DESIGN AND DEVELOPMENT OF A LORA COMMUNICATION SYSTEM FOR SCALABLE SMART IRRIGATION SYSTEMS

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ABSTRACT

The adoption of smart irrigation in Sub-Saharan countries such as Uganda is still hindered by several challenges, primarily related to the high initial costs, infrastructure dependence, and limited hardware availability. This study aimed to address these challenges by developing and testing an affordable smart irrigation system based on LoRa radio technology. The system design incorporates readily available hardware components and Chirpstack open-source software, which serves as both the LoRaWAN Network and Application server for scalable and license-free radio operation. A real-world scenario functionality test was conducted at the Makerere University Agricultural Research Institute Kabanyolo (MUARIK) in which a smart valve was connected to the LoRa gateway at two different locations. Two connection parameters, the Signal to Noise Ratio (SNR) and Received Signal Strength Indicator (RSSI), were compared to analyze the range and reliability of the system. Results demonstrated robust communication, particularly in areas with fewer obstructions, highlighting the importance of optimal antenna placement to ensure efficient communication to automate irrigation systems as well as agricultural systems. The LoRa radio enhances smart irrigation by offering low power consumption, long-range capabilities, and collaborative farmer access, which helps reduce initial costs. This system improves water efficiency and crop yields, aiding smallholder farmers in adapting to climate variability and promoting sustainable agriculture in Uganda.

INTRODUCTION

Agriculture remains a fundamental pillar of the economy in many Sub-Saharan African countries, including Uganda, where most farmers are smallholders residing in rural areas. These farmers frequently encounter significant challenges, such as food insecurity exacerbated by a rapidly growing population [1], [2]. Traditionally, Uganda's agriculture has relied heavily on natural climatic patterns, particularly the two annual wet seasons [3]. Furthermore, anthropogenic climate change has increasingly disrupted these patterns, leading to more frequent and severe dry spells, floods, and rising temperatures, all of which threaten food security [4], [5].

In light of these challenges, policymakers have emphasized the critical role of irrigation in enhancing food security amidst climate variability [6]. Initiatives such as the Micro-scale Irrigation Program supported by the World Bank and administered by Uganda's Ministry of Agriculture, Animal Industry, and Fisheries (MAAIF), are advancing sustainable agricultural practices by providing subsidized irrigation equipment and training to smallholder farmers. The adoption of technology-enabled smart irrigation has emerged as a vital strategy for adapting to climate change due to the potential benefits of these technologies which include increased agricultural productivity and more efficient use of resources, thereby contributing to the sustainability and resilience of food production systems. This is achieved through the deployment of extensive sensor networks that monitor crop water needs, coupled with automated actuators like pumps and valves.

Despite these advantages, the adoption of smart irrigation technologies in Uganda faces significant obstacles such as financial constraints that are a major barrier, as the average annual income of farming households in Uganda is only USD 222 [7]. Additionally, infrastructure challenges such as frequent power outages and limited internet availability hinder the effective operation of IoT-powered smart irrigation systems. Wanyama et al. [8] also identified the lack of material and service supply as a burden to irrigation adoption in many regions of Uganda. LoRa radio technology is particularly well-suited for connecting smart components due to its low power consumption and long-range coverage, making it ideal for IoT and smart farming applications [9], [10]. This article aims to propose a smart irrigation system designed to overcome these challenges, focusing on affordability, resilience to infrastructure limitations, and the use of readily available materials to ensure successful broad adoption in Uganda.

MATERIALS AND METHODS

Study Site

The study was carried out at the Makerere University Agricultural Research Institute Kabanyolo (MUARIK), located 21km north of Kampala city center, Uganda. The institute is located at coordinates 00°27'06.000" N, 32°03'60.240" E, with an altitude varying between 1250 and 1320 meters above sea level in the Wakiso district.

System Design and Assembly

In alignment with the principles of affordability and accessibility, the components for the system were selected based on their low cost and availability, either through international delivery or local sourcing in Uganda. To ensure independence from internet infrastructure, a local processing approach was adopted. The system includes battery backups to mitigate the effects of power outages. An overview of the proposed smart irrigation system is illustrated in Figure 1(a).

