Master's Thesis of Mechanical Engineering

# RF Based Smart Irrigation Monitoring System

## 무선 통신 기반의 스마트 관개 모니터링 시스템

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**Abstract**

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Agriculture is the backbone of the economy of most developing countries. In these countries, agriculture or farming is mostly done manually with little integration of machinery, intelligent systems and data monitoring. Irrigation is an essential process that influences crop production. The fluctuating amount of rainfall per year has led to the adaption of irrigation systems in most farms. This manual type of farming has proved to yield fair results, however, due to the absence of smart sensors monitoring methods and control, it has failed to be a better type of farming and thus leading to low harvests and draining water sources.

In this paper, we introduce an RF (Radio Frequency) based Smart Irrigation Meter System and a water prepayment system in rural areas of Tanzania. Specifically, Ngurudoto area in Arusha region where it will be used as a case study for data collection. The proposed system is hybrid, comprising of both weather data (evapotranspiration) and soil moisture data. The architecture of the system has on−site weather measurement controllers, soil moisture sensors buried on the ground, water flow sensors, solenoid valve, and a prepayment system. These sensors send data to the server through wireless RF based communication architecture, which is suitable for areas where the internet is not reliable and, it is interpreted and decisions and predictions are made on the data by our data analysis algorithm. The decisions made are, when to automatically irrigate a farm and the amount of water and the power needed. Then, the user has to pay first before being supplied with water. All these sensors and water usage are monitored in real time and displaying the information on a custom built graphical user interface. The RF−based smart irrigation monitoring system has both economical and social impact on the developing countries' societies by introducing a convenient and affordable means of Irrigation system and autonomous monitoring.

**Keywords :** Agriculture, Smart Irrigation, Smart Monitoring, Radio Frequency(RF), Anomaly detection, Water Prepayment.
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# Chapter 1. Introduction

The demands of agricultural water irrigation have recently increased due to the exponential population growth worldwide, and Agriculture is currently used around 64% of the available land [1].

According to the UN projections, world population will rise to 9.1 billion in 2050 that signifies food production has to be raised to feed the one third additional mouths. And, the agriculture industry is accountable for fulfilling humans' need for food, energy, and shelter to a great extent. But there are several issues related to traditional methods of agriculture such as excessive wastage of water during irrigation of field, dependency on non-renewable power source, time, money, human resource *etc*. The only solution to all these problems is agriculture modernization that has already started by some of the tech savvy farmers. For the next generation agriculture fields, data collected from sensors would become the fertilizer to grow crops [2].

It is estimated that around 80% of our water reserves are used in agriculture. In the coming future, as population explosion is rather inevitable, depletion of freshwater bodies will take a severe toll on agriculture, which is one of the indispensable lifelines of food security. Maintaining food security would require extensive agricultural monitoring and mapping.

Water management remotely is also a challenging task, especially the management becomes more difficult during the shortage of water, which may otherwise damage the crop.

In most parts of developed countries they still use traditional water canals fed by rivers or streams to irrigation their farms. This approach seems to drain a lot of water from the water sources due to lack of control or feedback on the amount of water needed by the farms. Therefore we propose a solution to these problems by introducing an RF based Smart Irrigation Monitoring System that is capable of providing remote control over the irrigation process wirelessly, real time monitoring of farm, water sources and whole irrigation process. This method would uncover the new ways that tap the full potential of agriculture yield and alleviate all the challenges that hinders the growth of the crop

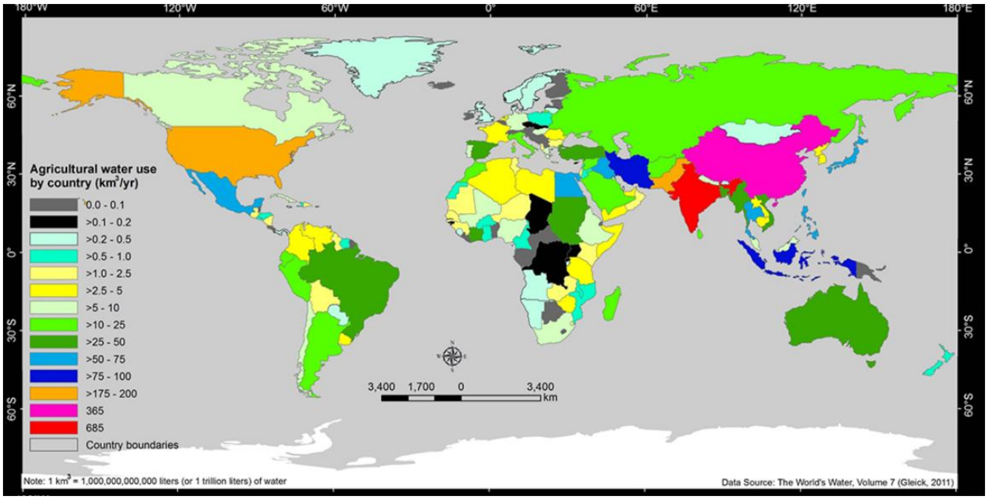


**Figure 1 Water usage in agriculture by country [4]**

# Chapter 2 Background of the study and Literature review

The IoT based automated irrigation system increases the efficiency of cultivation. The moisture sensor is used which observes the plants condition and level of water from distance. To reduce the waste of water and monitor the irrigation system, IoT gets the best results using innovative techniques. Message Queuing Telemetry Transport (MQTT) protocol is used in the system. So, the proposed GSM and IoT based irrigation design is energy saving and also cost effective [5]. However in this only applicable in areas where there is internet connectivity and this would fail in remote areas of developing countries.

Smart Irrigation Decision Support (SIDS) system based on fuzzy logic controller [6] is also developed to calculate the irrigation time according to the soil temperature and the rate of soil moisture reduction so that the soil moisture is maintained and the water utilization is saved. The agricultural farm consists of heterogeneous crops distributed in the farm. One Sensor Node (SN) is placed beside each crop to monitor the agricultural parameters and triggers the output actuators for proper agricultural activities. The agricultural farm consists of heterogeneous crops distributed in the farm. All the measurements received by the sink node are forwarded to the head quarter via the Internet, cellular network or using satellite communication.

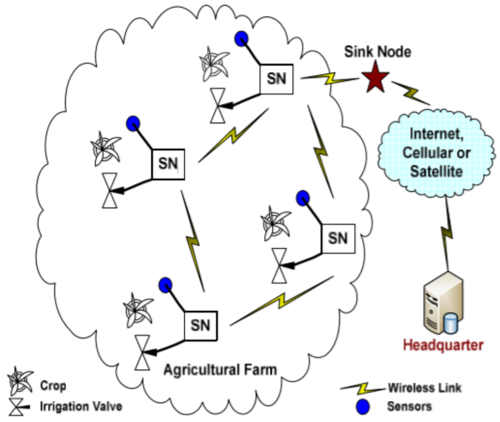


**Figure 2 Smart Irrigation Decision Support (SIDS) system [1]**

Pawar *et al.*, Introduced a smart irrigation technology based on IOT using Raspberry Pi microcontroller board [7]. The system can be used to control the water motor automatically and can also monitor the growth of plant by using webcam. We can watch live streaming of farm on mobile phone using suitable application by using Wi-Fi network. Raspberry Pi is the main heart of the overall system. The system would provide feedback control system which will monitor and control all the activities of plant growth and irrigation system efficiently. This method applies in areas where there is strong internet connectivity and also the cost of surveillance coverage of a large area by camera, therefore this method is limited in its application.

Table 1 Vegetation type, water requirement and irrigation system used for each type [8]

| Plantation type | Water requirement | Irrigation system used | Max daily operation timing for irrigation system |
|---|---|---|---|
| Palm trees | 100−150 Lit/day | Bubbler | 30 Minutes |
| Ornamental trees | 100−150 Lit/day | Drip Irrigation | 2 hours |
| Fruits | − | Drip Irrigation | − |
| Grass | 15 Lit/$m^2$/ day | Sprinkler/Sprays | Between 20 mins – 3hrs |
| | | | Depending on type of sprays and sprinkler |
| Shrubs/Hedges | 25 Lit/day | Drip Irrigation | 2 hours |
| Ground cover, Flowers, Creepers | 15 Lit/day | Drip Irrigation | 2 hours |

The economic analysis shows that the integration of soil moisture sensor isn't viable in large field projects when heterogeneous soils covers large areas. The upfront cost is higher compared to the controlled irrigation system, yet the long term will have larger impact on the plantation growth and water conservation. Moreover, failing to choose the right depth in which moisture is contained and sensor is buried might cause a negative effect. Nevertheless, integrating new technologies in the irrigation system is a way to move smarter and innovative. It can be seen that by the introduction of smart irrigation system into the irrigation practices, it is 25% more effective than traditional irrigation system where as water consumption is lowered and monitored.

Thus, improving the environmental sustainable aspect of the future of landscaping and agriculture in the region. The additional cost that will result in adding the smart irrigation system will have a positive impact in the long term, especially in terms of water conservation and management. Less labor is required on site, and their cost can be reduced [8].

McCready *et al.*, evaluated the effectiveness of smart Irrigation technologies which were Evapotranspiration (ET)-based controllers, soil moisture sensor controllers and a time-based treatment with 2 days of irrigation per week without any type of sensor on turf grass [9]. All irrigation controller programming presented settings that might be used in residential/commercial landscapes. The soil moisture sensor controllers at medium threshold setting resulted in high water savings of 11-53% and good quality turfgrass during all treatment periods. ET controllers resulted in water savings ranging from 25% to 63%. While with a 2 day/week irrigation only had 10% water saving. However, integrating soil moisture sensor and an irrigation frequency pattern will maximize water conservation potential and while maintaining turf grass quality.

