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Development of a smart irrigation system

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Abstract

The agricultural sector significantly contributes to the economic growth of every country. This sector faces challenges with respect to producing the right quantity and quality of food. Most traditional methods used in irrigating crops consume a lot of water. In most countries, including Algeria, 70% of consumed freshwater used for irrigation due to location of most agricultural investments is the south of the country; in the desert which is have a hot climate. Therefore, adjusting irrigation can solve the problem of water security and reduce the cost of irrigations which is in most cases energy. The aim of this work is to shed light on irrigation systems, how they can be optimized and make them behave intelligently in Algerian farms. With the help of solar energy; which is the source that strongly available in Algeria.

Keywords: Wireless network sensor, Moisture sensor, water level sensor, microcontroller, intelligent irrigation.

Résumé

Le secteur agricole contribue de manière significative à la croissance économique de chaque pays. Ce secteur est confronté à des défis pour produire la bonne quantité et la qualité de la nourriture. La plupart des méthodes traditionnelles d'irrigation des éspaces agricoles consomment beaucoup d'eau. Dans la plupart des pays, dont l'Algérie, 70% de l'eau douce consommée utilisé pour l'irrigation en raison de l'emplacement de la plupart des investissements agricoles dans le sud du pays. Par conséquent, l'ajustement de l'irrigation peut résoudre le problème de la sécurité de l'eau et réduire le coût d'irrigations qui est dans la plupart des cas: l'énergie. Le but de ce travail est de jeter la lunière sur les systèmes d'irrigation, comment les optimiser et les faire fonctionner intelligemment dans les fermes algériennes. A l'aide de l'énergie solaire; qui est la source le plus disponible en Algérie.

Mots-clés: Capteur de réseau sans fil, capteur d'humidité, capteur de niveau d'eau, microcontrôleur, irrigation intelligente.

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To our brothers, and sisters, have never left our side and are very special.

To our best friends. We will always appreciate all they have done.

Contents

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List of Abbreviations

SMS Short Message Service

GSM Global System for Mobile Communications

LED Light Emitting Diode

ROM Read Only Memory

RAM Random Access Memory

LAN Local Area Network

WAN Wide Area Network

LCD Liquid Crystal Display

EPROM Erasable Programmable Read Only Memory

ADC Analog to Digital Converter

DAC Digital to Analog Converter

CPU Central Processing Unit

ASIC Application-Specific Integrated Circuit

IC Integrated Circuit

MCU MicroController Unit

PC Personal Computer

OS Operating System

ADSL Asymmetric Digital Subscriber Line

USB Universal Serial Port

DC Direct Current

AC Alternating Current

SRAM Static Random Access Memory

EEPROM Electronic Erasable Programmable Read Only Memory

PWM Pulse With Modulation

RF Radio Frequency

OSI Open Systems Interconnection

ACK Acknowledgement

SSD solid-state drive

HDD Hard Disk Drive

VM Virtual Machine

GNU General Public License

CLI Command Line Interface

IDE Integrated Development Environment

SBC Single Board Computer

General introduction

The Algerian population is predicted to be about 44 million at the end of the year 2020. The rapid population growth together with the rise of living standards requires effective measures that will increase food production hence ensuring food security.

The agricultural sector is currently facing challenges to achieve food security by providing sufficient food quantities of quality that meet health standards. To achieve food security, many investors in the agricultural field go to invest in southern Algeria, due to the large surface of agricultural lands and the support provided by the state for land reclamation in the south.

The artificial watering of plants named irrigation which is the central feature of agriculture. Many types of irrigation are available depending on the type of soil and the quantity of water the crop need. In Algeria and especially in the south of the country, drip irrigation, center pivot irrigation, and sprinkler irrigation are the most used irrigation types.

As the agricultural domain growth. The needs for automated irrigation are essential because of its advantages. As a result of this growth, several automated systems developed to make the process of irrigation easier. These automated irrigation systems face some limitations especially cellular network coverage in the case of SMS based systems or wasting water in the case of Timer systems.

Due to the limitations of existing systems, we propose a smart irrigation system that irrigates the crops automatically and intelligently without any human interaction and saves resources (water and fuel, electrical energy...).

In order to implement this system, we organize work into four chapters as follow:

- Chapter 1: titled irrigation. It defines the different types of irrigation systems, shows the existing automated works, and present the proposed solution.

