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Automatic Irrigation System Using Fuzzy Logic Control

A Research Submitted in Partial fulfilment for the requirements of the Degree of B.Sc. in Electronics Engineering

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سورة الانبياء الاية (30)

DEDICATION

We want to dedicate this research to our parents, teachers and colleges. And a special dedication to Dr. Emad Bashir, Ibrahim Adam and Marwa Khaled who passed away but are still remembered in our hearts.

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In preparing this thesis, we want to thank all those who contributed towards our research and implementation. In particular, we wish to express our sincere appreciation to our thesis supervisor, Dr. AbuAgla Babiker, for his generous guidance, critics and patience. We are also very thankful to the project's coordinator T. Azza Kamal Aldeen for her monitoring, advices and motivation. Also special thanks to our parents and colleges, without their continued support and interest, this thesis would not have been the same as presented here.

ABSTRACT

Agriculture is the biggest consumer of freshwater in the world, amounting up to 70% of the total use. This study is concerned with reducing water waste in irrigation by maintaining an automatic irrigation system using fuzzy logic control to achieve a higher level of accuracy in using water and to keep plants healthier by providing the exact amount of water they need. The research is mainly focuses on cultivating wheat in winter season, however the case study is planting mint plants, the scale is 1:560 for each cm^2. It was found out from the research that the amount of water consumption in automatic irrigation system is 10% less than in traditional system.

المستخلص

تعد الزراعة أكبر مستهلك للمياه العذبة في العالم ، حيث تصل إلى 70٪ من إجمالي الاستخدام. تهتم هذه الدراسة بتقليل هدر المياه في الري من خلال تصميم نظام ري آلي باستخدام التحكم المنطقي الضبابي لتحقيق مستوى أعلى من الدقة في استخدام المياه والحفاظ على صحة النباتات من خلال توفير الكمية الدقيقة من المياه التي تحتاجها. يركز البحث بشكل أساسي على زراعة القمح في فصل الشتاء ، لكن دراسة الحالة كانت زراعة نباتات النعناع ، المقياس 1: 560 لكل سم 2. تم التوصل من البحث أن كمية المياه المستهلكة في نظام الري الآلي أقل بنسبة 10٪ من النظام التقليدي.

Contents

DECLARATION I

Dedication II

ACKNOWLEDGEMENT III

Abstract IV

المستخلص V

List of Tables X

List of Figures XI

Chapter One 1

Introduction 1

1.1 Preface 1

1.2 Background 1

1.2.1 Lack of water is caused by 2

1.2.2 Fuzzy Logic 2

1.2.3 Irrigated Agriculture 3

1.2.3.2 Semi-Mechanized Rainfed Agriculture 5

1.2.3.3 Traditional rainfed agriculture 5

1.2.1 Motivation 6

1.2 Problem Statement 6

1.3 Goals & Objectives 7

1.4 State of the Art 7

1.5 Proposal Solution 8

1.6 Expected Results 8

1.7 Research Scope.. 8
1.8 Thesis Layout 8
Chapter Two 9
Theoretical Background & Literature Review... 9
2.1 Theoretical Background.. 9
2.1.1 Agricultural Operations 9
2.1.2 Sudan’s crop portfolio 13
2.1.3 Main factors affecting cereal production in 2020/21 14
2.1.2 Rainwater Collection 16
2.2 Related Work.. 17
2.2.1 Smart Irrigation System for Mint Cultivation through Hydroponics Using IOT 17
2.2.2 water spray system 18
2.2.3 Design of new equipment for sampling and monitoring water bodies 19
2.2.4. Passive Water Harvesting... 20
Chapter Three.. 21
Methodology 21
3.1 Principle.. 21
3.2 Case Study 24
3.3 System Description.. 24
3.4 The big Picture:.. 25
3.5 The circuit consists of 28

3.6 Working step of the two modes 29
3.6.1 Manual mode 29
3.6.2 Automatic Mode 30
3.7 Circuit Components 31
3.7.1 LCD 1602A 31
3.7.2 MH sensor series driver 32
3.7.3 Arduino uno... 32
3.7.4 Rain sensor MHRD 33
3.7.5 Temperature sensor DHT11 33
3.7.6 Relay 34
3.7.7 Resistors 34
3.7.8 5v DC PUMP 35
3.7.9 Light-emitting diode (LED) 35
3.7.10 Global System for Mobile Communications (GSM) 36
3.8 Fuzzy logic 37
3.8.1 Input membership: 38
3.8.2 Fuzzy logic rules 41
3.9 Interfacing the components with the Arduino 43
3.9.1 Connecting Soil moisture sensor with Arduino UNO 43
3.9.2 Connecting Rain sensor with Arduino UNO 44
3.9.3 Connecting temperature and humidity sensor (DH11) with Arduino UNO 44
3.9.4 Connecting LCD (LM016L) with Arduino UNO 45

3.9.5 Connecting GSM module (SIM 900) with Arduino UNO 45
Chapter Four 46
Results and Discussions 46
4.1 Results 46
4.1.1 The first case 48
4.1.2 The second case 50
4.1.3 The third case 51
4.1.4 The fourth case 53
4.2 Discussion 54
4.2.1 Plant health and growth 55
4.2.2 Cost 56
4.2.2.1 Traditional systems 56
4.2.2.2 solar systems 56
4.2.2.3 Adding fuzzy logic Control 56
Chapter Five 57
Conclusions and Recommendations 57
Conclusion 57
5.2 Recommendations 57
References 59
Appendix .... A
A. The code .... A

LIST OF TABLES

Table 3-1: Fuzzy logic output 41

LIST OF FIGURES

Figure: 2-1: Ploughing process 10
Figure: 2-2: Manuring process 10
Figure: 2-3: Sowing process.. 11
Figure: 2-4: Weeding process 11
Figure: 2-5: Earthing up process 12
Figure: 2-6: Irrigation process.. 12
Figure: 2-7: Harvesting process 13
Figure: 3-1. a: The system flow chart 21
.... **Error! Bookmark not defined.**
Figure: 3-1. b: The system flow chart 22
Figure: 3-1.c: The system flow chart 23
Figure:3.2: shows the specific area under study 25
figure 3-3 a and b: sensors distribution among the land 26
Figure 3-4: Shows the contour map for the land slope 27
figure 3-5: Comparison between the prototype and the real irrigation system.. 27
Figure 3-6: Operating in manual mode 29
Figure 3-7: Operating in automatic mode 30
Figure 3-8: LCD 1602A 31
Figure 3-9: MH sensor series driver 32
Figure 3-10: Arduino uno.. 32
Figure 3-11: Rain sensor MHRD 33
Figure 3-12: Temperature sensor DHT11 33
Figure 3-13: Relay.. 34
Figure 3-14: Resistors 34
Figure 3-15: 5v DC PUMP 35
Figure 3-16: Light-emitting diode (LED) 35
Figure 3-17: Global System for Mobile Communications (GSM) 36
Figure 3-18: Membership functions for soil moisture 38
Figure 3-19: Membership functions for temperature............................... 39
Figure 3-20: Membership functions for humidity measurement 40
Figure 3-21: Membership functions for Output...................................... 40
Figure 3-22: illustrates fuzzy rule viewer in MATLAB (a)..................... 42
Figure 3-23: illustrates fuzzy rule viewer in MATLAB (b). 42
Figure 3.24: Shows the circuit and how the components connect with each other 43

Figure 3.25: Connecting Soil moisture sensor with Arduino UNO........ 43
Figure 3.26: Connecting Rain sensor with Arduino UNO...................... 44
Figure 3.27: Connecting temperature and humidity sensor with Arduino UNO 44
Figure 3.28: Connecting LCD (LM016L) with Arduino UNO 45
Figure 3.29: Connecting GSM module (SIM 900) with Arduino UNO. 45
Figure 4-1: Soil moisture sensor status in the first case.......................... 46
Figure 4-2: confirmation message from the system................................ 47
Figure 4-3: Choosing operation mode 47
Figure 4-4: selecting the automatic operation mode............................... 48
Figure 4-5: Soil moisture sensor status in the first case.......................... 48
.... 49
Figure 4-6: Temperature sensor status in the first case........................... 49
Figure 4-7: Humidity sensor status in the first case................................ 49
.... 49
Figure 4-8: pump status in the first case 49
Figure 4-9: Soil moisture sensor status in the second case..................... 50
.... 50
Figure 4-10: Temperature sensor status in the second case.................... 50
Figure 4-11: Humidity sensor status in the second case......................... 51
Figure 4-12: pump status in the second case.. 51
Figure 4-13: Soil moisture sensor status in the third case 52
Figure 4-14: Temperature sensor status in the second case.................... 52
Figure 4-15: Humidity sensor status in the third case............................. 52
Figure 4-16: pump status in the third case 52
Figure 4-17: Soil moisture sensor status in the fourth case 53
Figure 4-18: Temperature sensor status in the fourth case 53
.... 53
Figure 4-19: Humidity sensor status in the fourth case 53
Figure 4-20: pump status in the fourth case... 54
Figure 4-21: Temperature variation readings... 54
Figure 4-22: comparison of water consumption between irrigation systems 55
Figure 4-23: long-term cost for 3 different systems 56

Chapter One

Introduction

1.1 Preface

The economy of Sudan is highly dependent on agriculture, which occupies an estimated 39 percent of its labor force (International Labor Organization [ILO] estimates for 2020) and accounts for about 30 percent of its GDP (World Bank). About 175 million feddans, equivalent to 73.5 million hectares, are suitable for agriculture and the annual average area sown in the last three seasons is approximately 26 million hectares. Only 11% of it is cultivated. Traditional equipment cannot cover all this area in a short period and low cost, therefore in order to get advantage of this wasted area, we should automate the agricultural processes and also use modern electronic equipment to achieve the required efficiency.[1]

One of the most important processes in agriculture is the irrigation process. In order to reduce the consumption of water and to get all the advantage of the water we use; we should automate the irrigation process. This will also meet the United Nations sustainable development goal of providing water.

1.2 Background

Agriculture is the biggest consumer of freshwater in the world, amounting up to 70% of the total use, which makes the case for smart water management in order to guarantee water and food security to the world's population. Irrigation systems and field application methods for the cultivation of crops play an important role therein.

In an attempt to avoid loss of productivity caused by water stress (under-irrigation), farmers spray more water than needed (over-irrigation) and as a result not only productivity is challenged but also water and energy are wasted.[2]

Water is becoming a scarce commodity and it is considered as a liquid gold. The demand of water is also increasing day by day not only for agriculture, but also for household and Industrial purposes. It is estimated that water needed for drinking and other municipal uses will be increased from 3.3 MHm to 7.00 MHm in 2020/25. At the same time, more area should be brought under irrigation to feed the escalating population of the country, which also needs more water.

However, we are not going to get one litter more water than we get at present though the demand is alarming. The perennial rivers are becoming dry and the groundwater table is depleting in most of the areas. In Coimbatore, the depletion has been about 30-50m in the last 30-40 years.[3]

1.2.1 Lack of water is caused by

- Low water storage capacity
- Low infiltration
- Larger inter annual and annual fluctuations of precipitation (due to monotonic rains)[3]

1.2.2 Fuzzy Logic

Logic, according to Webster's dictionary, is the science of the normative formal principles of reasoning. In this sense, fuzzy logic is concerned with the formal principles of approximate reasoning, with precise reasoning viewed as a limiting case. In more specific terms, what is central about fuzzy logic is that, unlike classical logical systems, it aims at modelling the imprecise modes of reasoning that play an essential role in the remarkable human ability to make rational decisions in an environment of uncertainty and imprecision. This ability depends, in turn, on our ability to infer an approximate answer to a question based on a store of knowledge that is inexact, incomplete, or not totally reliable.

For example:

Most of those who live in Belvedere have high incomes. It is probable that Mary lives in Belvedere. What can be said about Mary's income?

Brian is much taller than most of his close friends. How tall is Brian?

There are two main reasons why classical logical systems cannot cope with problems of this type. First, they do not provide a system for representing the meaning of propositions expressed in a natural language when the meaning is imprecise; and second, in those cases in which the meaning can be represented symbolically in a meaning representation language, for example, a semantic network or a conceptual-dependency graph, there is no mechanism for inference.

Fuzzy logic addresses these problems in the following ways. First, the meaning of a lexically imprecise proposition is represented as an elastic constraint on a variable; and second, the answer to a query is deduced through a propagation of elastic constraints.[4]

1.2.3 Irrigated Agriculture

Irrigated agriculture is one of the types of agriculture that depends entirely on groundwater or on the water of rivers and bodies of water in the watering of crops. Mostly, this agriculture is widespread in areas where there is a lot of running water or groundwater, and is famous in the Mediterranean regions, which depend entirely in the winter it relies on rain to irrigate crops, while in the summer it relies on groundwater, water bodies and wells to irrigate and irrigate crops.

The types of irrigated agriculture are:

1. Surface irrigation that floods all or most of the cultivated area with water.
2. Sprinkler irrigation, which resembles rain.
3. Drip irrigation is done by dripping water on the soil so that it is directly on the roots only.
4. Irrigation with perfusion is a sub-surface perfusion of the root area and is carried out by tubes containing holes located inside the soil.
5. Irrigation by filtering, which in turn raises the level of the ground water enough to moisten the root area.

1.2.3.1 Irrigated agriculture in Sudan

The area under irrigation is estimated at about 1.6 million hectares (3.7 million feddans). Large-scale mechanized federal schemes account for about 1.26 million hectares (3 million feddans), including the Aj Jazirah Scheme which, at approximately 1 million hectares (2.38 million feddans), is one of the largest irrigation schemes in the world.

The irrigated sector is the main user of imported agricultural inputs as production is more reliable. However, yields in the federal irrigated schemes remain low compared to world standards, largely due to the poor maintenance of canals, the low capacity of drainage systems and the shortage of efficient modern pumps. In addition, the adoption of traditional agricultural practices that do not allow to make the most efficient use of the constant water resource and exploit the full potential of more intensive farming.