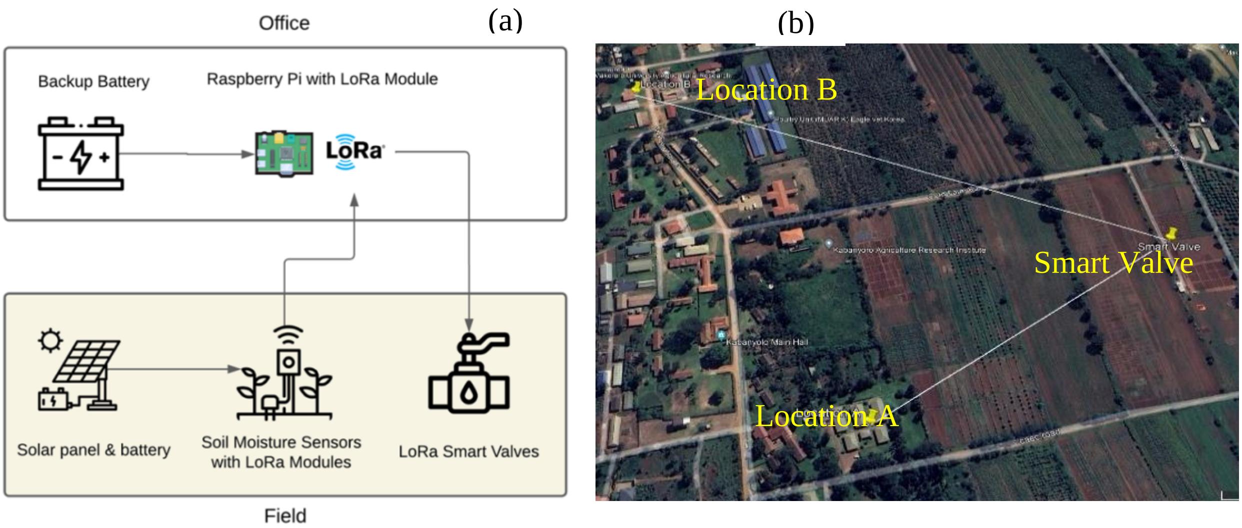

Figure 14. (a) Design overview of proposed LoRa Smart irrigation system, (b) Map of the locations and distances of the functionality test.

The system features a proposed sensor node positioned at the field level, which connects common soil moisture sensors, such as the commercial Watermark sensor [WATERMARK 200SS, Irrometer Company, Riverside, USA] or the more cost-effective Chameleon sensors [Chameleon Sensor Array, VIA Ltd, Melbourne, Australia], to an enclosed LoRa module consisting of an interface module [SMX, EME Systems, Berkeley, USA], a microcontroller [HUZZAH32, Adafruit Industries, New York, USA] and a LoRa transmitter [E220-900T22D LoRa Wireless UART Module, Ebyte, China]. These components are powered by a waterproof battery and solar panel [EESBAO-35W, Shenzen Tengyunfei Technology Co., Shenzen City, China]. The collected data is transmitted to a LoRa gateway unit, which is typically located in an office, farmer's house, or community center.

At the core of the gateway unit is a microcontroller [Raspberry Pi 4B, Raspberry Pi Ltd, Cambridge, United Kingdom], which is connected to a LoRa concentrator board [GPMLx9332-PX V3, Greenpalm, Hangzhou, China] and a 0.5-dB antenna. The gateway operates on open-source software [Chirpstack V4, Orne Brocaar, Amsterdam, The Netherlands], which includes network and application server functionality. To safeguard against power interruptions, a small uninterruptible power supply [UPS Module 3s, Waveshare, Shenzen, China] is integrated into the system. When irrigation is required, a command is sent to activate a wireless motorized shut-off smart valve [STREGA, Ohain, Belgium] that is programmed to open for a specific period depending on the soil's antecedent soil moisture and its field capacity. The valve is set to operate as a Class A LoRa device.

Functionality Test

The system was tested for its functionality by studying the signal strength and connectivity using the Received Signal Strength Indicator (RSSI) and Signal to Noise Ratio (SNR) of the periodic upload messages sent by the smart valve to the gateway communicating its status information (e.g. temperature and battery level) to the gateway. The valve was installed at an existing drip irrigation system at the Department Demonstration plot located at the study site and gateway set to operate in the 868 Mhz frequency. Two different locations were chosen: Location A had a much more unobstructed line of sight to the valve at a distance and elevation difference of 402 m and 7.6 m, and location B was obstructed by several buildings and vegetation. It also had a greater distance and elevation difference to the valve of 660 m and 8.5 m (Figure 1(b)). For each site, 10 of these messages were analyzed for their RSSI and SNR values to assess the quality of the connection.