Li *et al.*, developed a Precision Agriculture Monitoring System (PAMS) [10]. It is an intelligent system which can monitor the agricultural environments of crops and provide service to farmers. PAMS is based on wireless sensor network (WSN). The Precision Agriculture Monitor System is motivated by the need of monitoring the western region special agriculture products, *e.g.* apple, kiwifruit, salvia miltiorrhiza, melon, tomato and so on, which monitors the surrounding environmental factor *i.e.*, air temperature and humidity, soil temperature and moisture, $CO_2$ concentration, illumination intensity, *etc.*, in different grow period and the content of soil fertilizer and analyses the data to provide excellent environment for crops with human intervention. The Precision Agriculture Monitor System consists of WSN, gateways, and a communication sever. Researchers deployed the nodes in the monitored farmland, which could sense the related environmental information of crops, *e.g.* temperature, humidity, illumination and $CO_2$ concentration, *etc.* After the data collection, nodes would pack the data using the specific protocol and along the multi-hop routing to send the package to the Root node. And then, the Root node transmits the data to gateway.

Upon receiving the data, the gateway extracts the effective information that saved in local flash, at the same time, the gateway sends the data to communications server by GPRS. The communications server handles the data and then stored them into the agriculture database. Then the administrator or user could remote monitor the environmental conditions of monitored farmland or greenhouse by assessing to the database.

The drawback of this system is the cost of establishing GPRS gateways after every root node. In our research we introduce the use of radio frequency modules which collects data from the sensors and can travel more than 5000 m to the data collection center without having an intermediate gateway for communication and thus lowering the cost of the system.

Zografos *et al.*, describes a monitoring system that collects data using a wireless sensor network, and then relays this data through a gateway to a (cloud based) server [11]. At the server the data are stored and analyzed in order to provide the user with useful statistics and alerts as input to this user's decision-making process. The system can act as an early warning system for upcoming threats, a monitoring system constantly reporting on the status of farms or livestock or as a recommendation system for prospective farmers.

It is claimed that such a system is relevant in the network society and that there is sufficient technical knowledge (software and hardware components, standardized network protocols) to render its implementation not only feasible, but also cost effective. A prototype system is presented, demonstrating its functionality for retrieving data from sensors, relaying these data through a gateway and storing and analyzing the data on a server. Subsequently, the results are presented to users via a web interface.

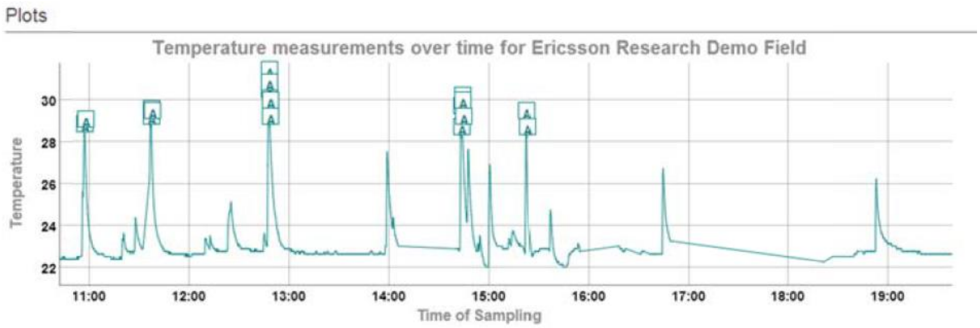


**Figure 3 Real Time data presentation [11]**

A Zigbee based Irrigation system using IoT [12] was discussed. It continuously observes, and maintains the desired soil moisture content through automatic irrigation of the field. The control unit is implemented by using a microcontroller on a PIC platform. This assembly utilizes soil moisture sensors in order to detect the correct moisture level in soil. Therefore, an appropriate quantity of water can be supplied to the land by using this system such over/under irrigation can be avoided. IoT can be utilized to let the farmers be updated continuously about the status of sprinklers. Information from the different sensors like soil sensors, humidity sensors, temperature sensors, PIR sensors is detected and is continuously updated on a webpage and an android app using ZigBee module for the communication which a farmer can verify whether the water sprinklers are on or off at any given time. This system's designed consisting of slave nodes and a master station. The frames are forwarded to the master station via a ZigBee ad-hoc network. The master station contains an embedded fuzzy logic irrigation algorithm. This algorithm can help us to water the plants, grass and trees based on a set of pre-defined rules. The system also has an alert SMS that will be send to a particular mobile when these values have exceeded particular threshold values. The range of the device is also quite long *i.e.*, 15 m-20 m.

Sahu *et al.*, discussed a low cost smart irrigation control system [13]. The objectives were to control the water motor automatically and select the direction of the flow of water in pipe with the help of soil moisture sensor. Finally send the information (operation of the motor and direction of water) of the farm field to the mobile message and g-mail account of the user. The prototype includes number of sensor node placed in different directions of farm field. Each Sensors are integrated with a wireless networking device and the data received by the microcontroller which is on a "Arduino UNO" development board. The Raspberry Pi is used for sending messages through internet correspondence to the microcontroller process.

An integration of IoT with digital image processing and wireless sensor network is also discussed in [14]. Existing systems use LASER network that cannot isolate the animal interference from human interference. The aim is using motion sensors to continuously monitor the output. If some motion is observed in the farm then the webcam is activated and it captures the image. The captured image is compared with the saved image sheet and then it was verified whether the image is of the human or animal. If animal is sensed then the buzzer is on with the message from the GSM module to the owner and email is sent. Moisture level is sensed and then the output is monitored. If the deficiency in water is sensed and then the data from the weather department was analyzed. If there is a possibility of rain during the next 4−5 hours of the operation then the motor for pumping is stopped or else the pump was started and then the irrigation system works. Water flow can also be controlled via the analog input of the soil moisture level. If there is urgent requirement of the irrigation system a reminder via mail is sent to the user for immediate turning on of the dc motor irrigation system remotely via user. A separate website is provided to the user to manually start the irrigation system via the webpage. And all the components are interfaced to the Raspberry Pi.

In most of the countries, the major problem in irrigation of crop is that it requires a lot of human efforts to irrigate a farm also, another major problem is that if one portion of farm needs water then the farmer irrigates the whole farm whether its required or not. The main problem here is that farmers are not able to track which particular portion of farm is actually needs to be irrigated. Globally, the 70% of fresh water is used for agriculture which needs to reduce by avoiding unnecessary irrigation of farm which also help farmers to avoid problems related to over irrigation and less irrigation of crop.

Aggarwal *et al.*, described a smart irrigation system to automate irrigation process using IoT and artificial neural network [15]. The collection of data related to a crop like humidity, soil moisture level, temperature and pH value of soil which will help in many ways for better growth of crop. They created a device made with Arduino and sensors to collect this data and sent to the server for its analysis and after that it analysed with the help of an artificial neural Network model so that the model will be able to generate results with a very high accuracy. Once these results are generated it will be used by the device to trigger a valve which will start or stop the flow of water in the required section of the farm. Finally, the collected data will be available to be checked by a user with the help of Web app and an Android app so that anyone can use it for some research purpose.

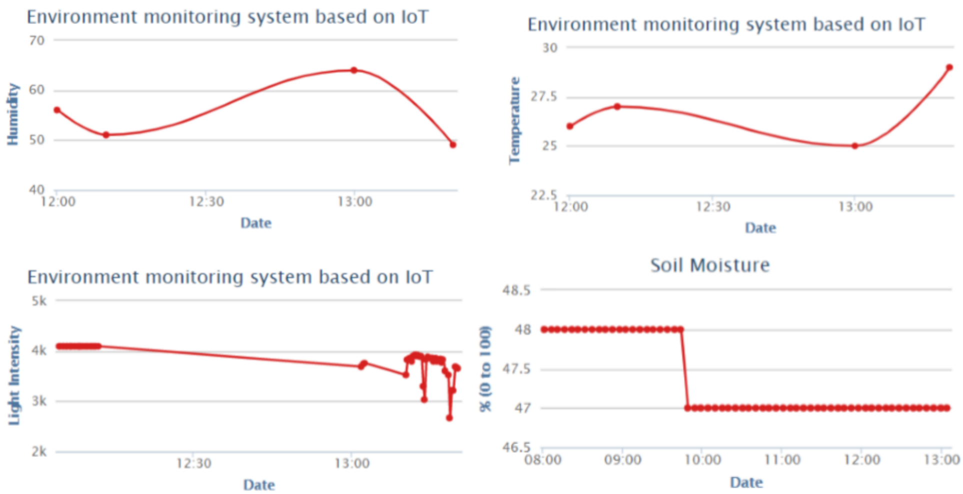


Figure 4 shows the data collected of temperature, humidity, light intensity and soil moisture [15]

A Study on Smart Irrigation System Using IoT for Surveillance of Crop-Field in [16] aims to overcome this challenge the challenge of irrigation in regions with scarcity amount of water/rainfall, they proposed a system which is micro control based and can be operated from remote location through wireless transmission so there is no need to concern about irrigation timing as per crop or soil condition. Sensor is used to take sensor reading of soil like soil moisture, temperature, air moisture and decision making is controlled by user (farmer) by using microcontroller. The data received from sensors are sent to server database using wireless transmission, which is Bluetooth in this case. The irrigation will be automated when the moisture and temperature of the field is reduced. The farmer is notified with the information regarding field condition through mobile periodically. The automated irrigation system implemented was found to be feasible and cost effective for optimizing water resources for agriculture production. This system reduces the water consumption to greater extent. It needs minimal maintenance. The power consumption has been reduced very much. The crop productivity increases and the wastage of crops are very much reduced. The extension work is to make user interface much simpler by just using SMS messages for notifications and to operate the switches. The challenge with this system is shorter communication distance, it cannot be implemented in large farms or transmit data over 15 m.

Khatri *et al.*, explains an artificial intelligence and fuzzy logic as solution implemented in an intelligent drip irrigation system [17]. It optimizes the supply of water to the agricultural crops using fuzzy logic by taking input from soil moisture, humidity and temperature to decide the amount of water irrigated on a farm by controlling the opening degree of a valve.

The application of agriculture networking technology specifically in modern irrigation is also seen in [18] where the automation of irrigation system using IoT is discussed. In this research various sensors like temperature, humidity, soil moisture sensors which senses the various parameters of the soil and based on soil moisture value, the land gets automatically irrigated by on and off of the motor. These sensed parameters and motor status are sent by a wireless sensor network for real-time sensing and displayed on user android application.