- Chapter 2: titled embedded system and it shows a brief overview of the embedded systems.
- Chapter 3: titled realization devoted to the steps and phases done to implement the system and the functional aspect of the system.
- Chapter 4: titled Implementation: devoted to the implementation and realization of our system and its validation.

Chapter 1

Irrigation

1 Introduction

Irrigation is the central feature in agriculture. It is the process of watering the soil artificially using several technics. In this chapter, we are going to define the irrigation, the types of irrigation and the irrigation methods used now days. In addition, we discus the actual automated irrigation system and we will show our proposed smart irrigation system that solve problems and limitations of actual systems.

2 Definition

Water is essential to plant growth for millenniums. Successful farmers have used different methods to apply water to their crops. This artificial addition of water is called irrigation. Irrigation is essentially the artificial application of water to overcome deficiencies in rainfall for growing crops .

Irrigation is defined also as Artificially supplying systematically dividing of water for agriculture horticulture in order to obtain higher or qualitatively better production [1].

3 Types of irrigation

There are many different types of irrigation systems, depending on how the water is distributed throughout the field. Some common types of irrigation systems include:

3.1 Drip irrigation

Drip irrigation is sometimes called trickle irrigation and involves dripping water onto the soil at very low rates (2-20 liters/hour) from a system of small diameter plastic pipes fitted with outlets called emitters or drippers. Water is applied close to plants so that only part of the soil in which the roots grow is wetted (Figure 1.1), unlike surface and sprinkler irrigation, which involves wetting the whole soil profile. With drip irrigation water, applications are more frequent (usually every 1-3 days) than with other methods and this provides a very favorable high moisture level in the soil in which plants can flourish [2].

Figure 1.1: Drip irrigation

3.2 Center pivot irrigation

The center pivot system consists of one single sprayer or sprinkler pipeline of relatively large diameter, composed of high tensile galvanized light steel or aluminum pipes supported above ground by towers move on wheels, long spans, steel trusses and/or cables (Figure 1.2). One end of the line is connected to a pivot mechanism at the center of the command area; the entire line rotates about the pivot. The application rate of the water emitters varies from lower values near the pivot to higher ones towards the outer end by the use of small and large nozzles along the line accordingly [2].

Figure 1.2: Center pivot irrigation

3.3 Surface irrigation

The surface irrigation system (Figure 1.3) should replenish the root zone reservoir efficiently and uniformly so that crop stress is avoided, and resources like energy, water, nutrient, and labour are conserved. The irrigation system might also be used to cool the atmosphere around sensitive fruit and vegetable crops, or to heat the atmosphere to prevent their damage by frost. An irrigation system must always be capable of leaching salts accumulating in the root zone. It may also be used to soften the soil for better cultivation or even to fertilize the field and spread insecticides [2].

Figure 1.3: Surface irrigation

3.4 Localized irrigation

Localized irrigation (Figure 1.4) is a method of applying water that results in wetting only a small area of the soil surface and sometimes only part of the root zone. Water is applied near the base of the plant so that the application is concentrated in the root zone. Water is generally applied at a low flow rate, in small amounts, and frequently. The application devices may be small tubes, orifices, nozzles, or perforated pipes. The water may either be applied above or below the soil surface [2].

Figure 1.4: Localized irrigation

3.5 Sprinkler irrigation

In recent decades various sprinkler irrigation (Figure 1.5) methods and installations, both solid and portable, have been developed to meet farmers' needs. The most widely adopted and least expensive system for irrigating small to medium-sized farms is the piped hand-move system with a low to medium operating pressure (2.0–3.5 bars). The sprinklers are mounted at equal spacings (6–12 m) on the lateral pipelines laid across the field at predetermined intervals (called lateral positions) of 6–18 m so that the irrigation water is sprinkled uniformly over the area covered [2].

Figure 1.5: Sprinkler irrigation

3.6 Literal move irrigation

Water is distributed through a series of pipes as figure 1.6, each with a wheel and a set of sprinklers, which are rotated either by hand or with a purpose-built mechanism. The sprinklers move a certain distance across the field and then need to have the water hose reconnected for the next distance. This system tends to be less expensive but requires more labor than others [2].

Figure 1.6: Literal move irrigation

3.7 Sub-irrigation

Water is distributed across land by raising the water table as in the figure 1.7, through a system of pumping stations, canals, gates, and ditches. This type of irrigation is most effective in areas with high water tables [2].