RESULTS AND DISCUSSION

The test of the system's functionality confirmed full operation between the gateway unit and the smart valve. The signal strength data showed that connectivity was stronger in areas with a clearer line of sight (Location A) than with more obstacles (Location B).

When analyzing the data packets sent to the gateway (Figure 2), Location B exhibited generally worse connectivity as compared to Location A with the SNR values here ranging between -12.5 to -18.8 dB and averaging -15.7 dB. RSSI values ranged from -93 to -98 dBm, with an average of -96.3 dBm as the valve communicated at a Spreading Factor of 12. On the other hand, the SNR values at Location A ranged from -2 to 6 dB, with an average of 2 dB. RSSI values ranged from -96 to -102 dBm, averaging -98.7 dBm as the valve communicated at a Spreading Factor of 7 after applying Adaptive Data Rate (ADR) protocol at both locations. This explains the lower RSSI values for Location B as the valve used more battery power to ensure the same communication. Additionally, the presence of blockages from buildings and vegetation, along with the effects of ambient factors like temperature and relative humidity, significantly impact signal strength, as corroborated by studies from Antoine-Santoni [11] and Iova [12]. The function test results highlight the critical role of antenna positioning on signal strength. For optimal performance, the LoRa antenna should be installed above all obstructions to ensure a clear line of sight to the smart valve.

This study introduces a cost-effective smart irrigation system for small-scale Ugandan farmers, using affordable, locally sourced components and open-source ChirpStack software to reduce expenses and reliance on commercial services. The system is adaptable to different Raspberry Pi models and supports advanced irrigation algorithms [8] to improve water efficiency and crop yields. It's designed to withstand Uganda's infrastructure challenges with a UPS and local computing, ensuring operation during power outages and without depending on unreliable rural internet. While the chosen motorized valve is costly, it is crucial to highlight the need for a more affordable low-pressure option such as latched solenoid valves as suggested by Maksudjon [13]. The system's use of LoRaWAN technology allows a single gateway to support an entire community, reducing individual costs and promoting community collaboration as demonstrated in the work of Dongore [14].

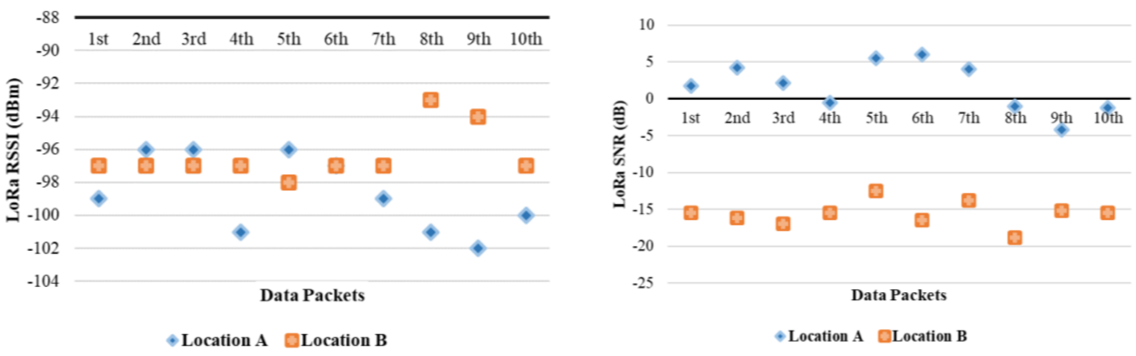

Figure 15. Visualization of the signal strength parameters RSSI (a) and SNR (b) received during the system functionality test.

CONCLUSION AND RECOMMENDATION

The study reviews challenges in smart irrigation in Uganda and proposes a LoRa-based system to address them. While the system shows promise, it requires field testing with sensor nodes to evaluate its scalability and effectiveness on smallholder farms. Successful implementation could lead to nationwide adoption, helping farmers increase profitability, sustainability, and resilience to climate change.

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