Recently, the agriculture domain has incorporated wireless sensor networks (WSNs) to support its operations. Following this, Precision Agriculture (PA) started to flourish. Precision Agriculture is the science of precise understanding, estimating and evaluating crops condition with the aim of determining the proper use of fertilizer and the real needs of irrigation both through sowing and harvesting period. Micrometeorological parameters like air temperature, air humidity, wind speed and direction, precipitation, as well as other weather data around and in the field of the deployment (either it is an open field or a greenhouse) are mostly collected.

As for the network issues, Radio Frequency (RF) is the most suitable form of wireless communication with the ZigBee protocol based on the IEEE 802.15.4 standard to be the most common used standard. RF is used for node-to-node and node-to-base station (BS) short distant communication. It is less expensive and simplest than the Bluetooth technology, and all these characteristics made it widely used. Wi−Fi is another way of wireless, long distant communication usually between the BS and a remote PC server [19].

Cellular communication is quite popular in agricultural WSNs, as the deployment areas in most cases, have the proper infrastructure GSM/GPRS. In some deployments Ethernet and RS232 links are also being used. There may be a need to strengthen the signal, so some repeaters may need to deploy. This depends on the distance between the sensor network and the base−station as well as the base−station and the server.

In addition, end users may connect directly with the server through Internet using web browsers as well as Graphical User Interface (GUI) tools for visualization of the data. Also, they may connect directly to the WSN. The connection between end users and server usually is established through GSM/GPRS or standard Ethernet depending on the communication infrastructure around the deployment area. The sensing and sending data packets must be time−based and the sensing time interval usually depends on the crop type. However, according to existing deployments and to professional farmers, every 5 minutes is sufficient [19−20].

Another challenge is the need to identify the tools used to acquire the generated data in order to be analysed and compared. The amount of data required to perform these actions is enormous. If this data is not organized and processed, it will become meaningless. Therefore, some of the difficulties in the adoption of precision agriculture are related to data handling and data processing as well as the significant investment cost in hardware solutions to save this large amount of data. It is also very important to provide a system that is economically viable and practical for a single farmer as well as to a big farming company.

The researchers proposed three technologies which include remote sensing (RS), geographical information system (GIS) and wireless sensor networks (WSN). The soil moisture sampling frequency is higher during irrigation periods because it is desirable to have more feedback information during these periods, and so the soil moisture measurements should arrive at the cloud platform faster than in periods of non−irrigation. It is crucial that the amount of time the irrigation system is turned on must be minimized [21].

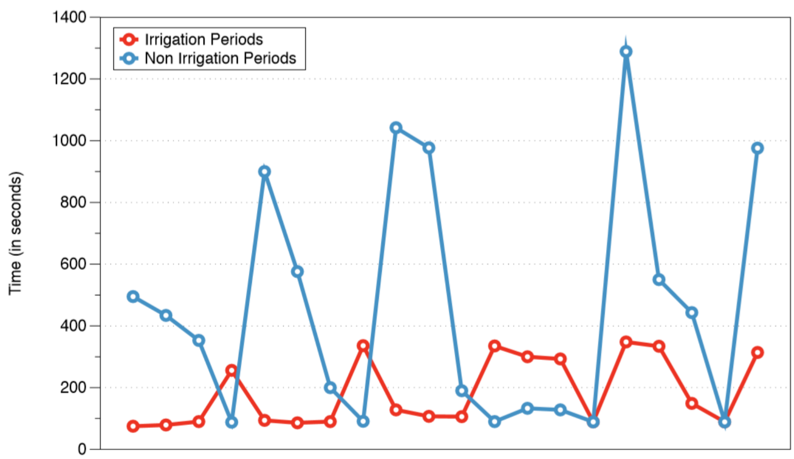


**Figure 5 A comparison of communication times between periods of irrigation and non−irrigation (in seconds) [21]**

In [22] research work, they have proposed and designed a solar−powered smart drip irrigation system for remote hilly areas. This system consists of a low−cost Raspberry Pi 3 board, which has inbuilt Bluetooth and Wi−Fi interface capabilities. This acts as a base station and provides an interface between the farmer and farms. Because of the remote hilly terrain, the fields are fragmented with small land-holdings. So, it is insufficient to install only one Arduino UNO R3 board, which are further connected with sensors and act as a remote station.

Therefore, they connected three Arduino UNO R3 board at the remote station. All boards communicate, share data, and pass information to the base station computer (Raspberry Pi 3). According to the present condition, it will check the status of the condition and accordingly will send processing signals to the remote stations. The base station can be also monitored and controlled through android application by the farmer. He or she can control and set different modes for smart irrigation.

This system optimizes the consumption of water by minimizing wastage, increase the production and quality of the crops, as well as in reducing the extra manpower efforts, water requirement, and fertilizer requirement.

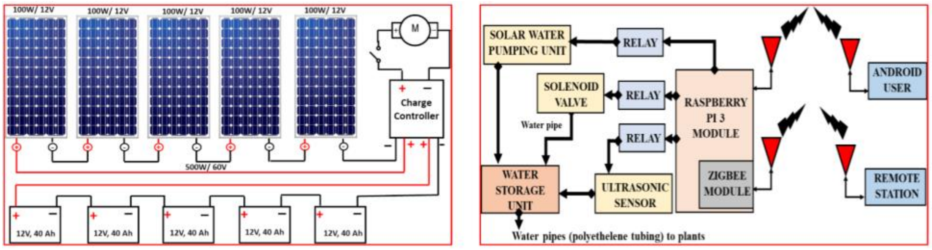


Figure 6 A 500W/60V solar panel on the left and Block diagram of Base station on the right [22]

## 1.1. Purpose of Research

In this research, a RF based smart irrigation monitoring system utilized in remote areas with no internet using RF signals and smart sensors is proposed. The WSN particularly using RF signal will be implemented in this thesis project for it is cheaper than the other two.

The Wireless Communication modules enable the sensors to send data in real-time from the farms located in remote areas in developing countries to a data collecting center where the internet is available for cloud storage.

In these farms, Irrigation schemes are still traditional and rely heavily on surface water sources. Many irrigation systems are inefficient and lose about 60% of the water that is transported through evaporation, leakage and farmers unlawfully reallocating irrigation channels to their farms (theft).

Figure 7 Traditional irrigation canals on the slopes of Mt. Kilimanjaro [25]

The challenge of having real-time monitoring and remote control in areas where internet connection is not available and having unreliable electricity, the crucial need for water management from natural water sources, the lack of autonomous monitoring and control  led to the design of smart irrigation meter powered by solar energy which is affordable, convenient and practical which enables farmers to pay for the irrigation water according to their farm needs and control the whole process of irrigation and payment wirelessly.

Target area: Ngurdoto Tanzania.

Location: data collection center: −3.322834, 36.909473 and Irrigation site: −3.325828, 36.923081


Figure 8  A map showing the location of irrigation site and data collection center in Tanzania

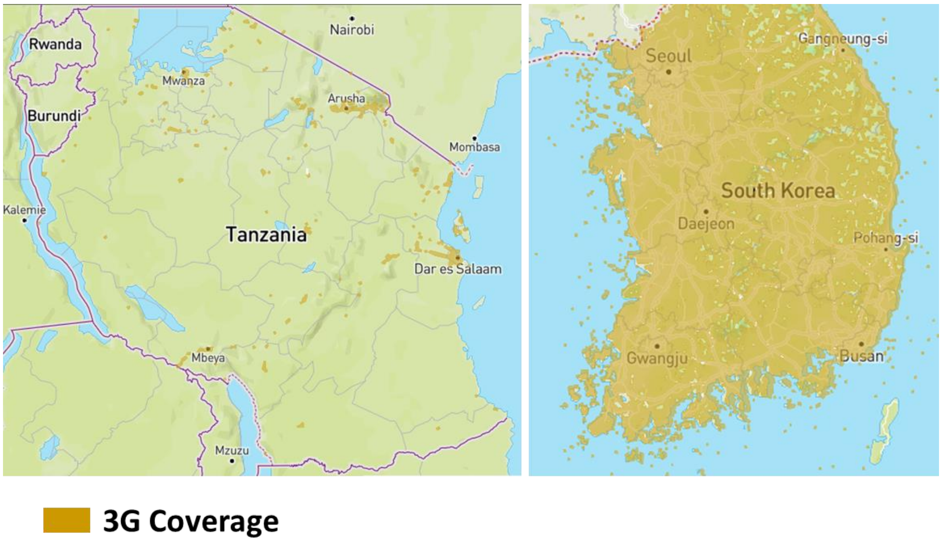


Figure 9 3G map coverage of Tanzania in comparison with South Korea.

From figure 9 above, we can observe the 3G network coverage of Tanzania in comparison with South Korea. The use of 3G network in Tanzania is only in major cities and in rural areas the signals is either so low or unavailable. All this contributes to the fact that 2G network system might be better in sending data in rural areas of Tanzania as compared to the use of internet.

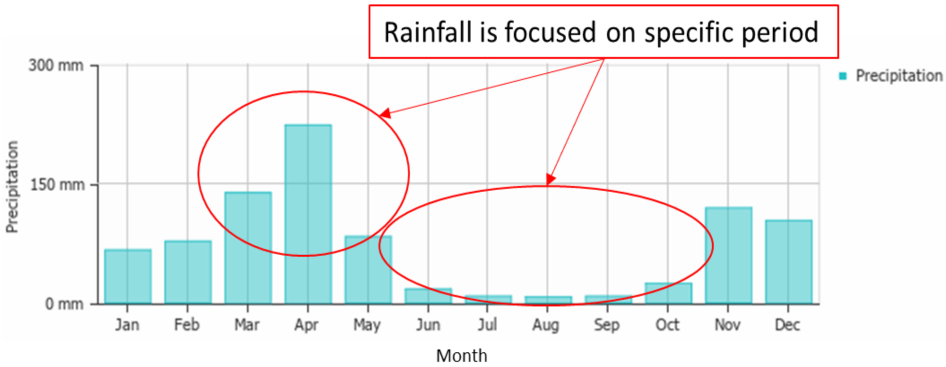


Figure 10 Average monthly precipitation over the year of Arusha, Tanzania [23]

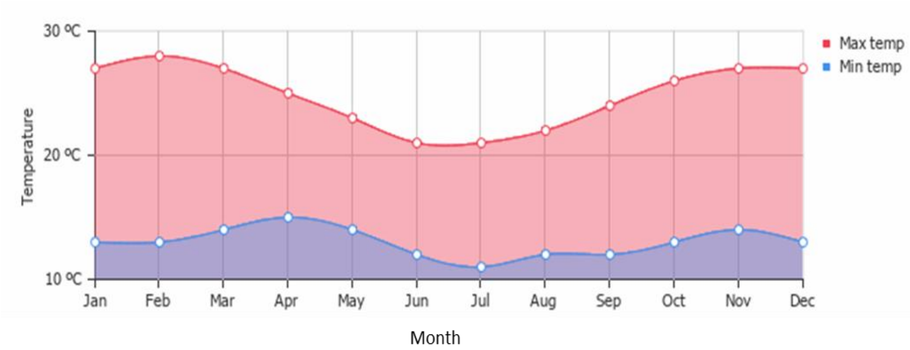


Figure 11  Average min/max temperature over the year of Arusha, Tanzania [23]

# Chapter 3. Requirements and System Design

## 3.1. Key Components

### 3.1.1. System Architecture

The RF based Smart Irrigation monitoring system is made up of a combination of Smart Irrigation Meter the RF wireless communication architecture and the pre−paid system.