Figure 1.7: Sub-irrigation

4 Irrigation methods

There are many factors which must be taken into account in the choice of an irrigation method [3]. Table 1.1 below, represents a comparison between different irrigation strategies:

	Surface irrigation	Drip irrigation	Sprinkler irrigation
Recommended crops	The rice fields, the pastures (alfalfa, clover), arboriculture (citrus, banana), cereals.	line crops (vegetables, fruits), arboriculture,vine	line crops, field crops and tree crops
Appropriate soil type	silty and clay soils	Clay and sandy soils	perfectly adapts to most types of soil
Equipment	Pump, irrigation, networks, sprinklers, cannons	The pumping unit, control unit, Main and secondary	The pumping unit main and approach pipelines
Workforce	Large workforce	Workforce economy	Workforce economy
Cost	Low cost of energy and investment	Low cost of energy and investment	High cost of energy and investment

Table 1.1: Comparison with most common irrigation methods

5 Existing automated irrigation systems

Now days, there are two major automatic technics use in irrigation in Algeria: SMS systems and timer system. These systems are described below:

5.1 SMS systems

The basic approach of this systems is using a Global System for Mobile Communications (GSM) module to receive phone calls or SMS messages and turn the irrigation system on or off based on the received SMS or call (Figure 1.8).

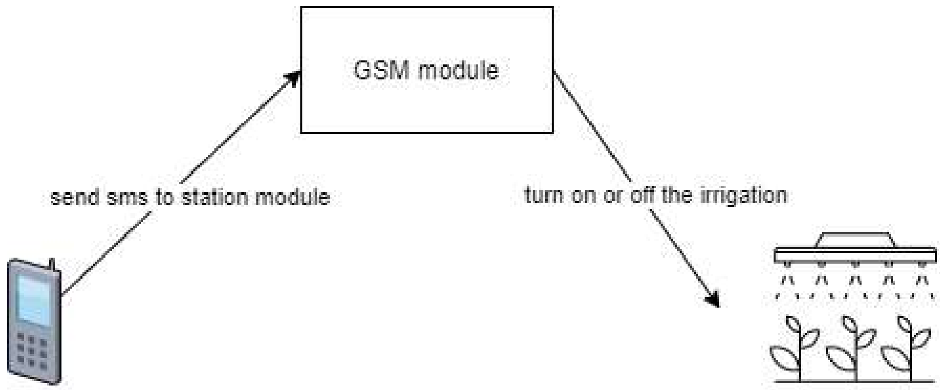

Figure 1.8: SMS automated irrigation system schema

The advantages of this system are there is no need to go to the farm for turning the irrigation system, all you need is to call the number of the GSM module and the irrigation process will automatically start.

As it has advantages, it also has disadvantages, we mention some of them:

- The system will only work in areas covered with cellular network.
- It need human interaction and it can damage the crops in case the farmer forgets to call the module.
- Can't control the amount of water consumed and can't monitor the soil moisture.

5.2 Timer systems

This systems is simple as the first one. It is based on timer that turn the irrigation system periodically and for a fixed duration. It used in crop that is not sensitive to amount of water (Figure 1.9).

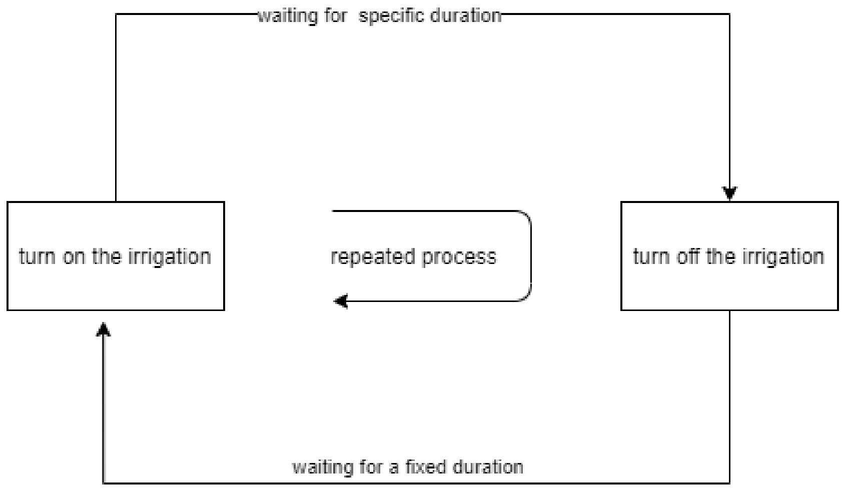

Figure 1.9: Timer automated irrigation system schema

This technic more advantages then the first, and among these advantages:

- No human interaction.
- Low cost.
- It can be applied to various irrigations types.