Irrigation water is mainly obtained from the Nile River and its tributaries by gravity or pumps and from spate flows from seasonal rivers at Gash and Tokar deltas. The irrigated sector also takes advantage of rain, especially during the establishment of summer crops. For example, rain is estimated to provide about 40 percent of the water requirements of crops in the Suki Irrigation Scheme. Rain is important to reduce production costs of privately-owned irrigated smallholdings along the banks of the Nile and its tributaries that depend on diesel-powered pumps.

1.2.3.2 Semi-Mechanized Rainfed Agriculture

In the semi-mechanized rainfed agriculture, mechanization is limited to land preparation, seeding and, only partially, to harvesting, while other field operations are carried out manually. Semi-mechanized rainfed agriculture is practiced in a broad belt of 6.7 million hectares which runs mainly through Kassala, Gedaref, Blue Nile, Sennar, White Nile and South Kordofan states and receives annually more than 500 mm of rainfall on average. This belt is considered as the granary of the country, with sorghum accounting for about 80 percent of the total cultivated land and usually producing about 45 percent of the country's requirements. Sesame, sunflowers, millet and cotton are also grown. Farms in the semi-mechanized sector are frequently very large with an average surface of 420 hectares and up to more than 50 000 hectares. Given the usual erratic nature of rainfall and, therefore, the possibility that yields could be very low.

1.2.3.3 Traditional rainfed agriculture

The traditional rainfed sector covers about 9 million hectares and occupies the largest number of farmers. The sector is characterized by small family units farming from 2 to 50 hectares for both income and own consumption.[1]

1.2.1 Motivation

Three of seventeen goals of the 2030 United Nations sustainable development involve access to energy, water, and food and providing security for them. To feed a global population of 9 billion in 2050, the Food and Agriculture Organization estimates food production will need to increase by 70%.[5]

In 2030, the hope is to achieve the three sustainable goals of the United Nations, with zero hunger and plenty of water and energy for the whole planet.

Moreover, due to Covid-19 pandemic and the social distancing imposed on us, and the reduction of the number of workers in offices, factories, and farms to limit the spread of the virus, the need arose for more automation and remote control of farming systems. As farms become larger, or temporarily less accessible, remote monitoring of climate, irrigation, and crop status becomes more important.

The impact of the restrictive measures to contain the COVID-19 pandemic resulted in labour shortages at the beginning of the season, until some restrictions were phased-out in August 2020.[1]

1.2 Problem Statement

Due to manual irrigation process, and human misbehaviours, a large amount of water is being wasted, this will also cause the plants to damage either because of over-irrigation or lack of water. Automatic irrigation system which based on AI techniques is highly required.

1.3 Goals & Objectives

The main goal is to improve agriculture and reduce water consumption by designing automated system that controls the irrigation process, capable of gaining time, cost and effort. moreover, the specific objectives will be summarized as follows:

1. To synchronized and adequate irrigation.
2. To reduce water consumption.
3. To keep plants healthy by providing the exact amount of required water.

The outcomes of the above-mentioned objectives will Enrich the economy of our country. Increase agricultural production by increasing exports, so that the country will be the world's food basket.

1.4 State of the Art

Agricultural fields of farmers may be located miles away from their residence. Sometimes, farmers need to travel to their agricultural field quite a few times in a day to start and stop water pumps for irrigation. They cannot guard the crops from unconditional rain every time. In order to remove these practical difficulties, a system is designed to take care of all these problems automatically.

More recently, a large number of companies are creating robots to develop drones, autonomous tractors, automatic harvesters, automatic irrigation, and robotic robots. Although these technologies are fairly new, an increasing number of traditional agriculture companies are adopting agricultural automation in their operations.

The smart agriculture irrigation controlling and plant disease monitoring system has four major units: end device node, coordinator node, web server node and mobile (controlling unit). The end device node consists of Arduino controller, GSM, soil moisture sensor, temperature sensor and humidity sensor. The microcontroller device is used as the end device. Data is continuously collected from sensors and then transmitted to the coordinator node.

1.5 Proposal Solution

Design an automatic irrigation system using fuzzy logic to automatically monitor the status of temperature, humidity and soil moisture of the land in addition to rain status and sends this information via SMS to the user, then adaptively control the pump and valves according to them to allow or stop water flow.

1.6 Expected Results

By using this system, we expect the consumption of water will decrease by 5-10%.

1.7 Research Scope

This research is specific to agricultural areas where the irrigation process is not depending on rain, in order to improve the irrigation process and reduce water waste.

1.8 Thesis Layout

Chapter two is a literature review, we discussed other researchers' work and their methods and solutions.

Chapter three represents our own methodology, the approaches and techniques used to solve the problem.

Chapter four is a summary of the research outcomes and results, and a comparison between our results and other’s.

Chapter five is the conclusion and recommendations to what could be done to enhance the project.

Chapter Two

Theoretical Background & Literature Review

2.1 Theoretical Background

2.1.1 Agricultural Operations

The agricultural operations vary according to the crops, the rainfall and the soil of the tract. These operations consist of opening the land by digging or ploughing, further pulverizing the soil, cleaning the fields, spreading the manure and mixing it with the soil, sowing the seed or planting the sets or seedlings, weeding, earthing up, irrigating, applying quick-acting manures as top dressings, spraying or dusting of insecticides, watching to protect the crops from birds, stray cattle and wild animals; harvesting, threshing and preparing the crops for the market, and storing.

2.1.1.1 Ploughing

is done almost every year by wooden or iron ploughs to open the land, to dig out deep-rooted weeds or stubbles, to aerate the soil and to trap and store water for crops.

Pulverization of the soil is done by one of three kinds of implements:

1. the beam harrow known as maind
2. the wooden plank called phali
3. the blade harrow called kulav.

Cleaning the field is usually done by women in batches of from six to eight for an acre. They pick up the remnants of the previous crop, like stubbles etc.

Figure: 2-1: Ploughing process

2.1.1.2 Manuring

The farmer takes out the well rotten farm-yard manure or compost from pits by means of a phavada (spade) and a ghamela (iron basket) and carts the same to his own field. This manure is heaped and is evenly spread over the field, and then mixed with the soil by means of a kulav (harrow). A man or woman usually spreads about five cartloads (each weighing half a ton) of farm-yard manure and a harrow worked by a man and two bullocks can mix to or three acres a day. In some places, sheep and goats are quartered on the fields for a few days. Their dung and urine serve as good manure. It has been estimated that one thousand of these animals quartered in an acre over a night give manure equal to about five to six cartloads.

Figure: 2-2: Manuring process

2.1.1.3 Sowing

In most of the crops, seeds are sown for starting the crop, but in some in which seeds cannot be produced easily, parts of the plants are planted either after irrigation or after rains.

Figure: 2-3: Sowing process

2.1.1.4 Weeding

The weeds that are in line with the crop escape the hoes and thus are required to be removed by hand with the help of a weeding hook.

Figure: 2-4: Weeding process

2.1.1.5 Earthing up

The next important operation is earthing up, i.e., digging the soil from near about the plant and heaping it up at the base of the plant. This is done in order to give support to the plant, to prevent lodging and to keep the tubers and roots under the soil.

Figure: 2-5: Earthing up process

2.1.1.6 Irrigation

Irrigation is done from canals or wells. In canal tracts, it is available mostly by gravitational flow, while in the case of wells, rivers and tanks the water is lifted by water-lifts such as mots, Persian wheels or pumps.

Figure: 2-6: Irrigation process

2.1.1.7 Harvesting

one of the most important agriculture operations, next only to ploughing and sowing, is the reaping or harvesting of the standing crops. The crops are harvested only when they're fully ripe. The period of ripening varies from crop to crop.

Figure: 2-7: Harvesting process

2.1.2 Sudan's crop portfolio

The Sudan's crop portfolio is quite diversified, including cereals (sorghum, millet, wheat, rice and maize), oilseeds (sesame, groundnuts and sunflowers), industrial crops (cotton and sugarcane), fodder crops (alfalfa, fodder sorghum and Rhode's grass), pulses (broad beans and pigeon peas) and horticultural crops (okra, onions, tomatoes, citrus, mango, etc.). Moreover, most land is suitable for animal husbandry, with an estimated total livestock population in 2020 of about 119.9 million heads of cattle, sheep, goats, camels and others.[6]

2.1.2.1 Crop production is practiced under three main patterns

1. Irrigated agriculture, which includes:

• Large national irrigation schemes (Al Jazirah, Suki, New Halfa and Rahad) using river flows from the Nile and its tributaries.

• Large spate irrigation schemes (Gash and Tokar) using seasonal floods.

• Small-scale irrigation along the banks of the Nile and its tributaries.

2. Semi-mechanized rainfed agriculture.
3. Traditional rainfed agriculture

Crop production in the rainfed sectors exhibits very wide annual fluctuations as a result of erratic rainfall amounts and distribution, which can result in late sowing, long dry spells, flooding from intense downpours, the necessity to re-sow and, not uncommonly, complete crop failure. The situation in the irrigated sector, however, is much more predictable. Nevertheless, viewed globally, yields are generally low in all sectors for various reasons in addition to rainfall. These include, inter alia, a shortage of efficient, well-maintained farm machinery, a shortage of credit and working capital, the use of low yielding crop varieties and low plant density with scarce availability of improved seeds, inadequate maintenance of irrigation canals, inefficient irrigation pumps and poor agricultural practices such as inadequate weed and pest control.

2.1.3 Main factors affecting cereal production in 2020/21

2.1.3.1 Rainfall

With rainfed agriculture accounting for about 95 percent of the total cultivated area in the country, rainfall is the most important driver of national food crop production. Precipitation is crucial also in the irrigated sector as it supplements irrigation water and supports crop establishment and development.

2.1.3.2 Irrigation

Normally, rainfall assists in the establishment of crops, which reduces the burden on the irrigation system in July and August, while in September and October the required amount of water is supplied by a number (two to three) of scheduled irrigations. However, irrigation water is seldom sufficient for all the main crops (sorghum, groundnuts and cotton).

2.1.3.3 Agricultural machinery

The availability of agricultural machinery was generally adequate. However, the cost of maintenance and spare parts was high, with spare parts often reported to have low quality. In addition, the restrictions imposed to contain the spread of the COVID-19 pandemic, including the closure of markets, disrupted maintenance and repair activities, especially at the beginning of the summer season. The rental rate of agricultural machinery doubled in 2020 compared to 2019, with a negative impact on farmers who do not own it.

2.1.3.4 Labor

As a result of the COVID-19-related restrictions of movements within and between states at the beginning of the season in April-May, labor shortages were reported in some states, especially in the semi-mechanized sector (Gedaref and Kassala). However, the labor availability in 2020 was overall adequate, but daily wage rates increased by 175 percent compared to 2019. In the traditional sector in Western Sudan, farmers with small agricultural holdings depend on family labor in performing the manual agricultural operation and were not affected by the labor shortages.

2.1.3.5 COVID-19 pandemic

The measures implemented by the Government to contain the spread of the COVID-19 pandemic affected crop production, mainly at the beginning of the season, with market closures resulting in shortages of some agricultural inputs and movement restrictions causing labor shortages and high costs of agricultural practices. However, the phasing out of some restrictions in August 2020 benefited agricultural operations. Livestock rearing activities were also affected by the restrictive measures, mainly through shortages of medicines and vaccines and access constraints to pastures.[1]

2.1.2 Rainwater Collection

Water is the source of life. However, the shortage of freshwater resources has increasingly become a major challenge. Recent research found that about two-thirds population of the world (about 4.0 billion people) live in a moderate water shortage for at least 1 month each year. And, more than 500 million people face extreme water shortages throughout a year. According to statistics, two-thirds population of the world will face water shortages by 2025.

Although 70.8% of the earth is covered by water, freshwater resources are extremely limited. According to data from the US Environmental Protection Agency, the total global water resources storage is ≈1.386 × 109 km3, and freshwater resources account for only 3% of them. Regarding the distribution of freshwater, more than 68% is in the form of glaciers in the north and south poles or frozen soil, and the other 30% are buried deeply and dispersively as underground water. At present, freshwater resources (river, freshwater lake, and shallow underground water) that are more easily used by humans account for only 0.3% of total freshwater resources, which is equivalent to 0.007% of the global total water storage, about 1 × 105 km3.

In ancient times, it was difficult to adjust the amount of water with the help of water conservancy and other projects. Therefore, the collection and utilization of rainwater have always been the top priority for household and agricultural water use.

With the economic development and population growth, the water consumption of city is increasing, and the problem of water shortage has become more acute. This phenomenon has promoted the collection and use of rainwater.[7]

2.2 Related Work

2.2.1 Smart Irrigation System for Mint Cultivation through Hydroponics Using IOT

Hydroponics is derived from hydro culture. It is a method for growing and nurturing plants in a soilless environment by mixing nutrient solutions in the water. Plants can be grown only by exposing their roots in the mineral solution. In few cases, the roots would be aided by inert soil like mediums such as gravel or perlite. The accumulation of nutrient solution is prepared from fish excreta, animal manure, bird manure or generic nutrients in hydroponics system. The hydroponic growth bed systems are built with materials like glass, stone, metal, wood, vegetable solids and concrete. The bed system constructed must be exempted from vulnerability to sunlight. This setup would help in prevention of algae growth in nutrient solution.

2.2.1.1 Smart Hydroponic Lettuce Farm using Internet of Things

pictures the difference in smart farming system with traditional farming. The difference lies upon the mixture of nutrient solution between the two. An ordinary farm requires 30 minutes of human labor to finish the task. This farmer has to make different solutions from its ingredient and has to hold on for dissolving of the solution. The preparation of the solution takes exactly 2-3 minutes without human interruption in smart farming system. The proposed model in the paper measures the average value of lettuce plants from smart Farm with respect to regular farm. The lettuce plants from smart farm produces 17.20% of extract leaves and 13.90% of bigger stems comparing to traditional lettuce plants. Moreover, there was a shortage of 36.60% growth with lettuce plants in a traditional planting system. The leaf area and width of the plants are found to be same in both the planting system. However, the average weight of fresh plants is found to be 36.59% higher and the nitrate concentration in plant is found to be 8.24% lower in smart farm system. On the whole, quality of product from smart farm is better comparing to traditional farm.