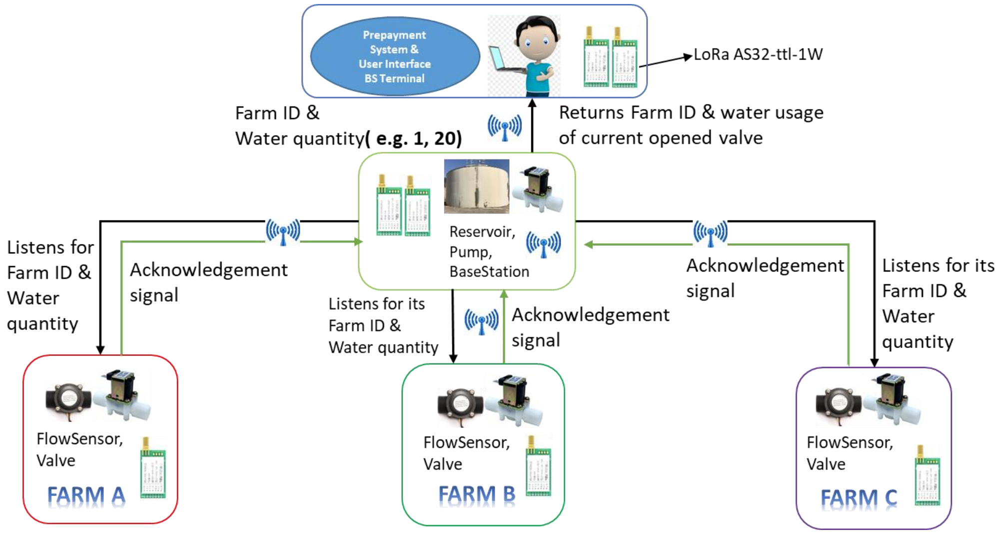


Figure 12 Wireless Smart Irrigation architecture

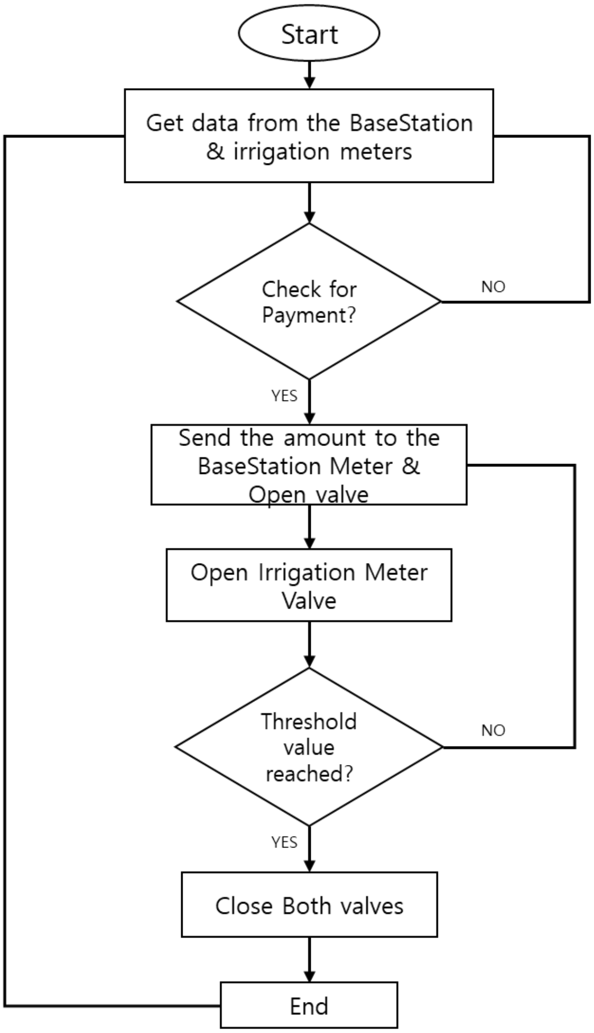


Figure 13 Flow Chart

### 3.1.2. The Smart Irrigation Meter

The working principle is to continuously monitor the amount of water flow to the farm, enable remote control on and off of valve, make a backup monitoring file to an memory card, enable real-time monitoring of sensors and connecting to the base-station or data collecting center through the wireless RF based communication module connected to it.

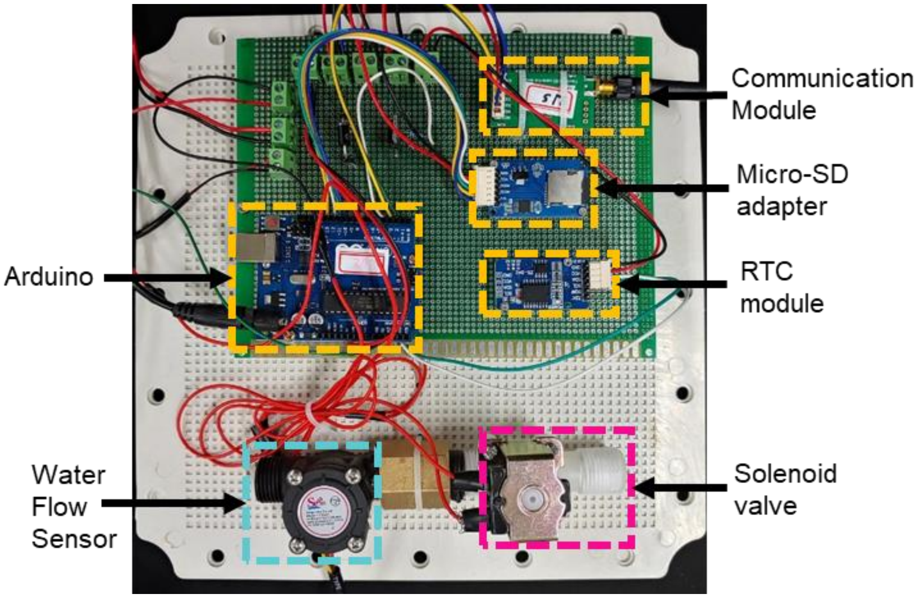


Figure 14　Smart Irrigation Meter Prototype developed at Seoul National University

### 3.1.2. Parts of Smart Irrigation Meter

a) Arduino Uno R3 board.

Arduino Uno board (Arduino, Italy) is based on ATmega328 micro-controller chip. This micro-controller is 8 bit with 16 MHz clock speed. It contains 32 kB Flash, 1kB EEPROM, and 2 kB SRAM. It has 14 digital I/O Pins, out of which 6 pins are assigned for PWM output and 6 pins are dedicated for analog input pins. It has a USB interface, a 2 × 3 in-circuit serial programming (ICSP) header, and a reset switch.

b) Communication Module – AS32−ttl−1W

The AS32−TTL−1W (Semtech, USA) is a 1 W industrial−grade wireless data transmission module with high stability working on 433 MHz frequency. The module uses SX1278 main chip, LoRa (Long Range) spread spectrum transmission, TTL level output, compatible with 3.3 V and 5 V IO port voltage. LoRa spread spectrum makes the module have a longer communication distance. AS32 operating frequency is 410 MHz to 441 MHz with a total of 32 channels. Its interface is UART, Power is 30 dBm (1 W), RF connector is SMA (SubMiniature version A) and communication distance is up to 8000 m.

c) Micro SD card Reader

Support Micro SD Card, Micro SDHC card (high−speed card). The level conversion circuit board that can interface level is 5 V or 3.3 V. The power supply is 4.5 V ~ 5.5 V, 3.3 V voltage regulator circuit board.

The communication interface is a standard SPI interface 4 x M2 positioning screw holes for easy installation. Control Interface : a total of six pins (GND, VCC, MISO, MOSI , SCK, CS), GND is ground, VCC is the power supply, MISO, MOSI, SCK is the SPI bus, CS is a chip selection signal pins 3.3 V voltage regulator circuit : LDO regulator for the 3.3 V output level converter chip, Micro SD card power supply. Level conversion circuit: Micro SD card to signal direction into a 3.3 V, MicroSD card interfaces to control the direction of the MISO signal is also converted into 3.3 V, general AVR microcontroller system can read the signal.

d) RTC Module

The DS3231 is a low-cost, extremely accurate I2C real-time clock (RTC) with an integrated temperature compensated crystal oscillator (TCXO) and crystal. The device incorporates a battery input, and maintains accurate timekeeping when main power to the device is interrupted. The RTC maintains seconds, minutes, hours, day, date, month, and year information. The date at the end of the month is automatically adjusted for months with fewer than 31 days, including corrections for leap year.

The clock operates in either the 24-hour or 12-hour format with an AM/PM indicator. Two programmable time-of-day alarms and a programmable square-wave output are provided. Address and data are transferred serially through an I2C bidirectional bus.

e) Solenoid valve

12 VDC 2 inch electric solenoid water and air valve switch (normally closed) Controls the flow of fluid + air and act as a valve between high-pressure water or any fluid. Rated current is 0.6 A, power consumption is 40 W. Pressure range is 0 to 90 Psi.

f) Water Flow Sensor

This is a 2 inch water flow sensor based on the principle of hall-effect. It has a flow range of up to 200 L/Min ±5%. Maximum operating current is 15 mA, Operating temperature up to 80℃ with water pressure of 1.75 MPa. Output waveform is a square wave output pulse signal.