The disadvantages of this technic are:

- Can't control the amount of water consumed and the moisture of the land.
- Can't monitor the irrigation process.
- It causes some damage to the crop in case of rain.
- The farmer can't know if the irrigation system failed or not.
- Resources consumption are high.

6 Related works

Several studies that address irrigation issues are found in literature, as follows:

1) Automated irrigation system using solar power in Bangladesh. This study was applied in the rice field in Bangladesh. The primary goal of this gadget is to balance out the level of water in agricultural fields to avoid losing the merchandise due to floods. The sensor sends a message from the field to an operator mentioning the level of water within the area and mentions whether it is expected to increase or decreases. The operator, then, controls the pump to regulate the water level accordingly [4].

2) Design and implementation of an Automatic irrigation system in Nigeria. The basic idea is to rely on the type of soil and the amount of water needed by each one. This process is carried out by measuring the level of moisture in each type and using the pump to supply water. The result indicates that sandy soil requires less water than clay soil [5].

3) Automated Irrigation System based on GSM for use of resource and crop planning in India. This device is placed on agricultural lands and works by using Bluetooth or GSM signal. The goal of this device is to monitor the humidity and temperature in the agricultural land in addition to monitoring the state of the climate through the weather temperature, humidity, and dew drops. It, then, sends a text message to the user's machine[6].

7 Our proposed system

Based on the limits of actual automated systems, we propose a solution that can irrigate crop automatically and intelligently without human interaction. It measures the temperature, humidity, soil moisture and energy level available for pumping the water. Then, retrieve the weather forecast.

After collecting the necessary data, the system takes a decision wheatear starting the irrigation or not based on collected data and crops need which is supplied as file describe the need of the crop in every month. In addition, it monitors the process of the irrigation and notify the user in case of irrigation failure.

The system is able to notify the farmer in case of failure with three types of notification:

- SMS in case of area covered with cellular network
- Push notification or email in case the system directly connected to the internet
- Alarm (Light Emitting Diode (LED)s and sound)

The figure 1.10 shows the steps that the system goes through in order to complete the watering process.

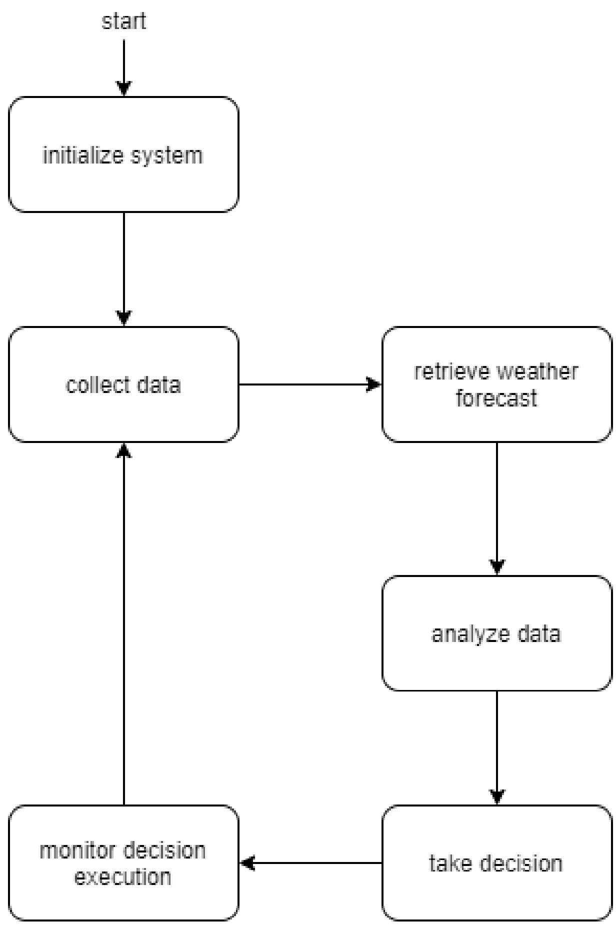

Figure 1.10: Proposed system

The agricultural land divided into small areas. Each area has measuring and actuators nodes which responsible for irrigating the area. These nodes are communicating with each other wirelessly.

We can classify these nodes into three categories based on their function as bellow:

- Measuring nodes: responsible for measuring temperature humidity and soil moisture.
- Actuators nodes: responsible for turning the irrigation in areas.
- Pump nodes: responsible for turning the pump of water.