Hydroponics suits well for growing green leafy plants like spinach, mint and lettuce. Mint is an herb that is largely grown for its aroma and flavoring recipe. Indoor and garden-based cultivation of mint is done by setting up a good hydroponic system. For the successful growth of mint, humidity must be maintained at 70 - 75%. It must be around 85 - 90%.

for mint samplings to have a good growth. It may take 7 - 10 days for rooting up of mint samplings. Temperature must be around 22 -28 ^{o}C with supporting daylight for 12-14 hrs. a day. In this proposed model, mint plant is grown in the NFT system occupied by a free running water. The mint samples are grown above clay pebble balls as a substrate.[8]

2.2.2 water spray system

A water spray system was created for a watermelon farm that is controlled by a drone carrying an android smart-phone. The system consists of 4 soil moisture sensors, a drone, an android smart-phone and a spray controller.

The sensors send a signal to the smart-phone via Bluetooth at a rate of 9600 bps, The smart-phone was used as a data collector, because the range of the Bluetooth connection is narrow and not suitable for large areas but by using the smart-phone it became possible and the smartphone analyses the data and sends the appropriate signal to the control unit, where the control unit consists of an ATMEGA 89C51 processor.

The control unit of the spray device starts the operation of the pressure pump and opens the necessary valve according to the transmitted signal.

The aggregation of soil conditions and control of the peripheral devices was more convenient with a drone carrying the smartphone for remote control rather than examining the human eye and controlling electronic switches in a wide-open area of a huge farm.[9]

2.2.3 Design of new equipment for sampling and monitoring water bodies

This system consists of a custom-built hex copter equipped with a multi-probe based on open-source electronic sensors that allow for measuring water temperature, electrical conductivity, dissolved oxygen, and ph. This device was tested on a 1.1 ha agricultural pond and the measurements proved to be reasonably accurate, allowing one to obtain maps displaying the spatial distribution over the pond of the measured parameters.[10]

The indicators used showed great variability between studied sites in the performance of MOD16, usually underestimating the transpiration. The authors concluded that MOD16 allows for a fair estimate of crop water requirements at the studied sites, given the lack of ground measurements this work shows a user-friendly tool that requires a low number of inputs, and describes the spatial variability of crop water demands within an entire field.

The changes in lighting intensity throughout the day can alter the performance of machine vision systems used in precision agriculture for managing irrigation. A generalized use of these tools requires a deep knowledge of crop water demands and the relations between them and the indices obtained by remote sensing.[10]

There are two methods used to transport the water to the field for irrigation. The simplest method is transportation with a water tractor in combination with manual watering, the other is transportation with a water tractor, in combination with a manual driven piston pump for irrigation using a portable drip irrigation system.[11]

2.2.4. Passive Water Harvesting

The traditional passive water harvesting system does not require external energy input to the system, and it can spontaneously harvest water in the air under different conditions. Because of its simple concept and low threshold for system installation, it was first developed and used by humans. It is generally divided into three types:

1. rainwater collection,
2. fog capture
3. passive surface cooling-induced dew collection.

So far, the common rainwater collection methods include large-scale projects such as building dams, surface runoff collection, barrage dams, ditches, etc. Building large-scale water storage spaces to collect and store rainwater, with water treatment methods like filtering and disinfecting, are used in production in life. There are also miniaturized collection systems such as roof rainwater collection, groundwater tanks, rain buckets, etc., which are mostly used for family life. Modern rainwater collection method for family is a potable rainwater collection system based on roof collection.[7]

Chapter Three

Methodology

3.1 Principle

In Sudan most of the agricultural fields located far away from their residence sometimes farmers need to travel to their agricultural fields to control and monitor the irrigation process by starting and stopping water pumps and it is a very cumbersome process nor can they permanently protect the crop from rain. In order to remove these practical difficulties a system is designed to get rid of all these problems automatically. The following block diagram represents the components of this system.

We build a circuit to control the irrigation system in the agriculture process using a control method called fuzzy logic control.

The following figures shows the system flow chart:

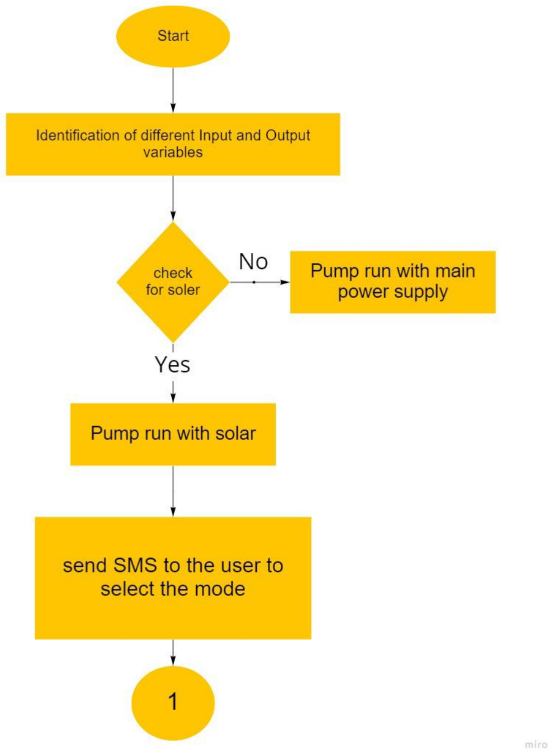

Figure: 3-1. a: The system flow chart

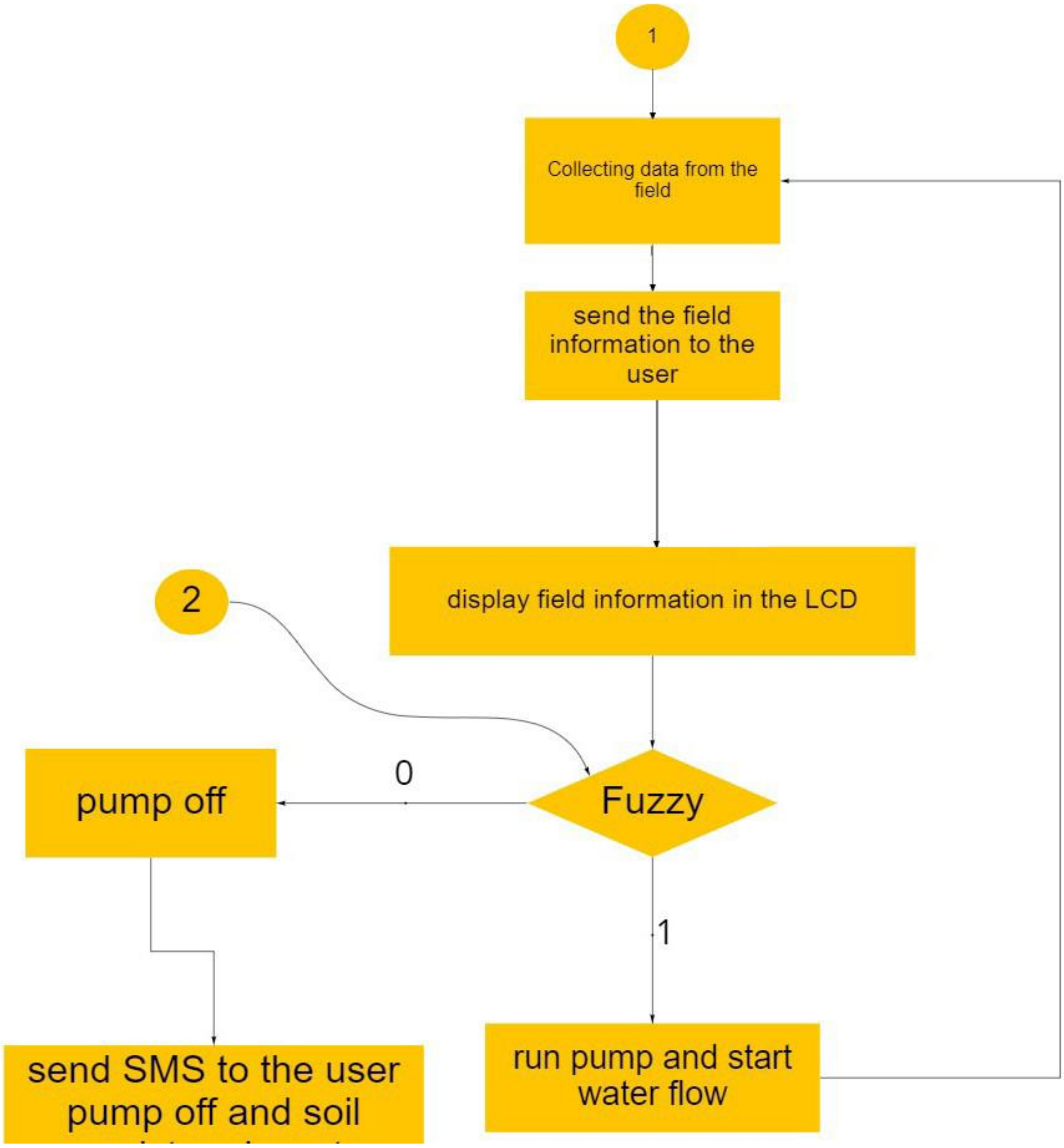

Figure: 3-1. b: The system flow chart

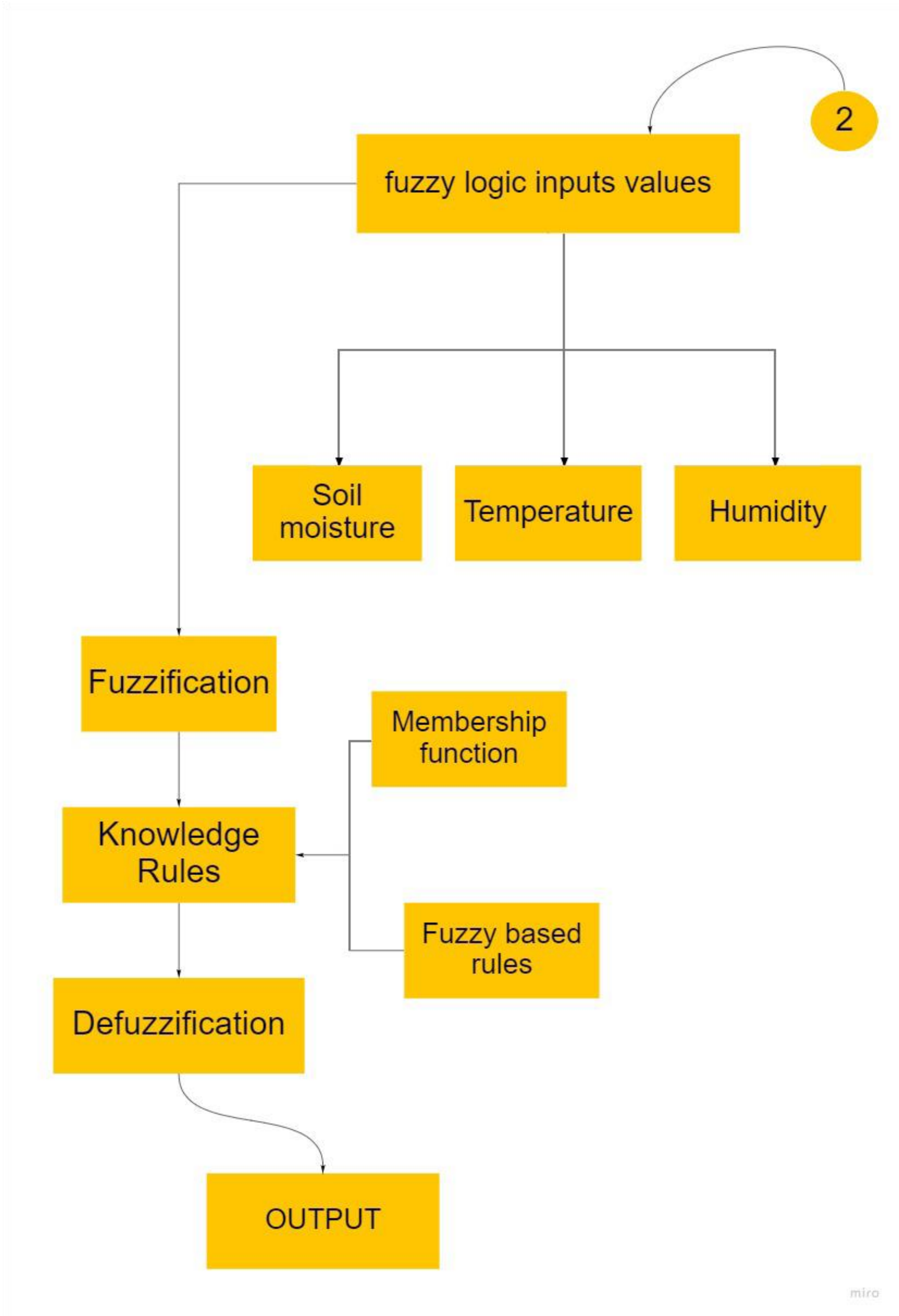

Figure: 3-1.c: The system flow chart

3.2 Case Study

Our research is concerned with applying this system in wheat cultivation in irrigated areas.

From an interview with a farmer, he said: “dividing the land for cultivation for the irrigation process depends on some factors, one of the main factors is the type of the plant, there are two main categories: field crops like seeds, and horticultural plants like vegetables.

When planting field crops, the land will not be divided into fields or tables because that will hinder the harvesting process since it requires heavy machines. However, this means a pre-process of land levelling should be done to ensure that the whole land receives the same amount of water.”

So as the wheat is a field crop, we use this previous technique to irrigate it.

However, our case study will be planting and irrigating mint plants, the outcomes and results of this study will be scaled to match wheat cultivation size.

In order to do our studies and ensure that water ration and reduce the loss as well as avoiding drought, we designed a circuit to control the irrigation process for the specific area to state the difference between the efficiency of traditional and automated irrigation systems. We want to prove the concept of water saving, we will not implement all parts as well as the final circuit in the big scale area.