### 3.1.3. The pre-paid system and the monitoring device

The pre–payment system consists of a platform where a farmer or user can pay for the irrigation water using an SMS 2G system and then the payment data will be interpreted by the Arduino and sent wirelessly to the water reservoir meter to release the equivalent amount of water paid. Once the flow sensor records the total amount of water irrigated is equal to the intended amount of water paid it will shut off the water automatically.

In the prepayment board also, there is an Arduino MKR ZERO which is responsible for data logging, sending payment data, receiving data from the smart irrigation meter and pass the data to the Arduino MKR ZERO it is respectively named as the monitoring device.

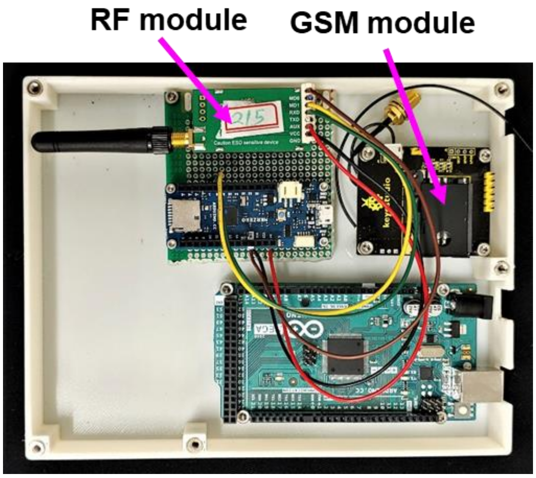


Figure 15 The pre–paid system with communication module developed at Seoul National University

### 3.2. The Monitoring Application and Cloud Server.

A windows application was developed for real−time monitoring of the Smart Irrigation Meter and the Prepayment System. Features of the application are: Serial Port Communication the Arduino Uno/MKR ZERO, Port control, data windows for both water payment and Irrigation meter data, remote On/Off turning of the water valve and pump, SQL connection to the database for data storage, User and irrigation data protection by password encryption, ability to save data to local folder, Real−time update of data from the field sensors, Back and sync connection to the cloud server, easy to use interface and robust design.

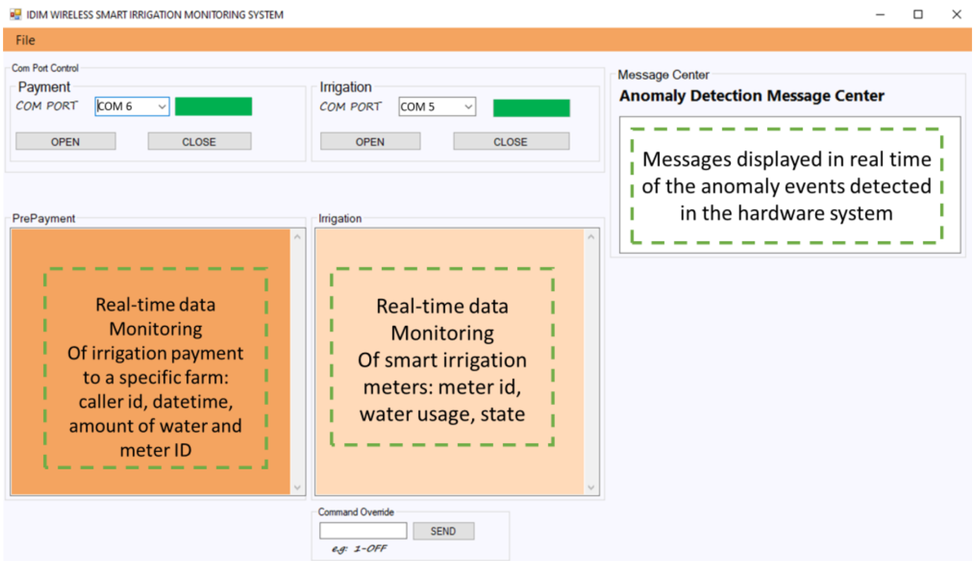


Figure 16 Monitoring Page from the GUI

After Login in the Next page we can the database page which consists of client's table storing the ID, name and contact. Then there is the smart irrigation monitoring table which stores the timestamp, ID, amount of water paid and total liters values from the irrigation meter and prepayment system.

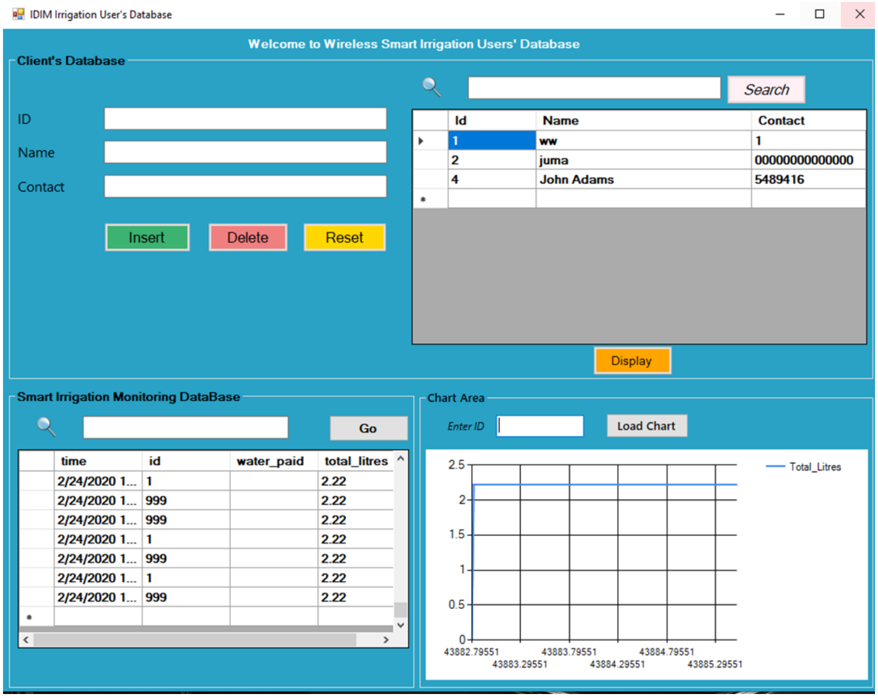


Figure 17 database and chart display page

The incoming data into the monitoring application is can simultaneously be stored in the local file in .txt format and then synchronized to the google drive for storage and therefore can be accessed anywhere in the world. The data saved in the google drive is updated automatically when the timestamp changes or when there is new data incoming.

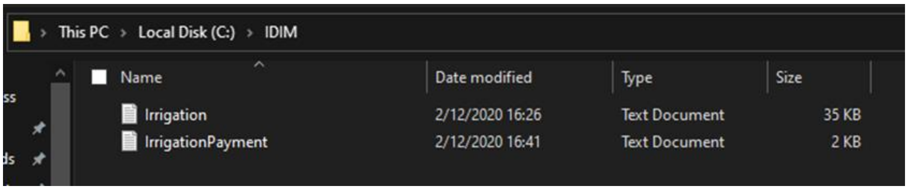


Figure 18 Local files to be synced to the google drive cloud storage

# Chapter 4. Experiment Setup

## 4.1. Testing Location

The RF based Smart Irrigation Monitoring system experimental test was setup in a farm in Hadong Province in South Korea. Location coordinates: 35°00'43.5"N 127°53'16.2"E. It is about 285km from Seoul, South Korea and data analysis from the google drive cloud storage is performed.

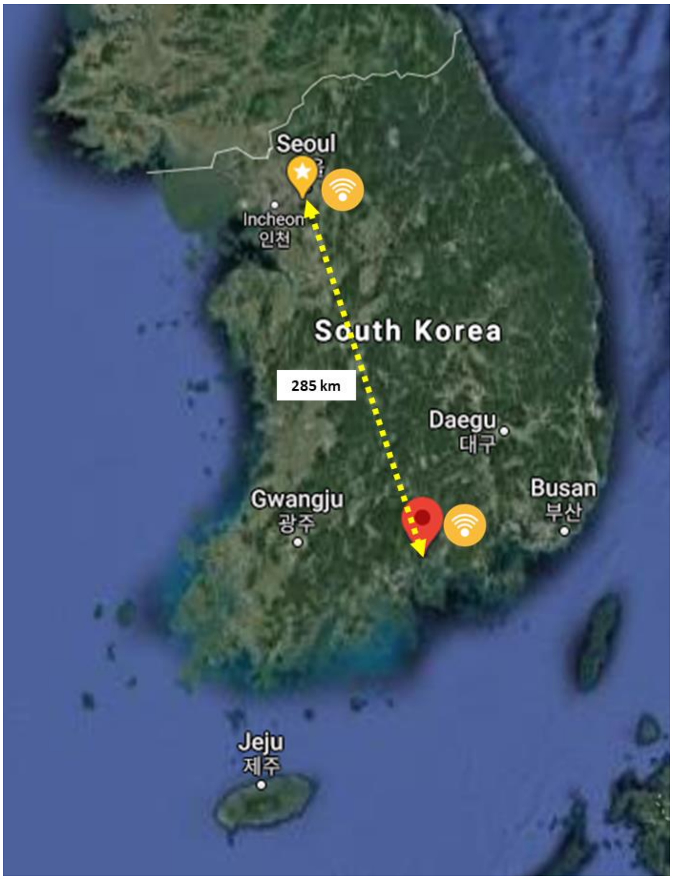


Figure 19　A map showing the distance between Seoul and Hadong

## 4.2. Hardware & Software Setup

The hardware setup consisted of two smart irrigation meters, one BaseStation, a prepayment system, one BaseStation terminal. The devices were powered using solar energy. We setup a charge controller rated at 30 A, to which we connected two 150 W solar panels respectively to feed energy into a 12 V 12 Ah battery which was then connected to a 1000 W 12 VDC to 220 VAC inverter. A 12 V water pump was connected to the water reservoir which supplied water from the Base-Station (BS) smart irrigation meter into the other smart irrigation meter for the farm. The size of the farm was about 70 m².