Every node needs to communication with a central processing unit to get the action or send the measured data (figure 1.11).

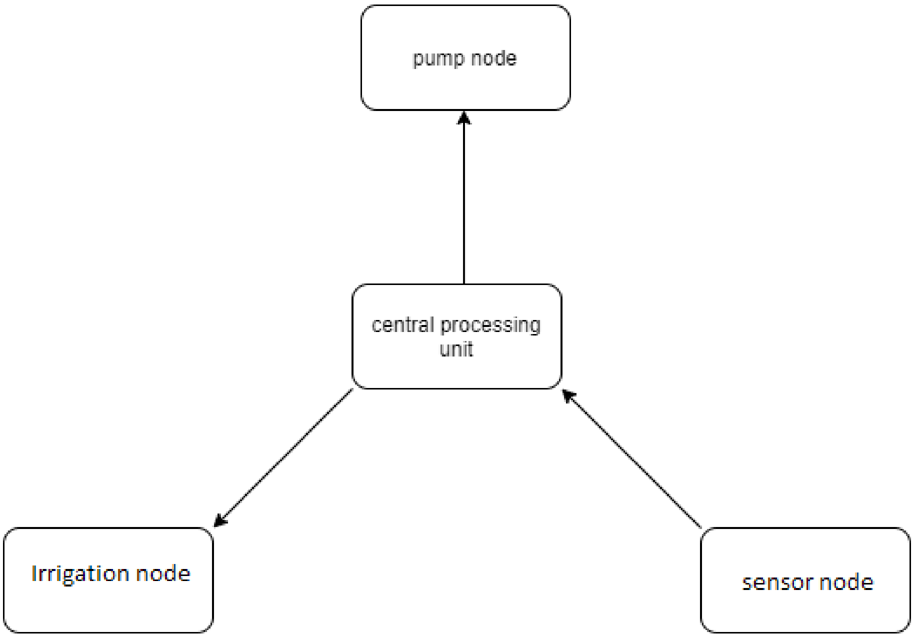

Figure 1.11: Smart irrigation system nodes

This system has many features that make the irrigation process reliable, safe and optimize. We summaries the feature bellow:

- Reduce the cost human resources.
- Irrigate the crop with the right water quantity.
- Reduce energy consumption by reducing irrigation times.
- Increase the quality of the crop and its quantity.
- Eliminate the risk of soil drought.
- Monitor the state of the crops.
- Fault tolerance.
- Environment friendly.

8 Conclusion

In this chapter, we define the irrigation and its types. Then, we show a table that compare most common irrigation types. After that, we present the automated irrigation system used now day in Algeria and some related works in the same domain. Finally, we present our proposed solution with a list of its feature.

Chapter 2

Embedded system

1 Introduction

Most devices, machines, or mechatronic systems used in daily life or industry are equipped with embedded systems thus they can be considered as the core of every electronic application field. biomedical, land transport and aeronautics, leisure electronics, machinery industry, household appliances, etc. In this chapter, we will present the basic characteristics and concepts of embedded systems.

2 Definition

An Embedded system is a special-purpose computer system that is designed to perform a small number of dedicated functions for a specific application [7]. It is a combination of computer circuitry and software that is built into the system for predefining purposes such as controlling, monitoring, and communication without human interaction.

An embedded system can be either an independent system, or it can be a part of a large system. It is mostly designed for a specific function or functions within a larger system [8].

Most modern electronic products around us are the result of the evolution of the embedded system.

3 History of embedded systems

One of the first examples of an embedded system is from the early 1960s. the Apollo spacecraft on-board computer, which brought N. Armstrong to the Moon. This computer-controlled flight parameter in real-time and adapted the trajectory. He worked in interactive mode.

Here, are the most important milestones from the history of embedded systems:

- In 1965, Autonetics developed the D-17B, the computer used in the Minuteman missile guidance system.
- In 1968, the first embedded system for a vehicle was released.
- Texas Instruments developed the first microcontroller in 1971.
- In 1987, the first embedded OS, VxWorks, was released by Wind River.
- Microsoft's Windows Embedded CE in 1996.
- By the late 1990s, the first embedded Linux system appeared.
- The embedded market reach $140 billion in 2013.
- Analysts are projecting an Embedded market larger than $40 billion by 2030.