3.3 System Description

The irrigation system has three major units: sensors unit, pumps unit, Coordinator unit.

Coordinator unit consists of an Arduino controller and GSM model. sensor unit content soil moisture sensor. Temperature and humidity sensor and rain sensor, Data are continuously collected from the sensors, the data acquirement is done in real time monitoring of farmland parameters, the coordinator unit sent the data to the user via GSM

The controller is programmed using fuzzy rules that the system helps farmers to check the irrigation process through remote monitoring of agricultural fields. The Arduino and the GSM get initialized when the power supply is turned on after that the system asks the user to select the mode either manual or automatic mode when the user selects the automatic modes.

3.4 The big Picture:

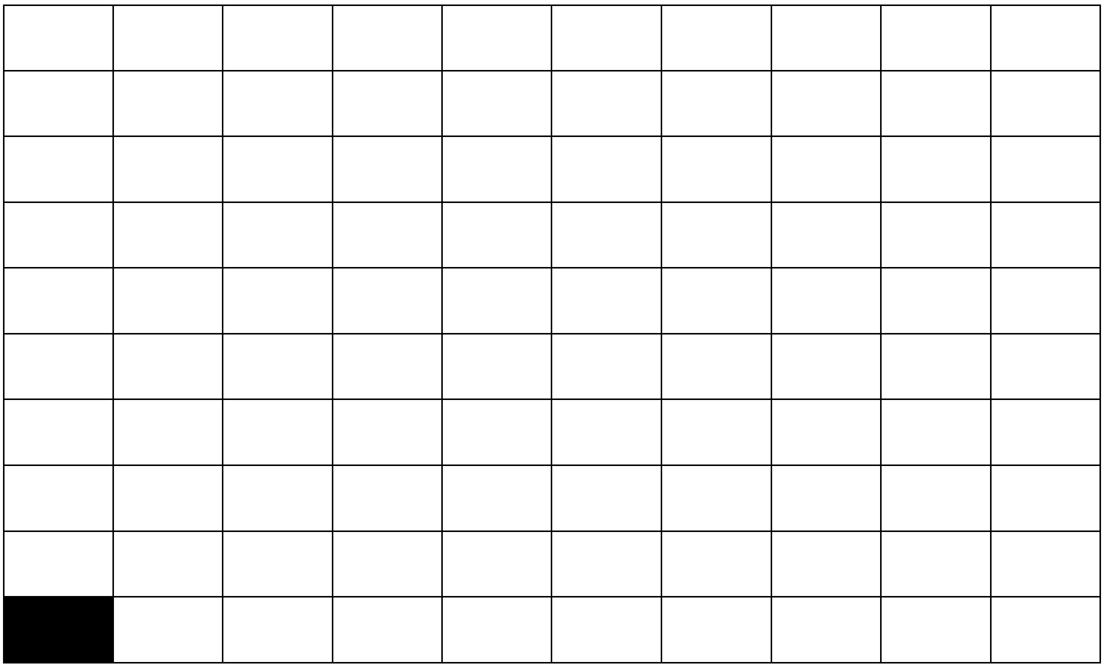

Figure:3.2: shows the specific area under study

The shaded area equal 380 CM^2 and contains the plant ventilation space and irrigation channels for the plant to be healthy and take their full amount of water, the total area of the figure is equal to 380*100 = 38000cm^2 which is 9% of the acre.

We will calculate the amount of saved water in every 380cm^2 then expand it to the whole area.

For the case study which is in a small space, we use simple elements that we connect to each other through one controller, while in wide spaces we use an appropriate number of sensors that are connected to one controller and a group of pumps that we control.

The automated irrigation system in the large area is on gates level, it controls the gates of the irrigation channels that prevail large areas up to 90 acres or more where each acre contains approximately 1105 plants, the gates and sensors are connected with a server to calculate the amount of water consumed in the previous season and calculates the amount of water will be consumed in the next season and determines the area should be cultivated from a specific crop to control the irrigation process and avoid human mistakes.

Soil moisture sensors are distributed according to the slope of the land, as they are placed in relatively high places after plowing and levelling the land. As for the temperature sensor and the rain sensor, they are placed in exposed areas so that the readings are clear, accurate and relatively.

(a) (b)

figure 3-3 a and b: sensors distribution among the land

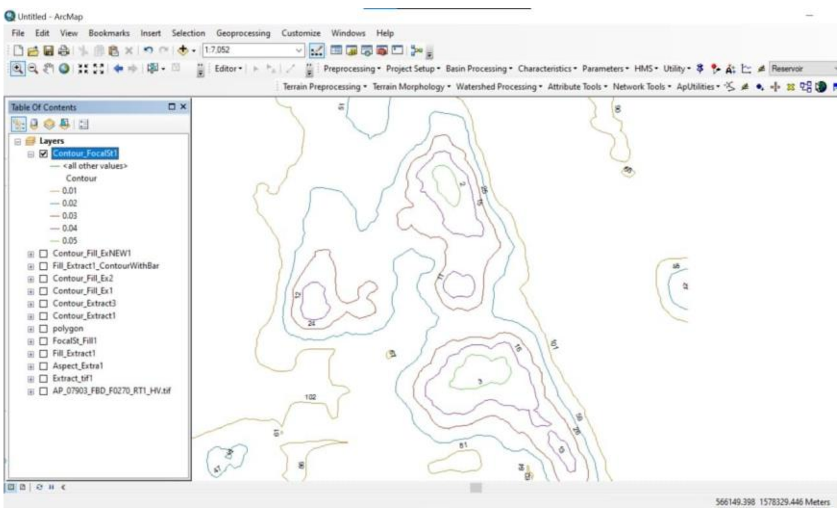

Figure 3-4: Shows the contour map for the land slope

The relationship between the existing prototype and the real irrigation in huge agricultural projects will be show by the bellow figure 3-5:

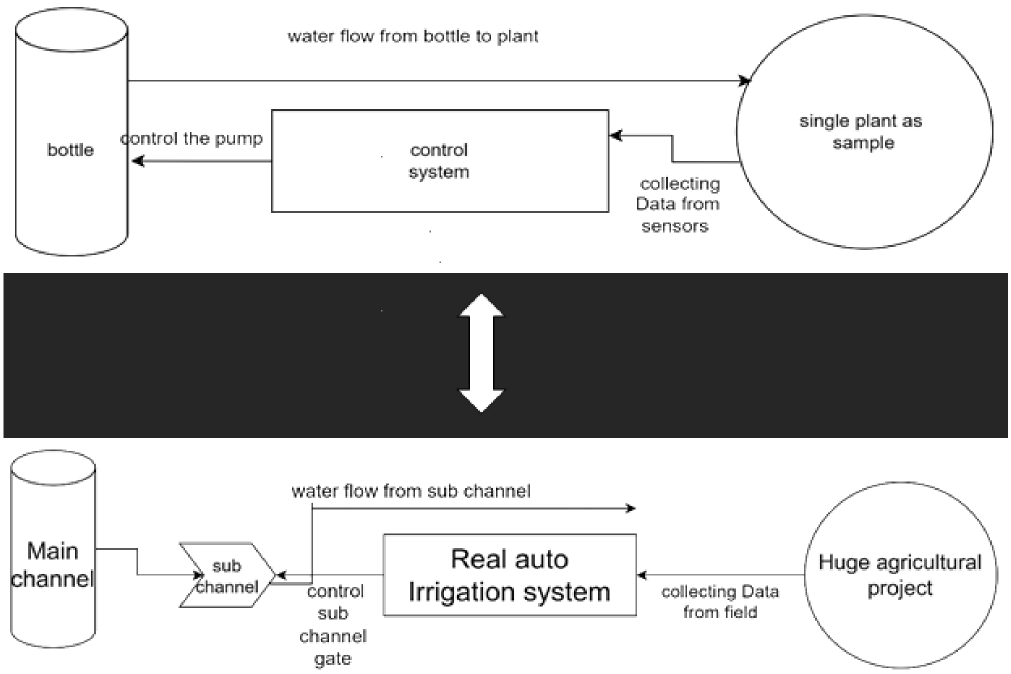

figure 3-5: Comparison between the prototype and the real irrigation system

3.5 The circuit consists of

Arduino UNO used as the brain of the circuit. Used to connect circuit sensors together which take the sensors values, calculate them based on fuzzy logic control, and finally control the irrigation system by starting the water pump or stop it based on the right situation.

DH11 sensor is used to measure the surrounding environment temperature and the percentage of the humidity, DH11 takes the temperature value and the percentage of the humidity from the soil and sends them back to the Arduino UNO through digital pin 2.

Soil moisture is used to measure how much wetness or dryness of the soil plant, it takes the data directly from the soil and sends them to the Arduino UNO through analog pin A0.

Rain sensor used to measure if the weather is rainy or not, it takes the weather condition and feed it to the Arduino UNO through pin analog pin A1.

LCD 1602A used to display the operation mode, and all sensors data used in this circuit on its screen. It connects with Arduino UNO through analog pins A4, and A5.

GSM Module SIM800L EVB used as communication channel between the system and its user.

Water pump used to control the water flow in the field by allowing the movement of water or not based on Arduino UNO decision.

After implementing the circuit in the field by placing each sensor in the right place, the system starts and the GSM Module send a confirmation message to the user that the system is on.

Then the GSM module sends another message to the user to choose the operation mode. If the user chooses the manual mode the system let the user to decide when to start or stop the pump to allow the water flow. If the user chooses the automatic mode, then the Arduino take control of the circuit, it collects the data of the surrounding environment display them on the LCD, and process them based on fuzzy logic control after that the Arduino UNO decide to start the pump to allow water flow in the field or not based on the results came after processing the data.

3.6 Working step of the two modes

The Soil Moisture sensor check the soil moisture when it is on maximum threshold is indicating dry so minimum threshold that means the field is wet

The temperature sensor measures the surrounding temperature

Rain sensor senses heavy rain

After collecting data and sent it to the user he selects between one of the two modes:

3.6.1 Manual mode

After the system sends the data to the user, the user selects the manual mode so the user must decide when the pump should starts pumping water, he sends “pump” to the system then the water start to flow to the field and the system will remain sending the collected data in a period of ten minutes, When the user sends “stop pumping” the system will stop water flow.

Figure 3-6: Operating in manual mode

3.6.2 Automatic Mode

If user select the Automatic Mode:

The Soil Moisture sensor check the soil moisture when it is on maximum threshold is indicating dry and the motor will pump water to the field so minimum threshold that means the field is wet the motor will stop pumping water to the field

The temperature sensor measures the surrounding temperature

Rain sensor senses heavy rain and the motor will stop pump water to the field

After collecting data and sent it to user which select between one of the two modes

The data collected in a period of two minutes compares the data to decide to keep water flow or stop the motor.

Figure 3-7: Operating in automatic mode

3.7 Circuit Components

3.7.1 LCD 1602A

LCD1602, or 1602 character-type liquid crystal display, is a kind of dot matrix module to show letters, numbers, and characters and so on. It's composed of 5x7 or 5x11 dot matrix positions; each position can display one character. LCD1602 can be categorized into eight-port and four-port connections.

Figure 3-8: LCD 1602A

LCD 1602A Properties

Display Mode: STN, BLUB

Display Format: 16 Character x 2 Line

Viewing Direction: 6 O'clock

Input Data: 4-Bits or 8-Bit's interface available

Display Font: 5 x 8 Dots

Power Supply: Single Power Supply (5V±10%)

Driving Scheme: 1/16Duty,1/5Bias

3.7.2 MH sensor series driver

MH-Series model MH position sensors measure the absolute position of hydraulic cylinders in mobile applications. Designed for full sealing and embedding in hydraulic cylinders. The position sensor features the proprietary M12 connector system to enable IP69K.

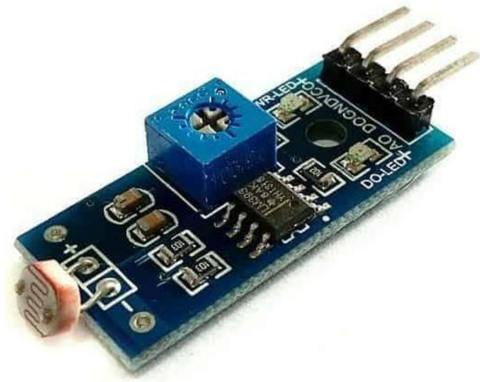

Figure 3-9: MH sensor series driver

3.7.3 Arduino uno

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online.

Figure 3-10: Arduino uno

3.7.4 Rain sensor MHRD

The rain sensor module is an easy tool for rain detection. It can be used as a switch, when raindrop falls through the raining board and also for measuring rainfall intensity. Connected to 5V power supply, the LED will turn on when induction board has no rain drop, and DO output is high.

Figure 3-11: Rain sensor MHRD

3.7.5 Temperature sensor DHT11

A temperature sensor is an electronic device that measures the temperature of its environment and converts the input data into electronic data to record, monitor, or signal temperature changes.

The DHT11 is a basic, ultra-low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and spits out a digital signal on the data pin.

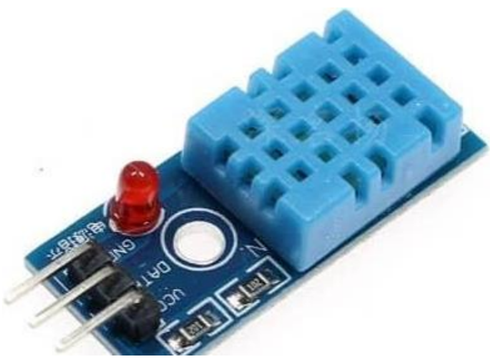

Figure 3-12: Temperature sensor DHT11

3.7.6 Relay

Controlling the passage of another electric current that is much greater than the current we are using. There are two types of relays: Single-phase and three-phase which select it according to the water pump and valve switch

Figure 3-13: Relay

3.7.7 Resistors

It is an electrical component that is added to an electrical circuit with the aim of regulating the current coming into this circuit, by dissipating the excess current into heat, making it one of the most important components in sensitive electronic circuits. Resistors vary in value and are expressed in ohms, and the current that a resistance transmits is inversely proportional to the value of this resistance.