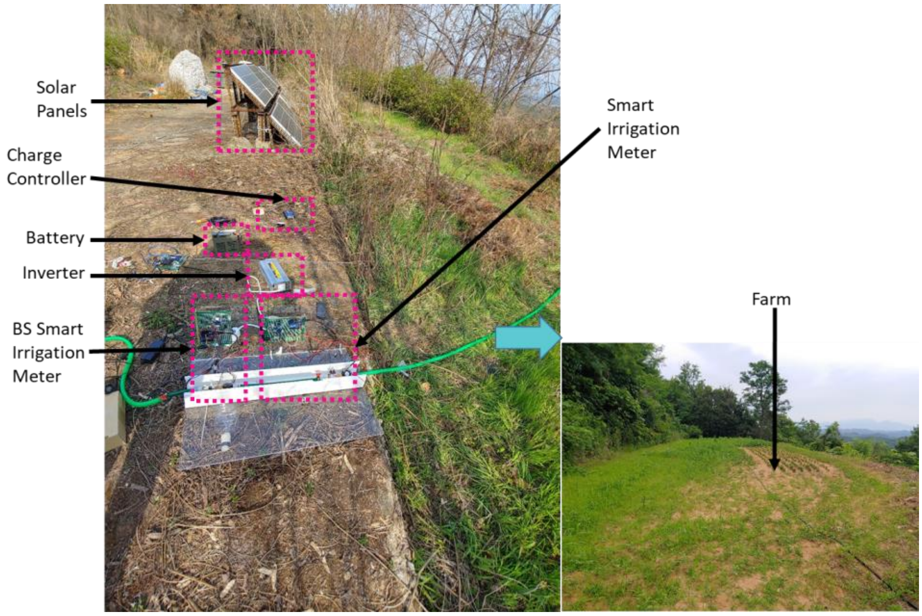


Figure 20  Power Source & Smart Irrigation meter setup

We set up three testing areas, first point is the data collection center which is about 85 m from the irrigation site, and the second point is the cemetery area about 105 m from the irrigation site and about 205 m from the data collection center. We successfully received the data from the irrigation site to the two testing sites and also payment of water for irrigation was successful. This communication of between all three points was through RF wireless signal as the area has no internet connectivity. Only the data collection center has a Wi-Fi connection so we can synchronize our data to the google drive cloud storage.

Coordinates for the map are;

1. Data collection center: 35°00'41.4"N 127°53'17.7"E.
2. Irrigation site: 35°00'43.5"N 127°53'16.2"E.
3. Cemetery: 35.0126057, 127.8868546.

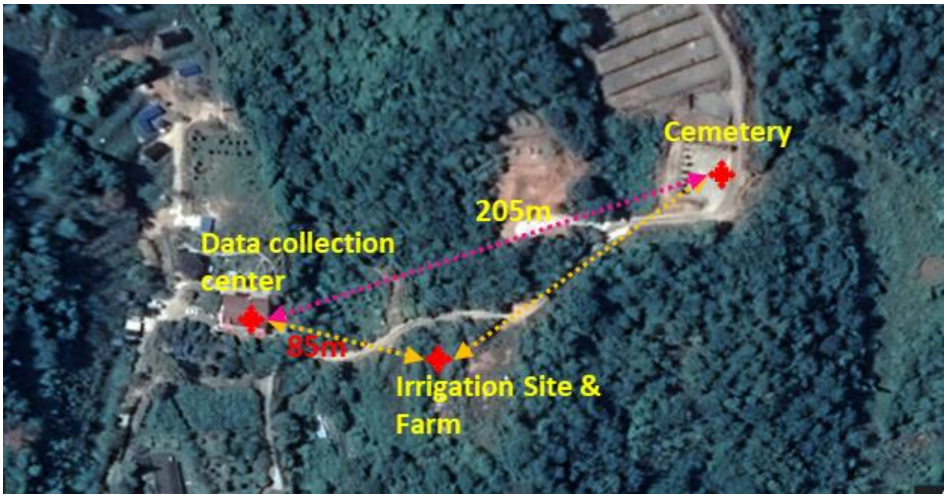


Figure 21 A map showing RF wireless connection route

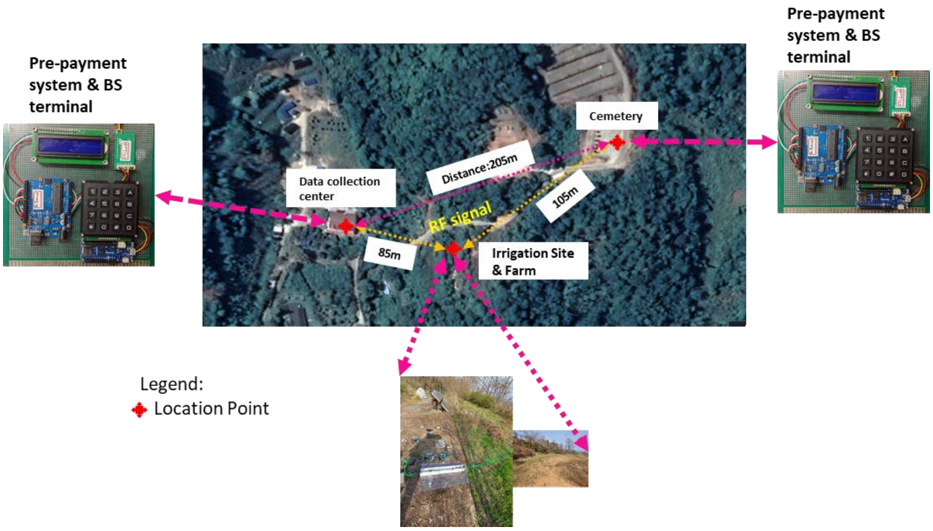


Figure 22 Map with complete description of the Experiment setup

The software setup part included the Monitoring application which received the incoming data through a serial port connected to the Arduino MKR ZERO. In this Monitoring application we could get payment data and smart irrigation data in real time. Then these data would then be stored in the database and local folder in the computer. Finally, the data is synchronized to a folder in the google drive so it can be accessed anywhere in the world.

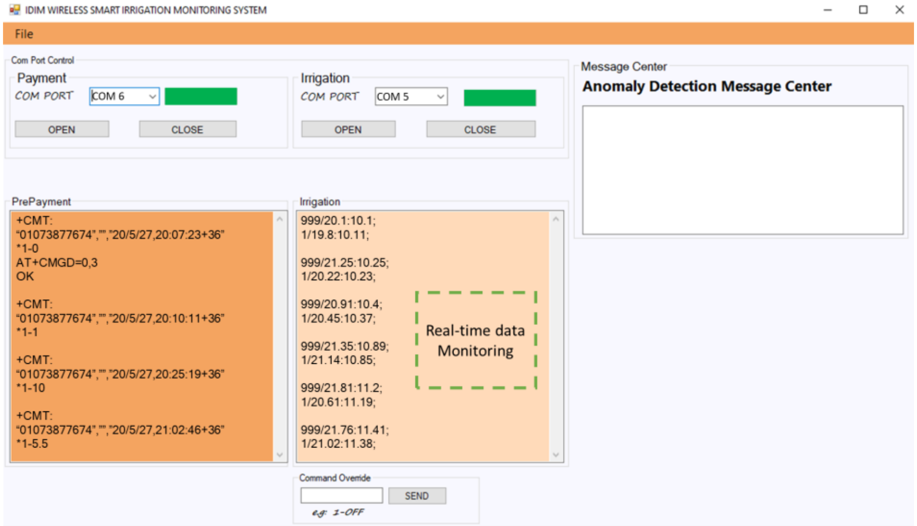


Figure 23 Data monitoring in real-time

The data received was from two smart irrigation meters with ID 1 and 999 respectively.

The data from is: 1/0.00:0.00 which means 1 is ID and the second part which reads 0.00 is the rate of flow of water and the third part after the colon is the total amount of water measured passing through the water flow meter.