4 Classification of embedded system

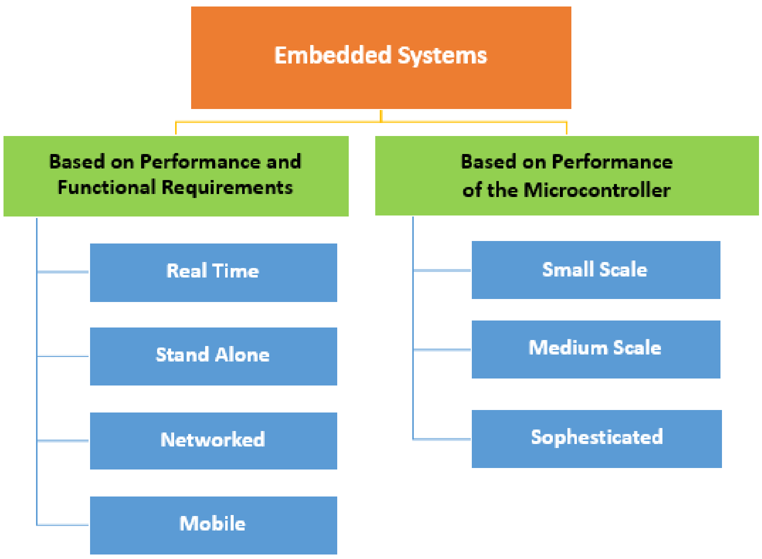

Figure 2.1: Embedded system classification

Embedded systems are classified based on two criteria: performance and functional component and performance of the microcontroller (Figure 2.1).

4.1 Performance and functional components

4.1.1 Standalone embedded system

It takes the inputs from the digital or analog input ports and processes, compute and gives the resulting data through connected output devices as an example displays [9].

4.1.2 Real-time embedded system

It gives a required output at a particular time. It follows the time deadline for completion of the task. Realtime embedded system is classified into two types soft and hard real-time embedded system based on time precision [10].

4.1.3 Networked embedded system

It is a system that allows accessing the resources remotely via a network which can be a Local Area Network (LAN) or Wide Area Network (WAN). The network connection can be either wired or wireless. This kind of embedded system is the fastest growing technological area in embedded systems [9].

4.1.4 Mobile embedded system

It is highly preferable in portable embedded devices like mobile phones, digital cameras, and home assistant ... The basic limitation of these devices is the other resources and limitations of memory [9].

4.2 Performance of the microcontroller

4.2.1 Small-scale embedded system

It consists of an 8-16-bit microcontroller. This system can perform tasks at a small level. They have on-chip Read Only Memory (ROM) and Random Access Memory (RAM). Small-scale systems can be even activated by the battery. The purpose of this system is not computation but to control as a computer embedded inside it. It behaves as a component of a computer and its function is not to compute. The small-scale system is dedicated to some specific task [9].

4.2.2 Medium-scale embedded system

This embedded system has 16-32-bit microprocessor or microcontroller with external RAM and ROM They can perform medium to complex level works. The integration between hardware and software is complex in these embedded systems [9].

4.2.3 Sophisticated embedded system

The embedded system which can do large-scale works with multiple 32-64-bit chips is known as sophisticated embedded systems. They can perform distributed work on a large scale. The complexity of hardware and software is very high in these systems. In sophisticated embedded systems, hardware, and software are assembled on a large scale, and designing hardware products is also included in these systems [9].

5 Characteristics of an embedded system

Some of the key characteristics of Embedded Systems are as mentioned below.

- All embedded systems do their task continuously and repeatedly over their lifetime.
- They are designed to perform a task within a certain time frame. It must therefore perform fast enough.
- Embedded systems are small-sized, shipper, and can work with less power.
- The program scripted for an embedded system is called a firmware and is stored on a read-only or flash memory.
- Embedded systems can either have no user interface or possess highly advanced graphical interfaces. It mainly depends on the purpose of the device or the function it is designed to carry out. Simple embedded systems use LEDs, buttons or Liquid Crystal Display (LCD) displays with simple menu options. Complex devices can use touch sensitive screens to provide flexibility and at the same time, minimize the need for space.
- Embedded systems are built to achieve certain efficiency and reliability levels.
- Microcontroller or microprocessors are used to design embedded systems.

- The hardware of an embedded system is used for security and performance.
- They are not always independent devices. Embedded systems form smaller parts of a much larger device that carries out a specific task. For instance, the Gibson Robot Guitar utilises an embedded system to tune the guitar strings but the primary function of the guitar is to play music. There are embedded systems in cars that carry out several assistive functions even though the main purpose is transportation.