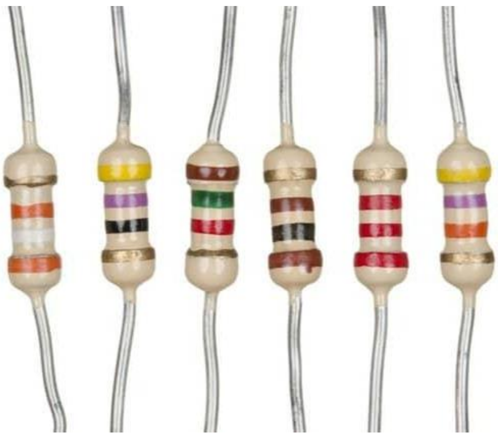

Figure 3-14: Resistors

3.7.8 5v DC PUMP

It is a machine that converts electrical energy into mechanical energy using direct current, and therefore it works only on its systems. It's used to pump water.

Figure 3-15: 5v DC PUMP

3.7.9 Light-emitting diode (LED)

It is a light source made of semiconductor materials that emits light when an electric current passes through it. In the on state, the light is green, and in the off state, the light is red.

Figure 3-16: Light-emitting diode (LED)

3.7.10 Global System for Mobile Communications (GSM)

It is a protocol for transmitting data in the field of communications through a mobile phone, in which a fixed frequency is assigned to each user on the network without changing it, as the GSM system uses the TDMA standard with a narrow frequency band, which provides for making 8 simultaneous calls on the same radio frequency, and Transferring data at a speed of up to 9.5 kb / s, which is specific to the second-generation networks. This system is based on the use of a SIM card.

Figure 3-17: Global System for Mobile Communications (GSM)

SIM800L GPRS GSM Module

ESP style and size board shape.

Built-in pcb antenna.

Input Voltage：DC 6 V.

Quad-band 850/900/1800/1900MHz.

Make and receive voice calls using a headset or an external speaker.

Send and receive SMS message.

Send and receive GPRS data (TCP/IP, HTTP, etc.).

Scan and receive FM radio broadcasts.

AT command interface with “auto baud” detection.

Lead out buzzer and vibrational motor control Port.

3.8 Fuzzy logic

The fuzzy rule base system is use to produce the outputs according to the given input for the system. In this study, four input parameters are considered and each parameter consists of three membership functions as shown in the below equations. The number of rules is calculate based on each input parameter's membership function. Hence, each parameter consists of three memberships function. The total number of rules framed is 27 (Table 3-1).

The membership function values and the fuzzy rules are frame by researcher's assumption based on the fuzzy inference concept

Demonstrates the Fuzzy Inference System in which the soil moisture, temperature and humidity are the input values. After completing Fuzzification.

Defuzzification methodology is use for producing the output for generating status of the motor. The input membership functions are formulate using the trapezoidal function, and the output membership function is formulated using the triangular membership function

Demonstrate the membership function for humidity whose parameters for analysing humidity are low, medium and high Illustrate the membership function for soil moisture whose parameters for analysing soil moisture are dry, medium and wet. Illustrates the membership function for temperature whose parameters for analysing temperature are cold, worm and hot. Demonstrates fuzzy rule settings for the fuzzy inference system that are the conditions for the membership functions. The fuzzy rules are framed based on if-then conditions of the soil moisture, humidity and temperature. The table 3-1 represents the various categories of the input and output parameters and figure 3-23: illustrates fuzzy rule viewer in MATLAB.

3.8.1 Input membership:

Membership functions for soil moisture measurement:

Moistwet (x) $=\{1, x \leq 60 \ \frac{x-560}{560-60}, 60 \leq x \leq 560$

Moistmed (x) $=\{\frac{x-330}{630-330}, 330 \leq x \leq 630 \ 1,630 \leq x \leq 650 \ \frac{945-x}{650-945}, 650 \leq x \leq 945$

Moistdry(X) $=\{\frac{715-x}{1023-715}, 715 \leq x \leq 1023 \ 1,1023 \leq x$

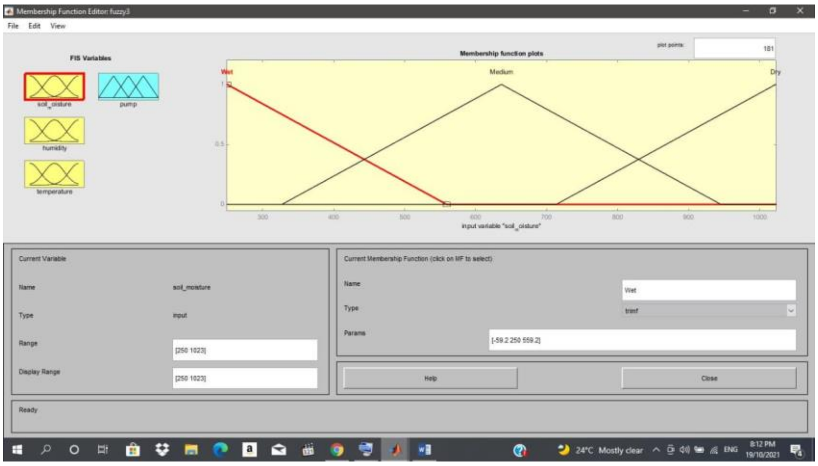

Figure 3-18: Membership functions for soil moisture

Membership functions for temperature measurement:

Tempcold(x) $=\{1,5 \leq x20 \ \frac{24-x}{24-10}, 10 \leq x \leq 24$

Tempwarm(x) $=\{ \frac{x-24}{32-24} 24 \leq x \leq 32 \ 1,32 \leq x \leq 35 \ \frac{36-x}{40-36}, 36 \leq x \leq 40$

Temphot(x) =$\{\frac{x-43}{45=43}, 43 \leq x \leq 45\ 1,45 \leq x \leq 52$

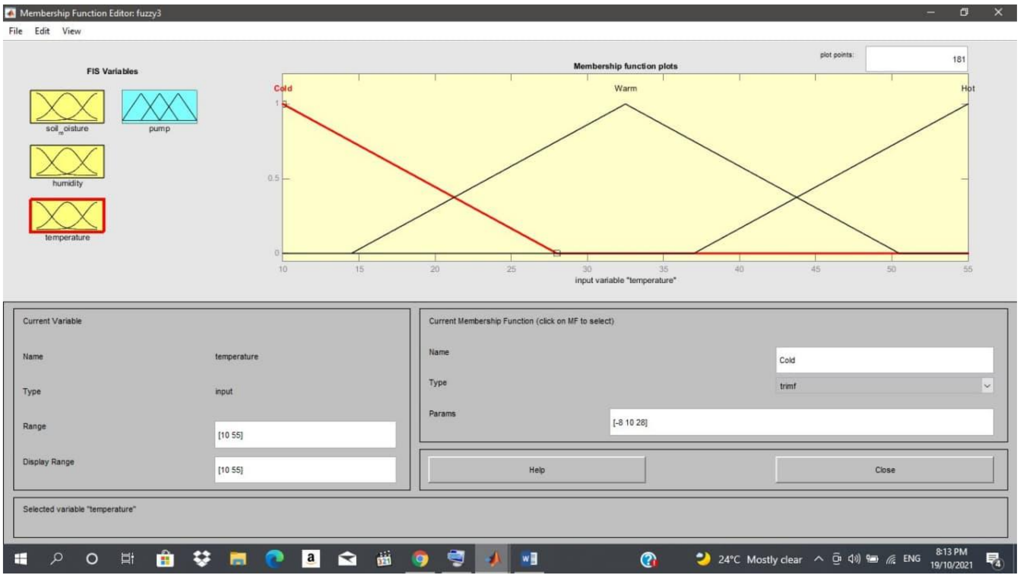

Figure 3-19: Membership functions for temperature

Membership functions for humidity measurement:

Humlow(x)) =$\{1, x \leq 60\ \frac{x-560}{560-60}, 60 \leq x \leq 560$

Humwarm(x) =$\{\frac{x-330}{630-330}, 330 \leq x \leq 630\ 1,630 \leq x \leq 650\ \frac{945-x}{650-945}, 650 \leq x \leq 945$

Humhigh(x)) =$\{\frac{715-x}{1023-715}, 715 \leq x \leq 1023\ 1,1023 \leq x$

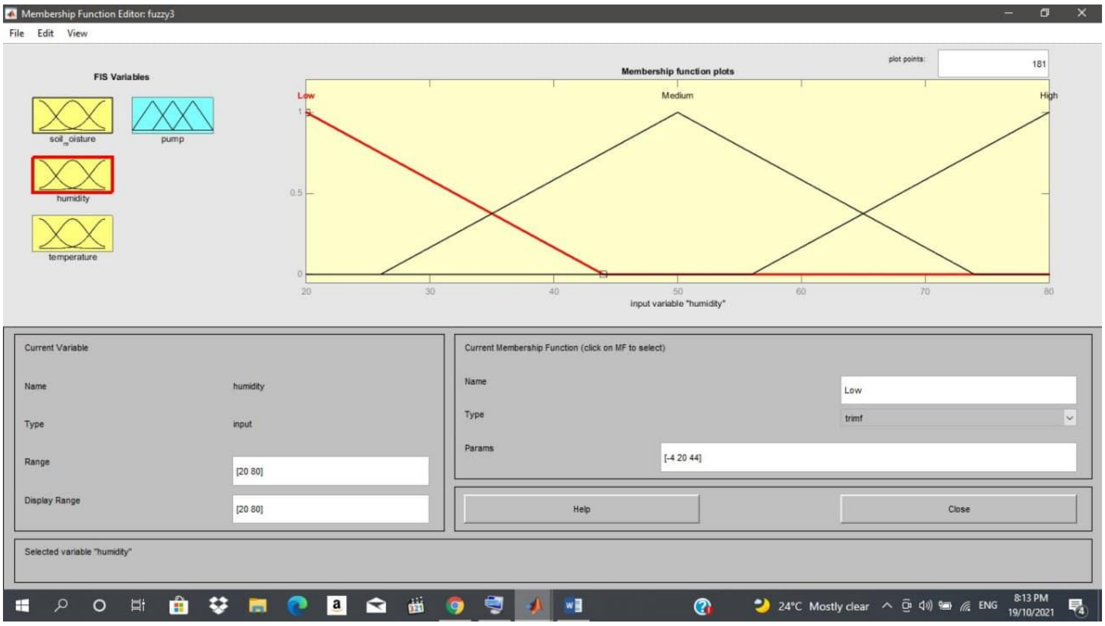

Figure 3-20: Membership functions for humidity measurement

Output membership:

Membership functions for pump state:

Motorst(x)= $\{0, x = 0 \; 1, x = 1$

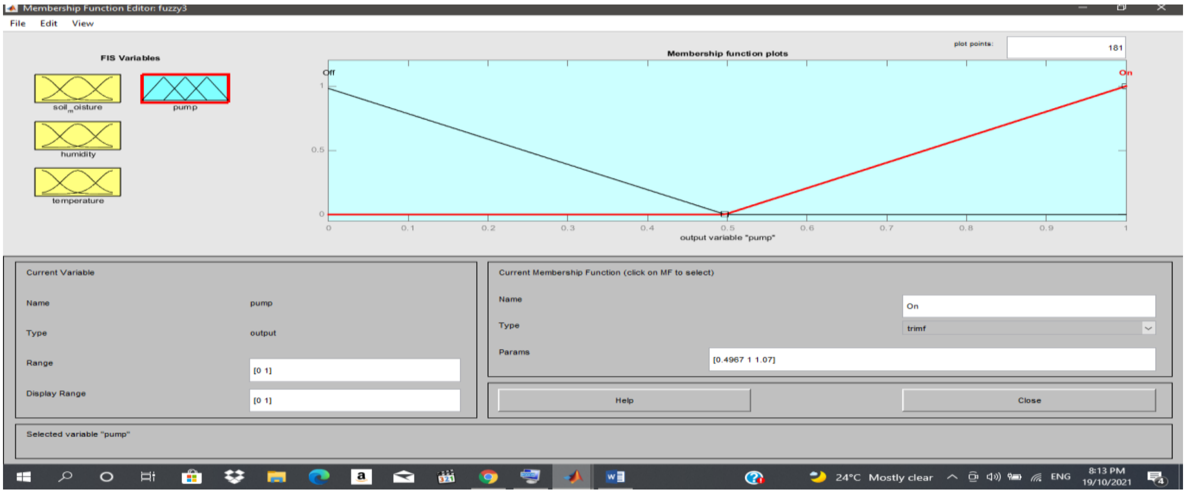

Figure 3-21: Membership functions for Output

3.8.2 Fuzzy logic rules

Table 3-1: Fuzzy logic output

Rules	Soil moisture	Temperature	Humidity	Pump status
1	Dry	Cold	Low	ON
2	Dry	Cool	Low	ON
3	Dry	Hot	Low	ON
4	Dry	Cold	Medium	ON
5	Dry	Cool	Medium	ON
6	Dry	Hot	Medium	ON
7	Dry	Cold	High	ON
8	Dry	Cool	High	ON
9	Dry	Hot	High	ON
10	Medium	Cold	Low	OFF
11	Medium	Cool	Low	OFF
12	Medium	Hot	Low	ON
13	Medium	Cold	Medium	OFF
14	Medium	Cool	Medium	OFF
15	Medium	Hot	Medium	OFF
16	Medium	Cold	High	OFF
17	Medium	Cool	High	OFF
18	Medium	Hot	High	OFF
19	Wet	Cold	Low	OFF
20	Wet	Cool	Low	OFF
21	Wet	Hot	Low	OFF
22	Wet	Cold	Medium	OFF
23	Wet	Cool	Medium	OFF
24	Wet	Hot	Medium	OFF
25	Wet	Cold	High	OFF
26	Wet	Cool	High	OFF
27	Wet	Hot	High	OFF

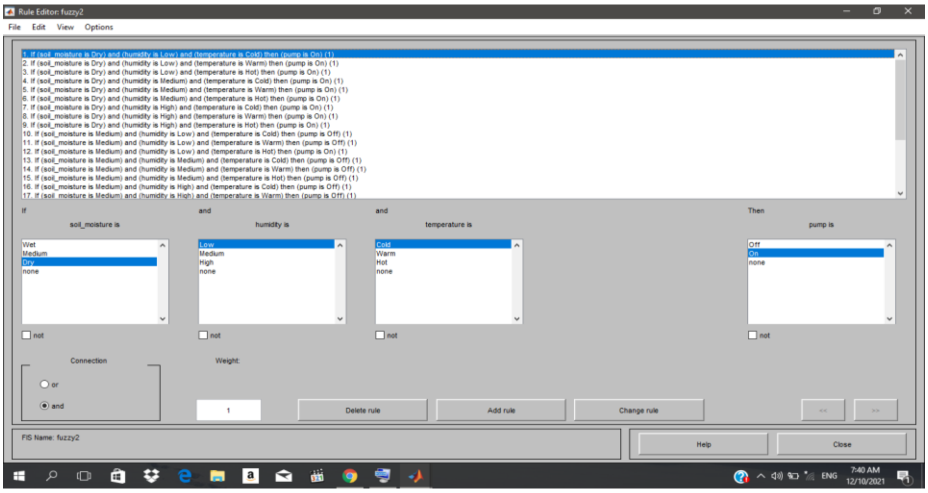

Figure 3-22: illustrates fuzzy rule viewer in MATLAB (a).