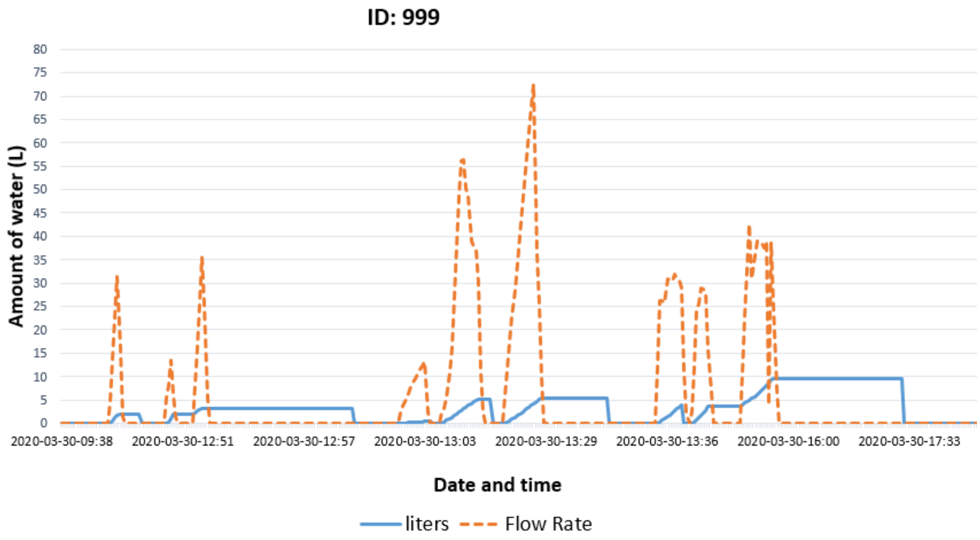


Figure 24 Data from BS smart irrigation meter

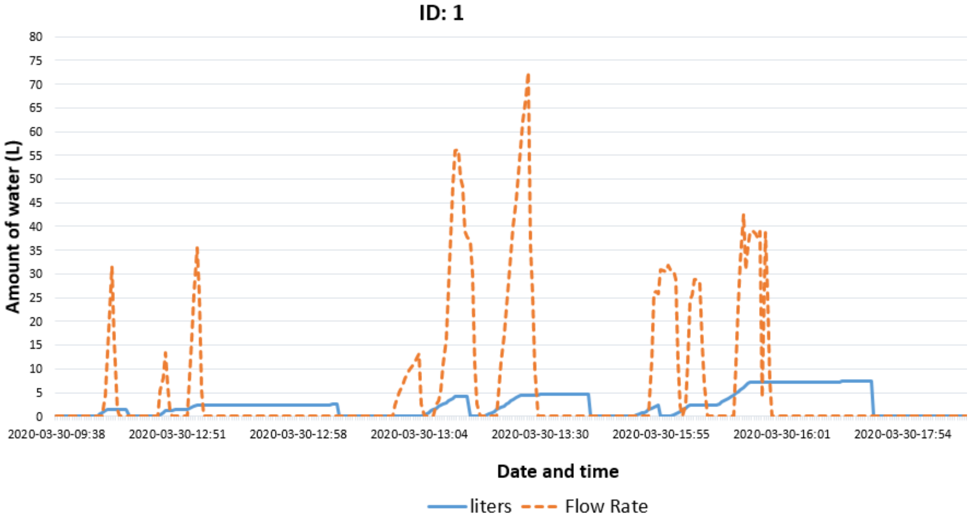


Figure 25 Data from smart irrigation meter from the farm

From the graph it can be seen that the amount of water from the BS smart meter and the Farm smart meter was almost perfect related. However, the base station smart irrigation meter recorded more liters used than the farm meter due to the loss happening in-between the two meters. The deviation is caused by the distance between the two meters and the pressure of water after the BS meter turn OFF its valve.

# Chapter 5 Results and Analysis

## 5.1 Optimization and anomaly detection algorithm

Having a smart system means applying methods and models which will be able to achieve the automation of specific tasks relating to the parameters being monitored and also detecting and rectifying anomalies which may arise as a result of internal and external factors. Internal factors may include faulty hardware, accuracy of measurement, data acquisition and being able to satisfy the primary goal of the smart system in an efficient and convenient way. External factors may include hardware or component theft, lack of resources to be monitored or resources needed to achieve the goal of the smart system. In this work two machine learning models are applied to achieve efficient output and the overall concept of automation.

#### 5.1.1 Dynamic Regression Model

In statistics, time series models can be divided into two groups:

- Auto-projective time series models, which are models that involve only the time series to be forecasted (*e.g.* ARMA models) [24].

- Dynamic regression models, which are models that may involve the time series to be forecasted and the history of another time series as well [24].

Dynamic regression model was chosen in this work to predict the amount/quantity of water needed, *i.e.*, the Demand cycle. It is crucial to know beforehand the amount of water needed by a farm before irrigating it so as to avoid exhausting our water sources and also to minimize the cost of irrigation in terms of resources and time.

The advantage of dynamic model over other models are: easy to apply, it does not entail complicated data prepossessing/ prewhitening to remove outliers, can be applied to independent sequences and also can be applied to the combination of multiple forecasts[24].

The model has dependent variable, *i.e.*, Water quantity and independent variables, *i.e.*, Flow rate, weather data (temperature *etc.*).

For this the Evapotranspiration rate (ET), Moisture Deviation (MD) of the soil finally yielded the Quantity of water needed (QW).

At 20℃ about 2.45 MJ per $m^2$ is able to vaporize 0.001 m or 1 mm of water.

$$ET = 0.0023Ra\ (T_{mean}+17.8) * TD^{\wedge 2}\ kg/m^2 day \text{ or mm/day.} \quad \text{Eq (1).}$$

where ET is Evapotranspiration rate, Ra is Solar Radiation in $W/m^2$, $T_{mean}$ is the mean air temperature, and TD is the air temperature difference.

$$QW\ (needed) = SMC*ET\ (kg/m^2 day). \quad \text{Eq (2).}$$

SMC or MD is given by the difference between previous soil Moisture and the current soil moisture content.

These variable were calculated under the formula:

$$Y = B_0 + B_1X_1 + B_2X_2 + \cdots B_p X_p + \in(error\ term). \qquad \text{Eq (3).}$$

which represents dynamic regression.

The performance of this model yielded better results and higher accuracy than linear regression.

#### 5.1.2 Naïve classifier algorithm for anomaly detection.

Naïve Bayes theorem calculates the conditional probability of the occurrence of an event based on prior knowledge of conditions that might be related to the event. It gives us the conditional probability of event A, given that event B has occurred.

The advantages of naïve method over other machine learning models are: it is simple and easy to implement, it does not require as much training data, can handle both continuous and discreet data, it is highly scalable with the number of predictors and data points, it is fast can be used to make real-time predictions and it is not sensitive to irrelevant features. With this understanding we are able to classify different occurrences in the RF based smart irrigation monitoring system. We are able to remotely monitor the health, performance and status of each device employed in the system. We can detect device and water theft at different stages of the system. The scenario of water theft can happen in between the water reservoir and the irrigation site and between the water source pumping site and the reservoir site.

We detect the changes in flow rate from the BS smart irrigation meter to the smart irrigation meter at the corresponding farm, the water pump power characteristics and classify these patterns according to their respective interpretation.

Here, we introduce an adaptive anomaly threshold $h$, which will be used to classify observations into different patterns with aim to identify anomalies in our system from real time data monitoring. The algorithm flow can be seen in figure 26.

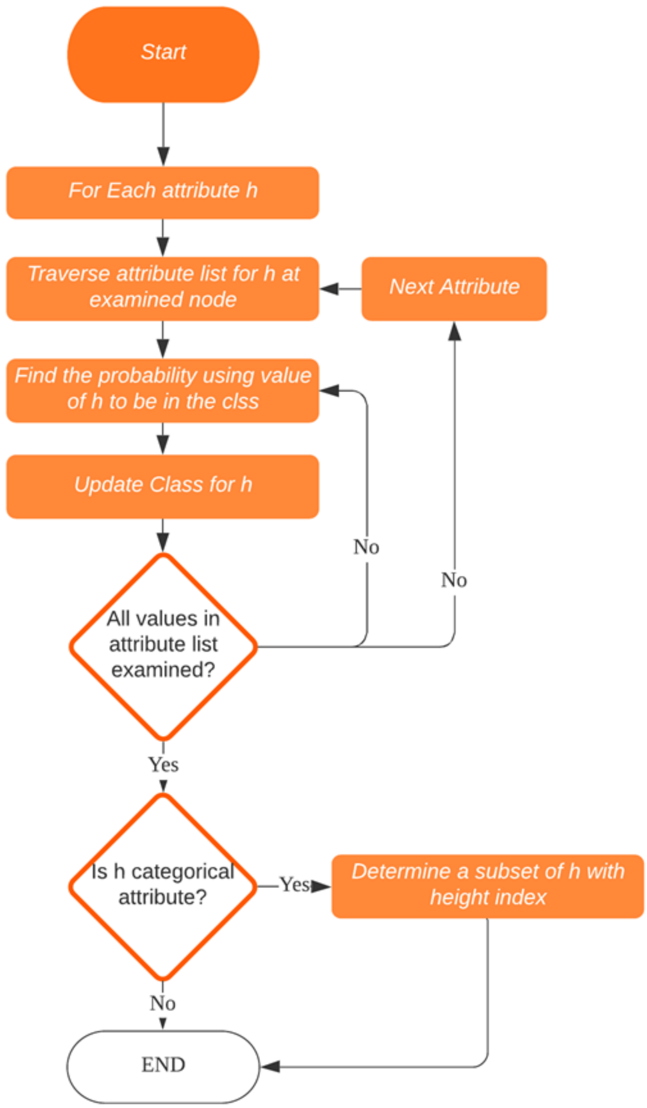


Figure 26 Flow chart of Anomaly detector.

Then the recurring observation with values outside the interval given by:

*[Mean – hourly standard deviation, Mean + hourly Standard deviation]*

These observations are treated as anomalies, where threshold *h*, is given beforehand.

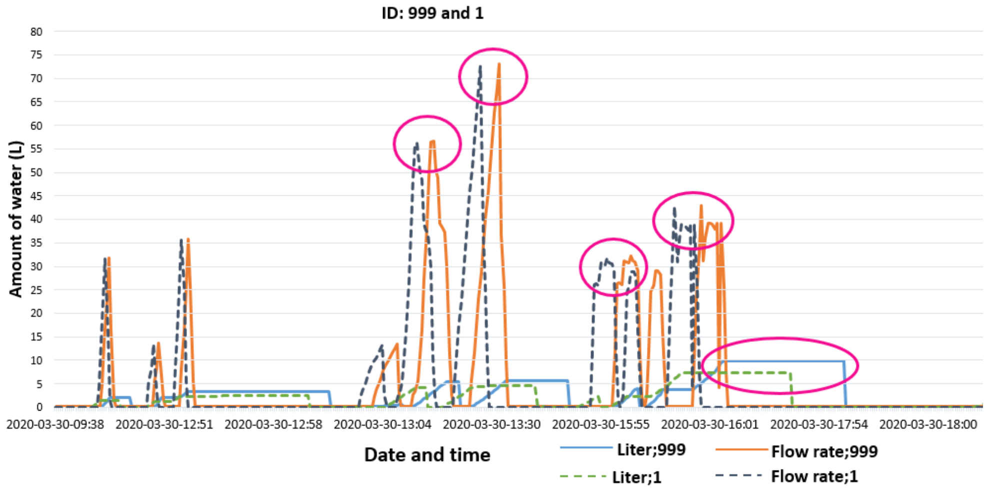


Figure 27  A graph showing mean deviation flow rate of two smart irrigation meter

From figure 27, we can observe and classify the deviation of total amount of water in liters and flow rate between the two smart irrigation meters and this deviation is classified as a normal occurrence due to the distance between the two smart irrigation meters. The pressure inside the pipe changed because of absence of water pump in between the two smart irrigation meters.

The anomaly detector is also used to monitor the water pump remotely. In figures 28 and 29, we see the pattern of current when the water pump is under normal pumping conditions and when the water pump is under abnormal conditions precisely when there is absence of water to pump. Here, the power usage of the pump is updated every five minutes at a sampling rate of 4 Hz by auto switching the pump for 5 seconds and finally three classification are made:

- Water pump failure.

