testing of the proposed system

## 5. RESULTS AND DISCUSSION

Figure 6 shows the operation of LoRa module to turn 'On' and 'Off' the water pump. To start the testing of the LoRa module, the microcontroller initiates the serial communication with the LoRa module. Once the serial connection is established with the LoRa module, LoRa pins are configured, and a connection is established between master and slave LoRa modules. Upon successful initialization of master-slave modules, pump 'On' and 'Off' operation is tested. If not, self-testing of the module is conducted until there is successful communication between master and slave LoRa modules.

Figure 7 illustrates the water pumps operating at different time slots and measured water levels from the sensor. These levels are measured at actual too. For testing purposes, a water tank of height 140 cm is taken, the lower limit is set at 110cm, and the upper limit is set at 20cm from the sensor position. A sensor is installed at the top of the tank which measures the distance or water levels from its position. At these limits master can send the "on" or "off" command to slave pumps, it is observed on mobile applications.

Validation of water levels to be measured, are illustrated in Table 1. Water level is measured at actual with measuring scale and those with the sensor reading on the mobile application. It is seen that there is an accuracy of 99.5%.

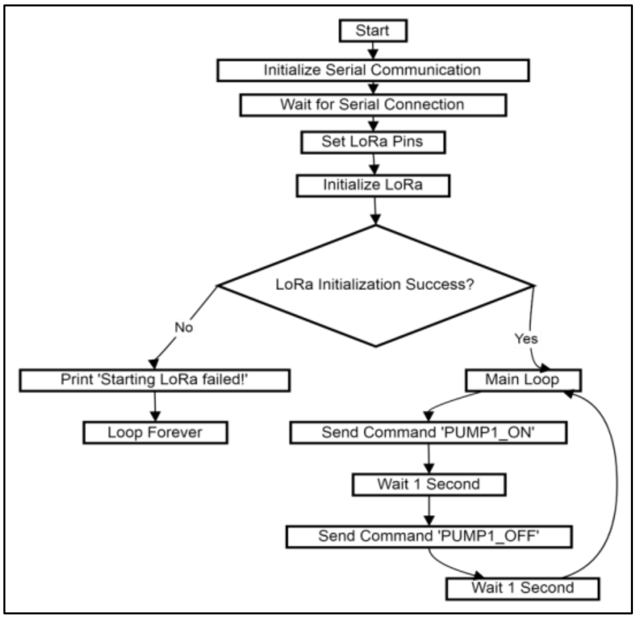



**Figure 6.** Testing of LoRa module for water pump operation

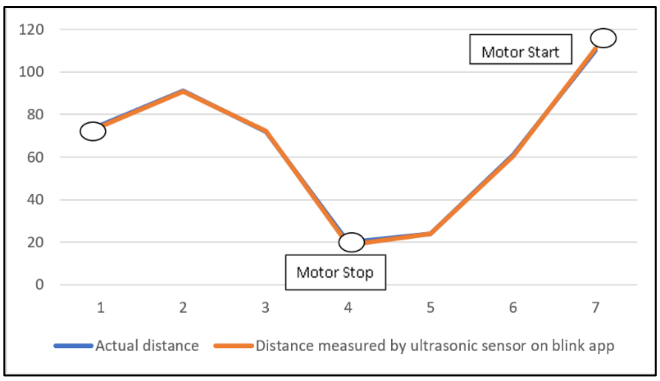



**Figure 7.** Water level measurement and pump control

**Table 1.** Water level measurement validation

| Sr. No. | Actual Water Level (cm) | Measured by Sensor and Displayed on Mobile App (cm) |
|---|---|---|
| **1** | 75 | 74.4 |
| **2** | 91 | 90.8 |
| **3** | 72 | 72.2 |
| **4** | 20 | 18.6 |
| **5** | 24 | 23.8 |
| **6** | 61 | 60.5 |
| **7** | 110 | 111 |

Latency of LoRa is computed in terms of the average delay to turn ON and OFF the water pump, and found that it has a higher latency (400ms) than that of Wi-Fi (10-100ms) due to the spreading factor and the network topology. Due to the higher latency, LoRa is not suitable for real-time applications.