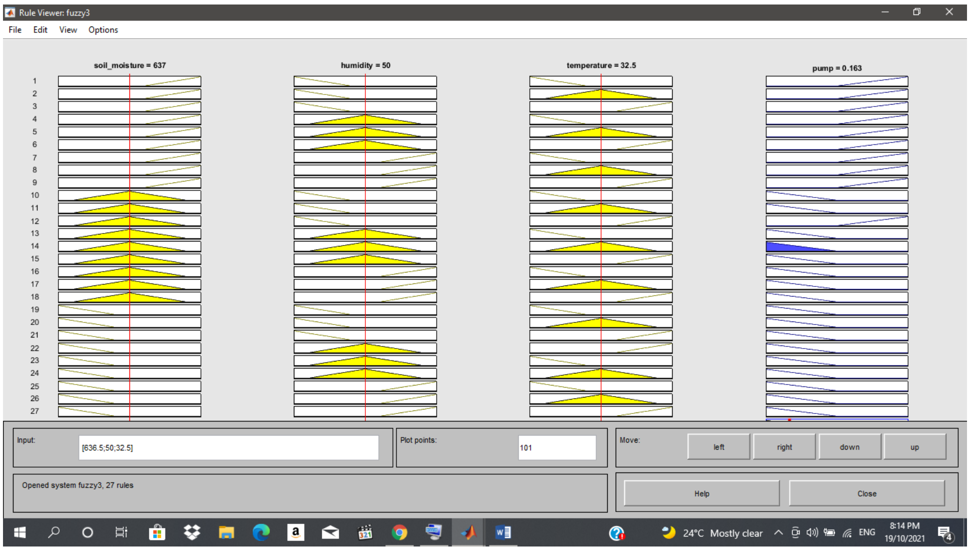

Figure 3-23: illustrates fuzzy rule viewer in MATLAB (b).

3.9 Interfacing the components with the Arduino

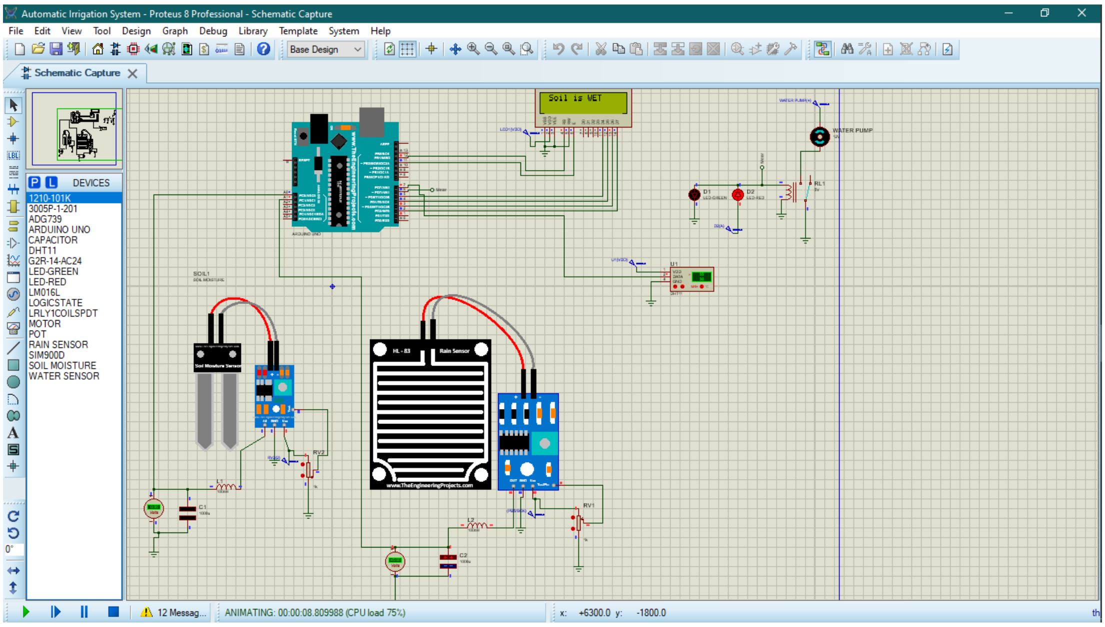

Figure 3.24: Shows the circuit and how the components connect with each other

3.9.1 Connecting Soil moisture sensor with Arduino UNO

Using jumper wires to connect 5v and GND pins of the Soil moisture sensor to another pin of the left column pins and the right column pin respectively. And connect the output pin of the Soil moisture sensor to the analog pin of the arduino uno A0.

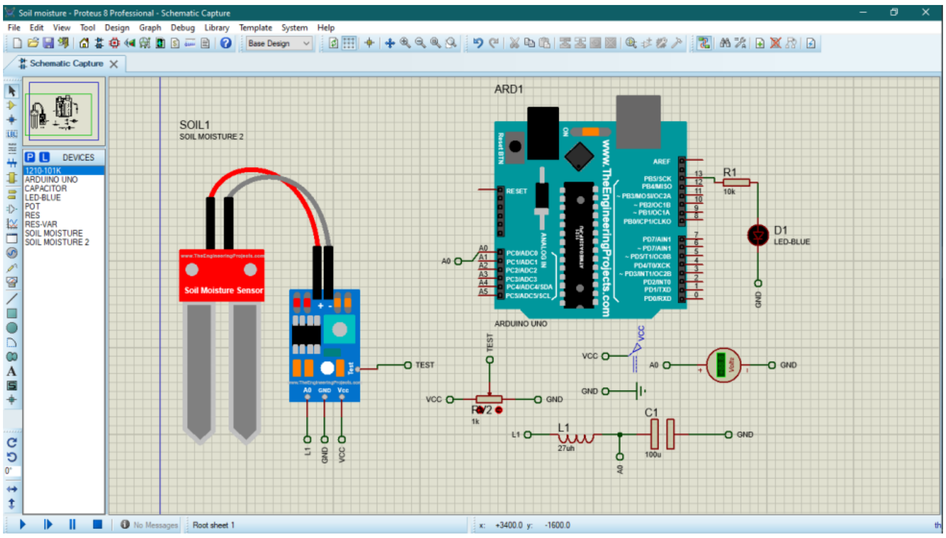

Figure 3.25: Connecting Soil moisture sensor with Arduino UNO

3.9.2 Connecting Rain sensor with Arduino UNO

Using jumper wires to connect 5v and GND pins of the Rain sensor to another pin of the left column pins and the right column pins respectively. And connect the output pin of the Rain sensor to the analog pin of the Arduino uno A1.

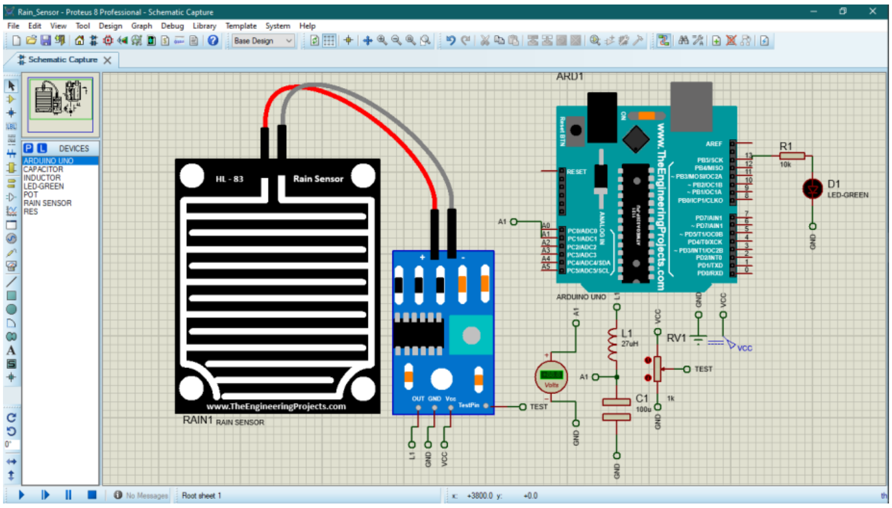

Figure 3.26: Connecting Rain sensor with Arduino UNO

3.9.3 Connecting temperature and humidity sensor (DH11) with Arduino UNO

Using jumper wires to connect 5v and GND pins of the DH11 sensor to another pin of the left column pins and the right column pins respectively. And connect the data pin of the DH11 sensor to the digital pin of the Arduino uno Pin7.

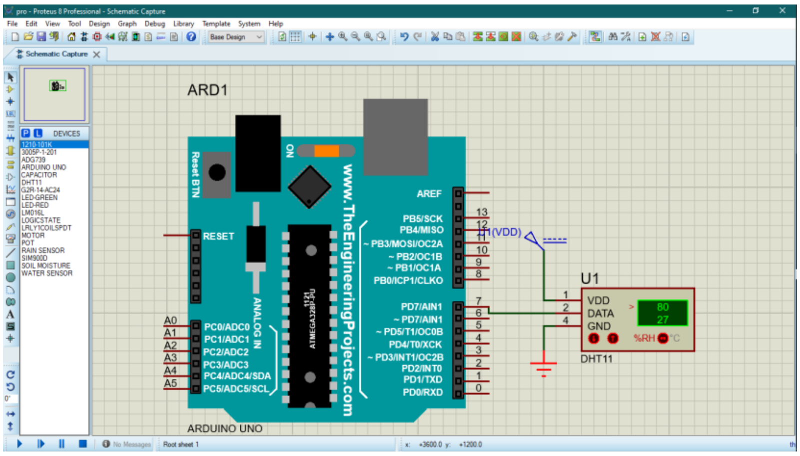

Figure 3.27: Connecting temperature and humidity sensor with Arduino UNO

3.9.4 Connecting LCD (LM016L) with Arduino UNO

Using jumper wires to connect the VDD pin of the LCD to another pin of the left column pins, and connect VSS, VEE and RW to three other pins of the right column pins. Then connecting pins RS, E, D4, D5, D6, and D7 of the LCD to pins Pin12, Pin11, Pin5, Pin4, Pin3, and Pin2 of the digital arduino pins.

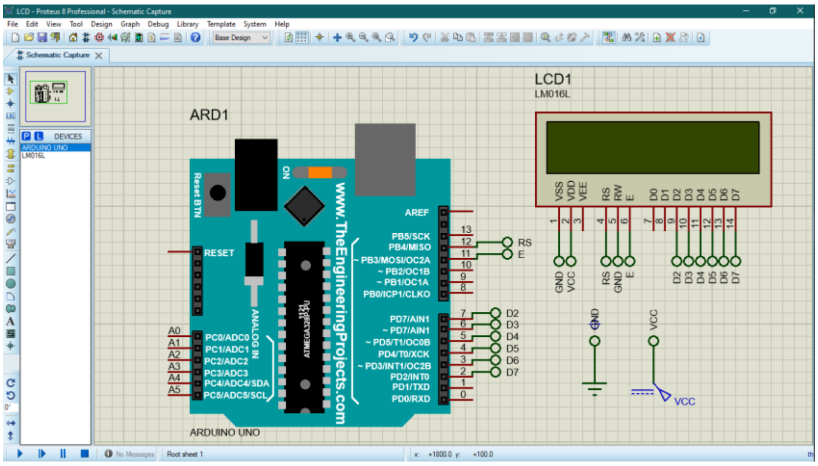

Figure 3.28: Connecting LCD (LM016L) with Arduino UNO

3.9.5 Connecting GSM module (SIM 900) with Arduino UNO

We need to select two **PWM** enabled pins of the arduino so we connect RDX and TDX to pins 9 and 8 respectively, and the GND pin of the GSM module connects to another pin of the right column pins of the white board.

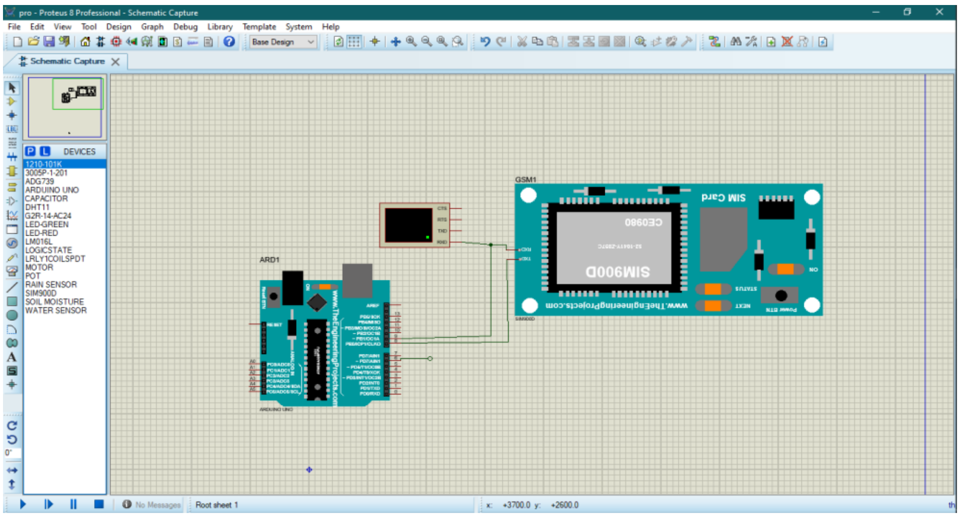

Figure 3.29: Connecting GSM module (SIM 900) with Arduino UNO

Chapter Four

Results and Discussions

4.1 Results

The figure: 4-1 shows the designed circuit prototype for the system, the sensors measure the temperature, humidity, and soil moisture status and displayed the data on the LCD then communicates with the user and sent him the data via SMS with the GSM module.