- Water absence therefore the water pump is pumping air instead of water.
- The water pump is stolen.

The water pump ratings are 180 W and 12 V deep well pump. The normal threshold working current for the water is between 6~8 A and this is classified by our algorithm as normal. The abnormal threshold to indicate low water level in between 16~18.5 A. When the current feedback indicates 0 A it is classified as no current which means the water pump is non responsive or stolen.

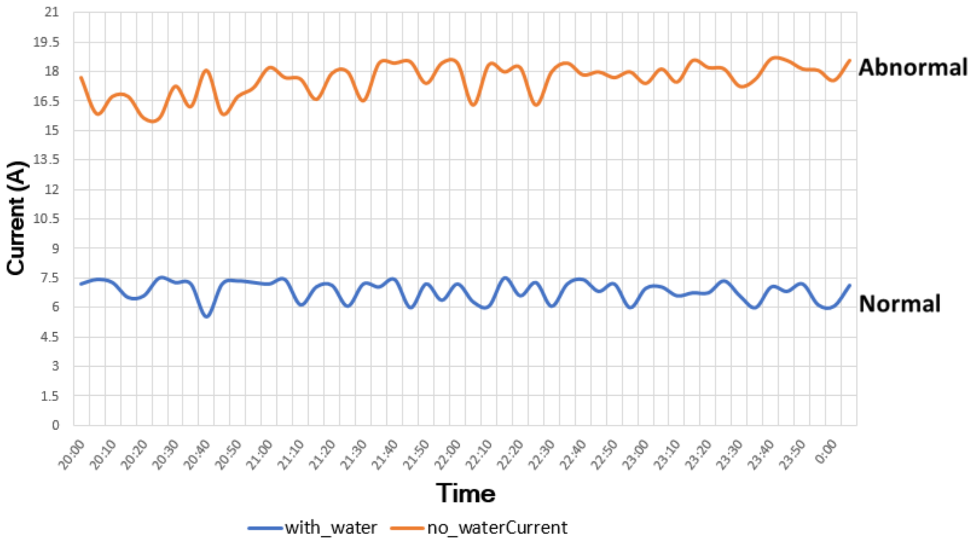


**Figure 28 Water pump power monitoring, classifying normal and abnormal water pump operation.**

The results of the classification are displayed in the monitoring application for immediate action as seen in figure 30.

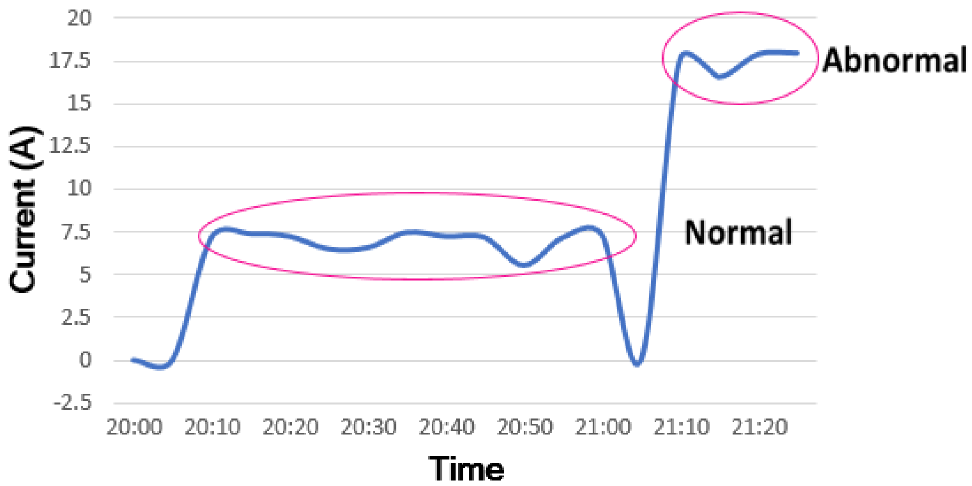


Figure 29 Water Pump normal and abnormal responses

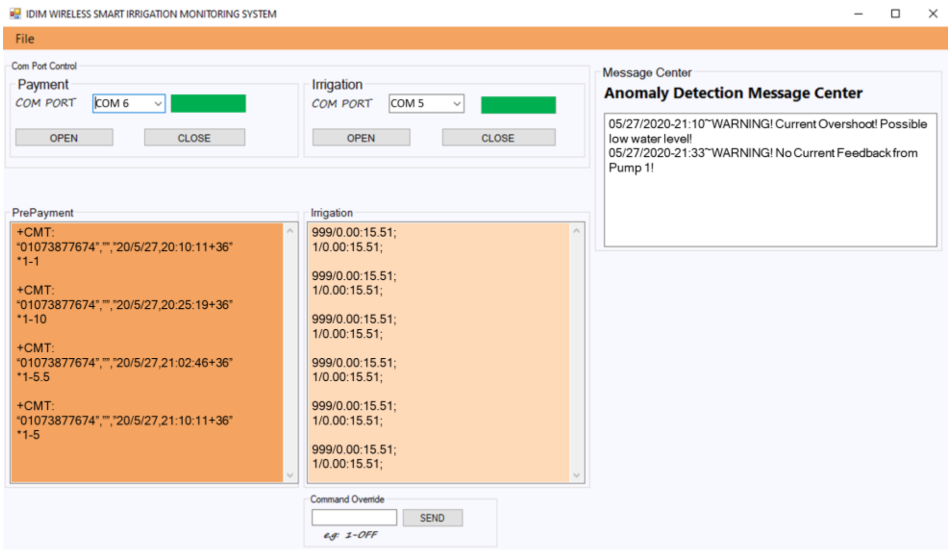


Figure 30 Warning displayed on GUI from the classifier.

# Chapter 6. Conclusion

This work presents a standalone RF−based smart irrigation meter with the ability to autonomously control its operations and anomaly detection framework for accuracy and robustness of the system.

With the results of this work we can cover areas of existing real−time monitoring models which cover only internet accessible areas. (*E.g.*, they use the internet, Wi−Fi, ZigBee, *etc.*) Using radio frequency which can transmit data up to 8000 m.

Therefore, the data collected from the sensors to the base stations do not consider improved energy to cost efficiency. Many authors did not extend their research to the modern payment system, which is reliable and efficient; the focus is directed at the irrigation technology.

A research gap is also seen in anomaly detection algorithms *e.g.*, theft, flow control, hardware malfunction in the field, resource availability detection; many authors are focused on the irrigation process.

We hope with this research, developing countries can tackle problems related to irrigation which include:

- Inadequate use of proper technical equipment.
- Poor effective and sustainable management of irrigation systems.
- In sub−Saharan Africa, irrigated areas are 2.5 times more productive than rain−fed agricultural productivity.
- In developing countries, many irrigation systems are

inefficient and lose about 60% of the water that is transported through evaporation, leakage, and farmers unlawfully reallocating irrigation channels to their farms (theft).

- Traditional water intake from rivers for irrigation has led to the drying up of rivers.
- Another problem is the lack of monitoring and control over the quantity of water that is used for irrigation and as well the lack of efficient water management.

Therefore, this work provides farmers and farm owners in developing countries a large scale smart irrigation monitoring systems at low costs and with minimum human intervention.

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# 초 록

## 무선 통신 기반의 스마트 관개 모니터링 시스템

농업은 개발 도상국들의 경제적 중추임에도 불구하고 대부분의 개발 도상국에서는 자동화된 장비나 데이터 모니터링 등의 지능형 시스템이 거의 적용되지 못한 상태에서 인력에 의해 농업의 모든 과정을 수행하고 있다. 관개는 농작물의 생산성에 결정적 영향을 미치는 필수적인 농업 공정중 하나로서, 연중 강우량의 변동에 대한 대응을 위하여 대부분의 농촌지역에는 농업용수 관개 시스템의 구축을 위해 노력하고 있다. 하지만, 이러한 인력에 의한 농업 방법에서의 관개 시스템은 스마트 센서를 이용한 모니터링 및 제어 등의 기술적 요소가 적용되지 못하여 효율적인 수자원의 활용이 제한되고 이로 인해 농작물의 생산성 또한 낮은 실정이다.

본 논문에서는 개발 도상국의 농촌 지역에서 적용 가능한 무선통신 (RF: Radio Frequency) 기반의 스마트 관개 모니터링 시스템 및 요금 선불 시스템을 제안한다. 본 연구는 탄자니아 아루샤(Arusha) 지역의 응구루도토(Ngurudoto) 마을을 대상으로 수행되었다. 본 연구에서 제안하는 시스템은 기상 데이터와 토양 수분 데이터를 하이브리드로 분석하여 농업 용수의 소요를 모니터링한다. 하드웨어 시스템은 기상 측정 컨트롤러, 토양 수분 센서, 수류 센서, 솔레노이드 밸브 및 요금 선불 시스템 등으로 구성된다. 시스템의 각 센서는 무선 통신을 통해 서버로 수집된 데이터를 전송하도록 구축되었는데, 이러한 무선 통신 시스템 아키텍처는 인터넷의 운용이 제한되는 네트워크 오지 지역에 적합하도록 설계되었다. 수집된 데이터에 대한 분석 및 예측은 데이터 분석 알고리즘을 통해 수행되는데, 이를 통하여 농장에 용수를 공급할 시기 및 수량과 함께 요구되는 전력량이 자동으로 판단된다. 한편, 선불시스템은 데이터 분석 결과에 기반하여 용수 사용자가 용수를 공급받기 전에 비용을 우선 지불하도록 개발되었다. 본 시스템의 모든 센서에서 수집된 정보는 실시간으로 모니터링되도록 그래픽 기반의 사용자 인터페이스를 활용하여 정보를 제공한다. 본 연구를 통하여 개발된 무선 통신 기반 스마트 관개 모니터링 시스템은 사용자 중심의 편의성과 경제적인 관개 및 모니터링 시스템을 제공하여 개발 도상국의 경제적 기반인 농업 분야의 발전에 긍정적인 영향을 미칠것으로 기대한다.



주요어 : 농업, 스마트 관개 시스템, 스마트 모니터링, 무선 통신(RF), 이상감지, 용수 비용 선불.학 번: 2018-28776