Experimentation is carried out to test the operating range of the LoRa module. Figure 8 illustrates the performance of the LoRa module in terms of the operating range between the master and slave modules. Motor pump is operated from different locations, in the range of 1KM to 6KM, to test the operating range of LoRa. From the figure, it is seen that it is best suited for the operating range of 0 to 4KM, from 4-5KM, the signal is moderate and from 5KM to 6KM, the signal becomes weak. The comparative of signal strength of LoRa and other communication technologies like Bluetooth, Zigbee, Wi-Fi and 5G are shown graphically in Figure 9, which confirms that LoRa gives best range of remote operation.

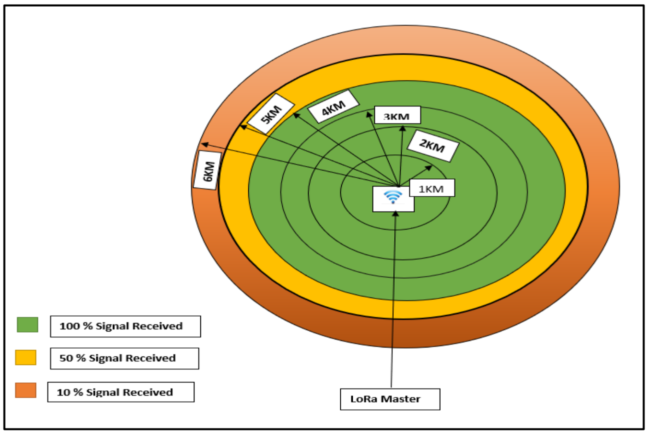



**Figure 8.** Operating range testing of the LoRa module in the field of installation

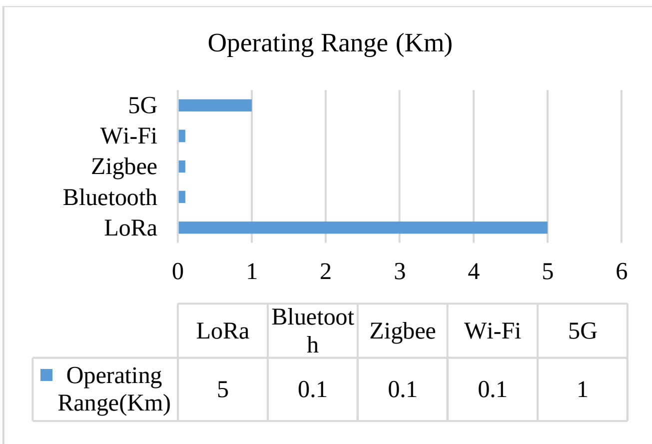



**Figure 9.** Performance of LoRa for remote operation

## 6. CONCLUSIONS

The proposed work aims to assist the user in controlling multiple motor pumps remotely with the help of a mobile application for real-time water level notifications and pump control. Experimentation has been carried out successfully to test the ON/OFF control of two water pumps through the mobile application.

We have displayed the water level on the mobile app using ultrasonic sensors, ensuring the automatic pump turns off upon reaching the desired water levels. It reveals the successful measuring of the water level with the acceptable error of +/- 0.05. Range testing revealed occasional discrepancies between expected and actual pump positions due to distance variations, affecting sensitivity. Operating limitations are observed beyond 4KM radius; accuracy decreases with increase in distance. The performance of the LoRa varies with the surrounding atmosphere too. It is different for indoor or outdoor operations. The proposed system's ability to dynamically adapt to varying water demands, detect faults, and minimize wastage significantly improves operational efficiency and sustainability.

In the future, we will explore the use of renewable energy sources, such as solar panels, to power remote nodes. Also, we may expand the proposed framework over other utilities like electricity distribution, irrigation, sewage systems, precision farming, etc.

## ACKNOWLEDGMENT

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