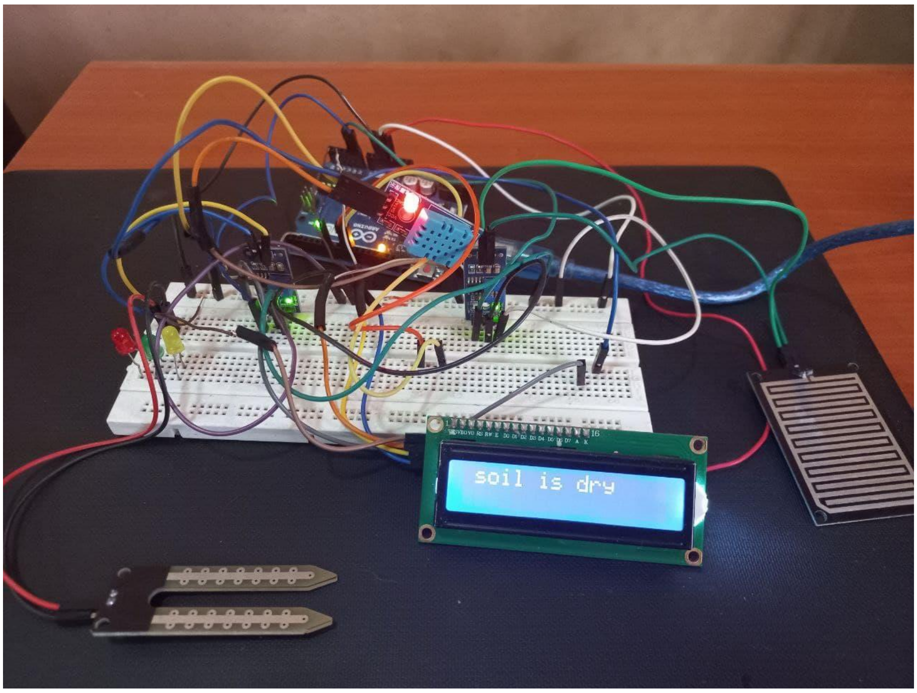

Figure 4-1: Soil moisture sensor status in the first case

Soil moisture varies depending on soil type and different seasons of the year. Each crop has its humidity need based on the required amount of water and the season of cultivation, so we took the results from mint planting in winter season, the soil moisture sensor is reading the moisture in rang of (1023-143) the temperature sensor is reading the temperature in a certain time, humidity sensor is reading the humidity in the same certain time and displays the results on the LCD.

When the system starts, the GSM Module send a confirmation message to the user that the system is on, as shown in the figure bellow:

Figure 4-2: confirmation message from the system

The GSM module sent the mode selecting message to the user:

Figure 4-3: Choosing operation mode

The user selected the automatic operation mode:

Figure 4-4: selecting the automatic operation mode

4.1.1 The first case

In this case, the soil moisture value is equal to 1020, it is greater than 800 mL this means the soil is dry, the temperature is 26c that means it's cool, the humidity is 45% that means its medium based on these readings the Arduino will run the pump and the water starts to flow.

Figure 4-5: Soil moisture sensor status in the first case

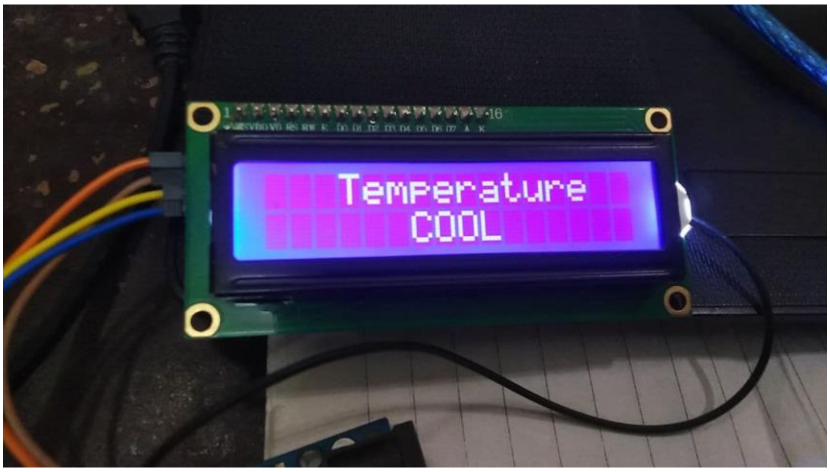

Figure 4-6: Temperature sensor status in the first case

Figure 4-7: Humidity sensor status in the first case

Figure 4-8: pump status in the first case

4.1.2 The second case

In this case, the soil moisture value is equal to 750, its greater than 450 and less than 800 this means the soil is not wet enough and the temperature is 27c and the humidity is 45% that means its medium, so the pump will keep the water flows.

Figure 4-9: Soil moisture sensor status in the second case

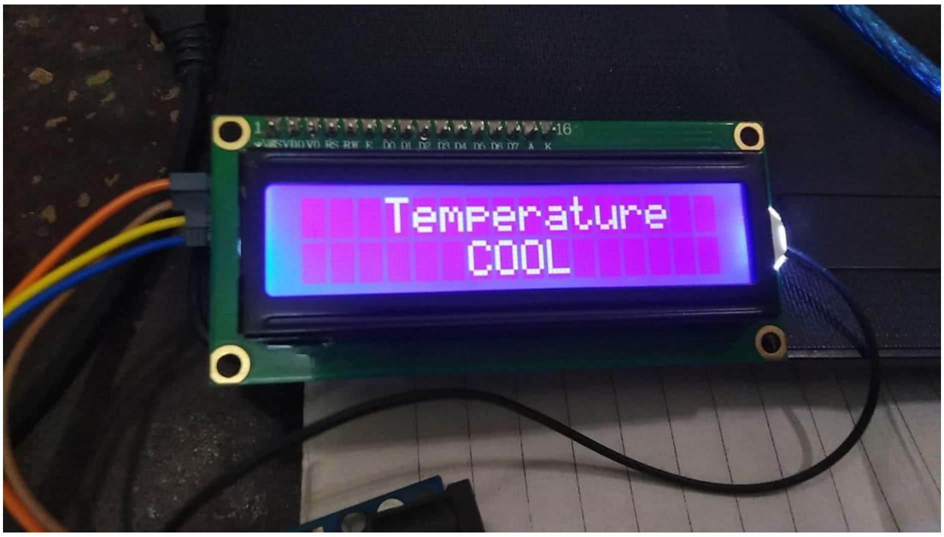

Figure 4-10: Temperature sensor status in the second case

Figure 4-11: Humidity sensor status in the second case

Figure 4-12: pump status in the second case

4.1.3 The third case

In this case, the soil moisture value is equal to 390, it was less than 450 and greater than 300 this means the soil is wet but its better to keep water flow, the temperature is 27c and the humidity is 45% that means its medium, so the pump will also keep water flow.

Figure 4-13: Soil moisture sensor status in the third case

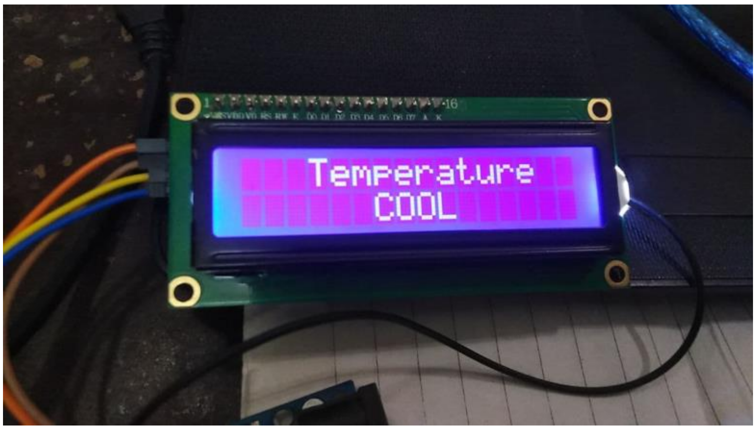

Figure 4-14: Temperature sensor status in the second case

Figure 4-15: Humidity sensor status in the third case

Figure 4-16: pump status in the third case

4.1.4 The fourth case

In this case, the soil moisture value is equal to 250 this means the soil is wet, the temperature is 27c and the humidity is 45% that means its medium, so the pump needs to stop water flow and the system sends a message to the user telling him that the pump is off.

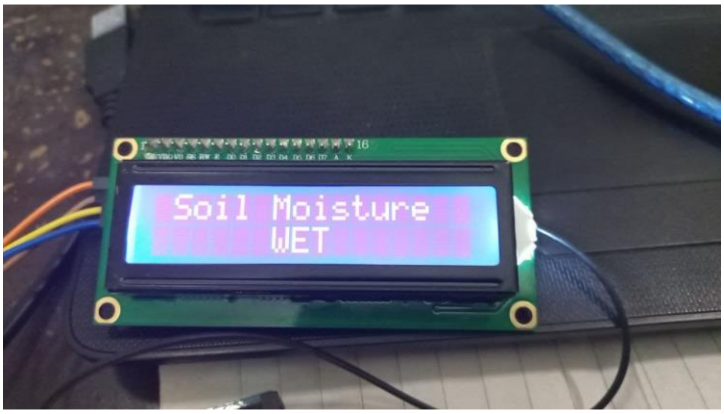

Figure 4-17: Soil moisture sensor status in the fourth case

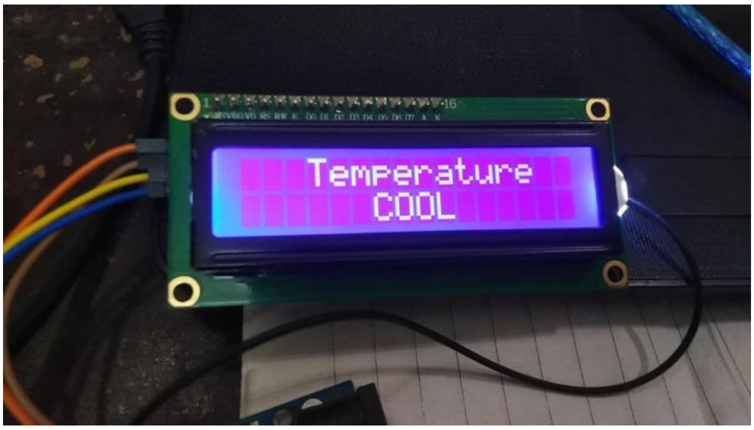

Figure 4-18: Temperature sensor status in the fourth case

Figure 4-19: Humidity sensor status in the fourth case

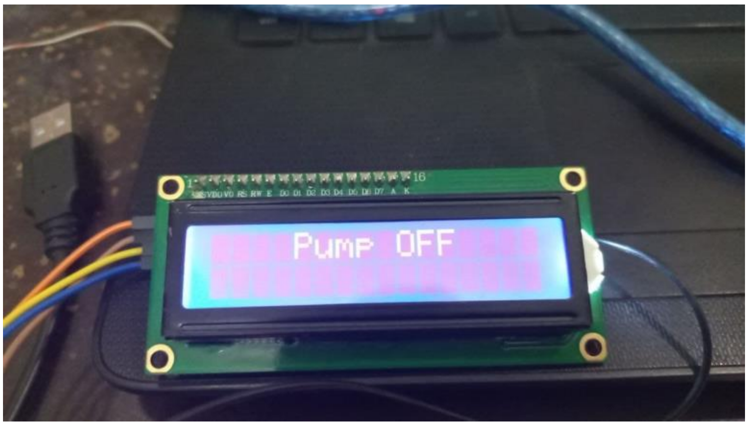

Figure 4-20: pump status in the fourth case

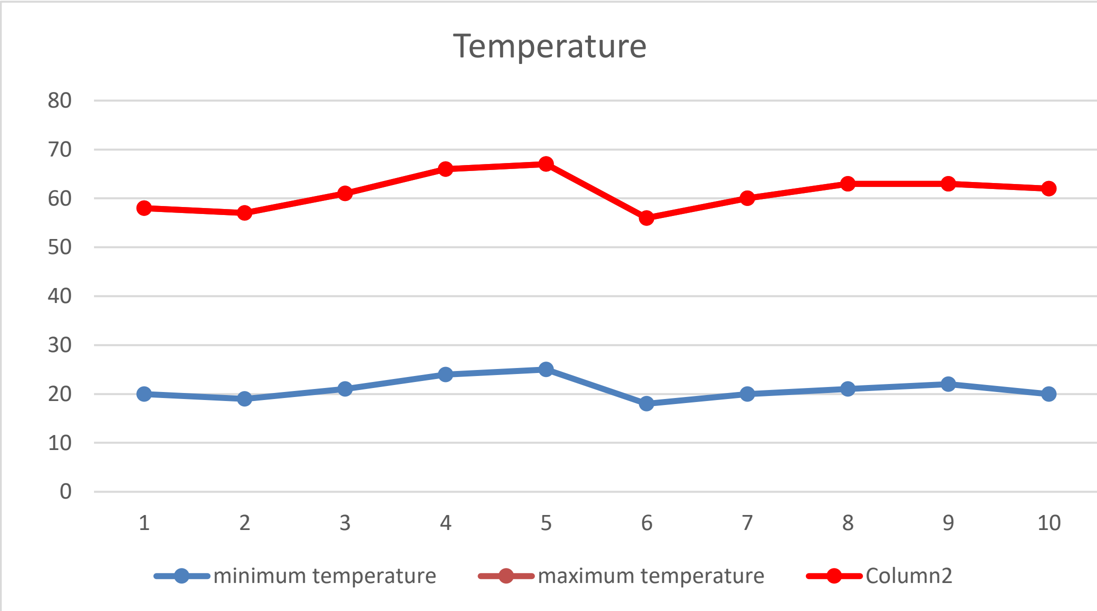

Figure 4-21: Temperature variation readings

4.2 Discussion

The fuzzy logic was applied to control the irrigation system based on the data coming from the sensors on a small area of 380 cm^2, where the area of an acre is 42,000,000 cm^2, meaning that the area on which the experiment was carried out is equal to 0.0905% of the area of an acre. The comparison was made between the traditional irrigation system and automated irrigation using logic. It was noticed that the amount of water consumed in traditional irrigation is 10% more than automatic irrigation, while ignoring the percentage of water evaporation in water and ignoring the percentage of water consumed in water delivery channels. It was found that the percentage of water savings can reach more than 10% of the amount of water consumed for irrigation, which saving 10% of water in acre the amount of water is nearly to 7000 gallon of water in each acre.

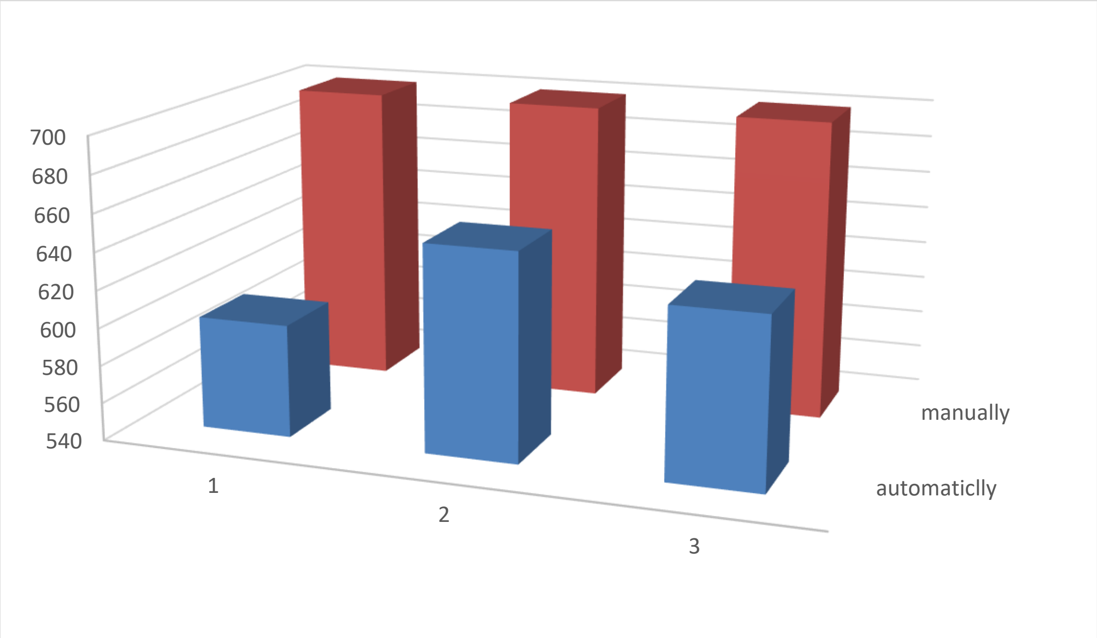

Figure 4-22: comparison of water consumption between irrigation systems

4.2.1 Plant health and growth

4.2.1.1 In case of water decrease

leads to the revocation of the bills and lending down as well as the wrap therapy and turning their color to yellow and then the edges will turn to brown and the confrontation.

4.2.1.2 In case of water increase

The plant is exposed to several changes, the leaves are turned into the yellow color gradually and transform the parties to the brown as well as the papers and the falling virginity that the roots of the water rose by the extension of water and their discharge properly.

4.2.2 Cost

4.2.2.1 Traditional systems

The traditional irrigation system which uses machines that depend on diesel fuel, the machine costs approximately 500,000SDG, taking into account the recurring cost of fuel, which costs 1800SDG per gallon, as well as paying workers and farmers to carry out the irrigation process, which costs 3000SDG per acre. Also, this system needs regular maintenance.

4.2.2.2 solar systems

For the irrigation systems using solar energy, it costs approximately 2,500,000SDG, and this cost is divided on pumps and solar energy installation.

4.2.2.3 Adding fuzzy logic Control

When the control circuit using fuzzy logic is added to the solar system, the cost becomes 2,600,000SDG, which returns to save the cost in the long term by saving workers and farmers rent for the irrigation process, as well as fuel cost and frequent maintenance. the next figure shows the long-term cost for each system.

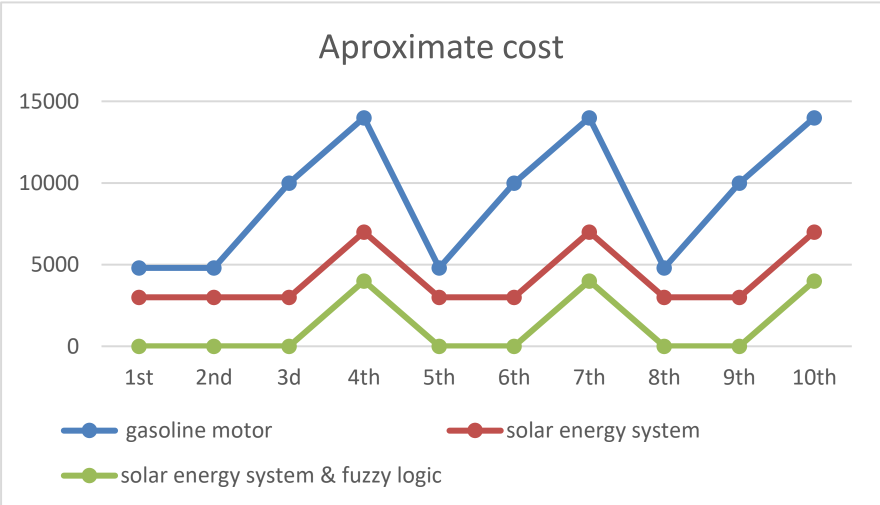

Figure 4-23: long-term cost for 3 different systems

Chapter Five

Conclusions and Recommendations

Conclusion

It has been verified from the experiments that excellent result is achieved such as low manual labor cost and effective usage of water for irrigation through the automatic irrigation system.

The use of the fuzzy control maintains the soil moisture above the user - defined value and eliminates the risk of under irrigation.

The obtained results show the efficiency and reliability of the system during winter seasons for a small area, which can be generalized by expanding the area to hectares.

It is very important to make water for everybody's business. Every household and community have to become involved in the provision of water and in the protection of water resources.

5.2 Recommendations

Modern electronic equipment can be used to automate all the agricultural processes in order to achieve more efficiency.

The Internet of Things (IoT) is the natural choice for smart water management applications, which will facilitate both growers and farmers to minimize effort, cost and time.

Solar energy is a suitable energy source, as it satisfies both the prerequisites of cost-effectiveness and energy-efficiency.

Controlling and monitoring this system will be easier and more efficient by using a mobile application with Graphical User Interface (GUI).

Future expedition should be in consideration for the system prototype in order to be applied in wide area projects to control the gates of irrigation channels.

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APPENDIX

A. The code

```
#include <Adafruit_Sensor.h>

#include <DHT.h>

#include <DHT_U.h>

#include <Wire.h>

#include <LiquidCrystal_I2C.h>

#define DHTPIN 2  // Digital pin connected to the DHT sensor

#define DHTTYPE    DHT11     // DHT 11

#include <SoftwareSerial.h>

SoftwareSerial sim(10, 11);

int _timeout;

String _buffer;

String number = "+2499000000000"; //-> change with your numb

int motor_ON = 8;

int motor_OFF = 7;

int rain_sensorPin = A1;

int rain_sensorValue;

int soil_sensorPin = A0;

int soil_sensorValue;

DHT_Unified dht(DHTPIN, DHTTYPE);

LiquidCrystal_I2C lcd(0x27,20,4);  // set the LCD address to 0x27 for a 16 chars and 2 line display

uint32_t delayMS;

void setup() {

  Serial.begin(9600);

  dht.begin();

  lcd.init();                      // initialize the lcd

  lcd.init();
```

```
  lcd.backlight();
  pinMode(7, OUTPUT );
  pinMode(8, OUTPUT );
  lcd.setCursor(4,0);
  lcd.print("System ON");
  delay(2500);
  lcd.clear();
  lcd.setCursor(1,0);
  lcd.print("Atomatic Mode");
  delay(2500);
  lcd.clear();
}
void SendMessage()
{
  //Serial.println ("Sending Message");
  sim.println("AT+CMGF=1");    //Sets the GSM Module in Text Mode
  delay(200);
  //Serial.println ("Set SMS Number");
  sim.println("AT+CMGS=\"" + number + "\"\r"); //Mobile phone number to send message
  delay(200);
  String SMS = "System ON \n Operation Mode";
  sim.println(SMS);
  delay(100);
  sim.println((char)26);// ASCII code of CTRL+Z
  delay(200);
  _buffer = _readSerial();
}
void RecieveMessage()
{
  Serial.println ("SIM800L Read an SMS");
  sim.println("AT+CMGF=1");
```

```
  delay (200);
  sim.println("AT+CNMI=1,2,0,0,0"); // AT Command to receive a live SMS
  delay(200);
  Serial.write ("Unread Message done");
}
String _readSerial() {
  _timeout = 0;
  while  (!sim.available() && _timeout < 12000  )
  {
    delay(13);
    _timeout++;
  }
  if (sim.available()) {
    return sim.readString();
  }
}
void fuzzy (){
[System]
Name='fuzzy3'
Type='mamdani'
Version=2.0
NumInputs=3
NumOutputs=1
NumRules=27
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'
[Input1]
Name='soil_moisture'
```

```
Range=[250 1023]

NumMFs=3

MF1='Wet':'trimf',[-59.2 250 559.2]

MF2='Medium':'trimf',[327.3 636.5 945.7]

MF3='Dry':'trimf',[713.8 1023 1332]

[Input2]

Name='humidity'

Range=[20 80]

NumMFs=3

MF1='Low':'trimf',[-4 20 44]

MF2='Medium':'trimf',[26 50 74]

MF3='High':'trimf',[56 80 104]

[Input3]

Name='temperature'

Range=[10 55]

NumMFs=3

MF1='Cold':'trimf',[-8 10 28]

MF2='Warm':'trimf',[14.5 32.5 50.5]

MF3='Hot':'trimf',[37 55 73]

[Output1]

Name='pump'

Range=[0 1]

NumMFs=2

MF1='Off':'trimf',[-0.351 -0.00921 0.49783315276273]

MF2='On':'trimf',[0.496749729144095 1 1.07]

}

}

void callNumber() {

  sim.print (F("ATD"));

  sim.print (number);

  sim.print (F(";\r\n"));
```

```
  _buffer = _readSerial();
  Serial.println(_buffer);
}
void loop() {
  rain_sensorValue = analogRead(rain_sensorPin);
  Serial.println("Rain Analog Value : ");
  Serial.println(rain_sensorValue);
 if (rain_sensorValue <= 500){
  lcd.setCursor(1,0);
  lcd.print("rainy ");
   delay(2500);
  lcd.clear();
 }
 else if (rain_sensorValue >= 500)
  {
  lcd.setCursor(1,0);
  lcd.print("no rain");
  delay(2500);
  lcd.clear();}
  delay (200);
   soil_sensorValue = analogRead(soil_sensorPin);
  Serial.println("Soil Analog Value : ");
  Serial.println(soil_sensorValue);
  if (soil_sensorValue<=500){
  lcd.setCursor(1,0);
  lcd.print("soil is wet");
  rain_sensorValue = analogRead(rain_sensorPin);
  Serial.println("Rain Analog Value : ");
  Serial.println(rain_sensorValue);
   delay(2500);
  lcd.clear();
```

```
}
else if(soil_sensorValue>=500){
lcd.setCursor(1,0);
lcd.print("soil is dry");
if (soil_sensorValue >= 500){
  digitalWrite(motor_ON, HIGH);
  digitalWrite(motor_OFF, LOW);}
else {
  digitalWrite(motor_ON, LOW);
  digitalWrite(motor_OFF, HIGH);      }
delay(2500);
lcd.clear()  }
delay (200);
  sensors_event_t event;
dht.temperature().getEvent(&event);
if (isnan(event.temperature)) {
  Serial.println(F("Error reading temperature!"));
  lcd.setCursor(0,1);
  lcd.print("T: error");
   delay(2500);
lcd.clear(); }
else {
  if (event.temperature>=20){
  Serial.print(F("Temperature: "));
  Serial.print(event.temperature);
  Serial.println(F("°C"));
  lcd.setCursor(1,0);
  lcd.print("hot");
   delay(2500);
lcd.clear();  }
  else if (event.temperature<=20){
```

```
  lcd.setCursor(1,0);
  lcd.print("Temperature is");
  lcd.setCursor(1,1);
  lcd.print("cold");
   delay(2500);
lcd.clear();    } }
 delay (200);
// Get humidity event and print its value.
dht.humidity().getEvent(&event);
if (isnan(event.relative_humidity)) {
  Serial.println(F("Error reading humidity!"));
  lcd.setCursor(8,1);
  lcd.print(",H: error");
   delay(2500);
lcd.clear(); }
else {
  if(event.relative_humidity>=50)
  {Serial.print(F("Humidity: "));
  lcd.setCursor(1,1);
  lcd.print("high");
   delay(2500);
lcd.clear();}
 else if(event.relative_humidity<=50){
  lcd.setCursor(1,0);
  lcd.print("humidity is");
  lcd.setCursor(1,1);
  lcd.print("low");
   delay(2500);
lcd.clear();}  }
delay(100);
```