6 Comparison with standards systems

	Embedded systems	**Standards systems**
Power	Use less power, most of embedded system use batteries as the main power and draw a power less than 5 watts	Use high power, need an electrical outlet and consume energy more than 30 watts
performance	Use microcontrollers which have low clock cycle (¡ 400 MHz) or sometimes small microprocessor	Most times, use CPUs with multiple cores and high frequency (more than 1 GHz)
Memory	Some kilobytes to megabytes of memory	Most of then have a memory more than 1 GB
Storage	Most embedded systems have permanent storage ROM which stores the firmware and user settings	They have a hundred of GB with multiple form factor of external storage devices
User experience	The user interface is simple: LEDs, sound, buzzers and in some case LCD	Sophistical user interfaces with complex input devices like mice or digital input.

Table 2.1: Comparison with standards systems

7 Benefits of an embedded system

Because embedded systems usually only have one function, they are able to operate with very little power consumption and can fit in a tiny space compared to other components. They are also very cheap, making them a hugely efficient way of controlling devices.

Embedded systems are also very low maintenance, rarely needing any hardware or programming changes. This makes them very useful for integrating into devices that don't need end-user servicing [9].

Because they only need to complete one task, over and over and over again, embedded systems are great for use in devices that don't need updating to work effectively. For example, a high proportion of aeroplane entertainment systems using embedded systems were able to run Windows XP for much longer than laptops - that was until Microsoft withdrew support [9].

8 Architecture

This architecture (Figure 2.2) can be different base on the use of the system. Some embedded system doesn't have a user interface, others don't have a diagnostic interface and sometimes the bootloader included into the firmware itself.

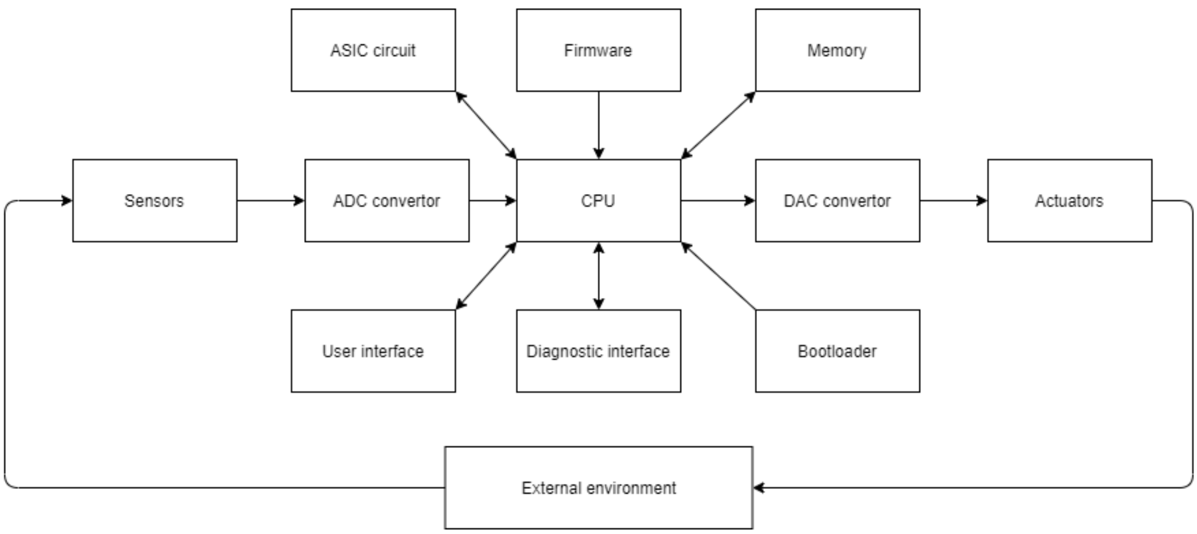

Figure 2.2: General architecture of an embedded system

As in figure 2.2, An embedded system has different part described as follow:

- CPU: This is the processor that receives and analyzes data, makes decisions, manages memory. . . .
- Memory: it is the part that responsible for storing data and is divided into two types RAM which is a volatile memory and ROM which stores the firmware and user settings.
- Firmware: it is hardware-specific computer software that provides low-level control over the device. It can embed an operating system and is burned into an Erasable Programmable Read Only Memory (EPROM) which is a special type of memory designed to store data for a long period without data loss and in a safe manner.
- Bootloader: A small piece of software specific for each firmware that runs before the operating system boots, It is responsible for creating a bridge between the actual hardware and the operating system in the firmware to make them boot successfully, it is also used as a firmware recovery in case of a failure.
- Analog to Digital Converter (ADC) and Digital to Analog Converter (DAC) converter: they are electronic circuits responsible for converting digital to an analog signal in the case of DAC and analog to a digital signal with the ADC. Embedded systems that interact with the external environment have these converters because most data retrieved from the external environment are analog signals.
- Sensors: In an embedded system, a sensor is a module; a device, or a subsystem whose purpose is to measure changes or detect events in the environment around it and send the information to the processor.
- Actuators: is a module; device or subsystem whose purpose is to applies action generated by Central Processing Unit (CPU) to the external environment.
- Diagnostic interface: it is an interface that has direct access to the whole system and capable of making changes to the embedded system as an example firmware upgrade or repair. Most of the time, it is used by a system designer or its expert.
- User interface: it is a simple and clean interface between the user and the system with minimal user experience.
- Application-Specific Integrated Circuit (ASIC) circuit: it is an Integrated Circuit (IC) designed to perform specific tasks faster than using the CPU.

Most embedded systems use a microcontroller (Figure 2.3) which is an IC that integrates a CPU, a fixed amount of RAM, ROM, some sensors, and converters.

A microcontroller is a compact integrated circuit designed to govern a specific operation in an embedded system. A typical microcontroller includes a processor, memory and input/output (I/O) peripherals on a single chip [8].

Sometimes referred to as an embedded controller or microcontroller unit (MicroController Unit (MCU)), microcontrollers are found in vehicles, robots, office machines, medical devices, mobile radio transceivers, vending machines and home appliances, among other devices. They are essentially simple miniature personal computers (Personal Computer (PC)s) designed to control small features of a larger component, without a complex front-end operating system (Operating System (OS)).

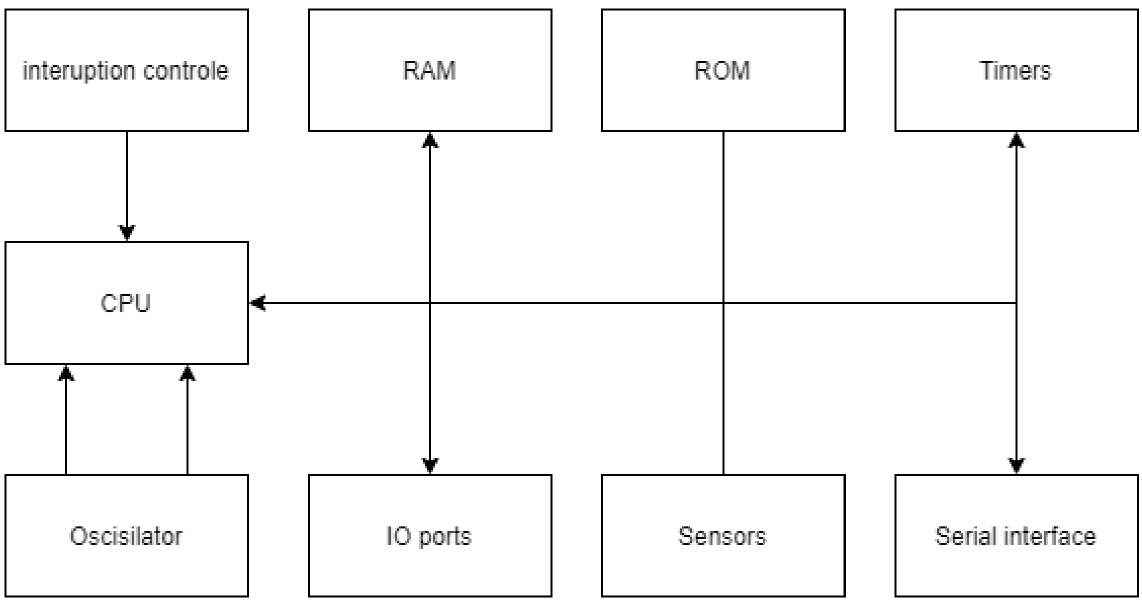

Figure 2.3: Microcontroller architecture

9 Example of an embedded system

Many of the devices we use in our daily life, such as phones, cars, washing machines, modems ... contain embedded systems. And to illustrate an embedded system we chose modem as an example of embedded systems, especially the Netgear DG632 as shown in the figure follows (Figure 2.4).

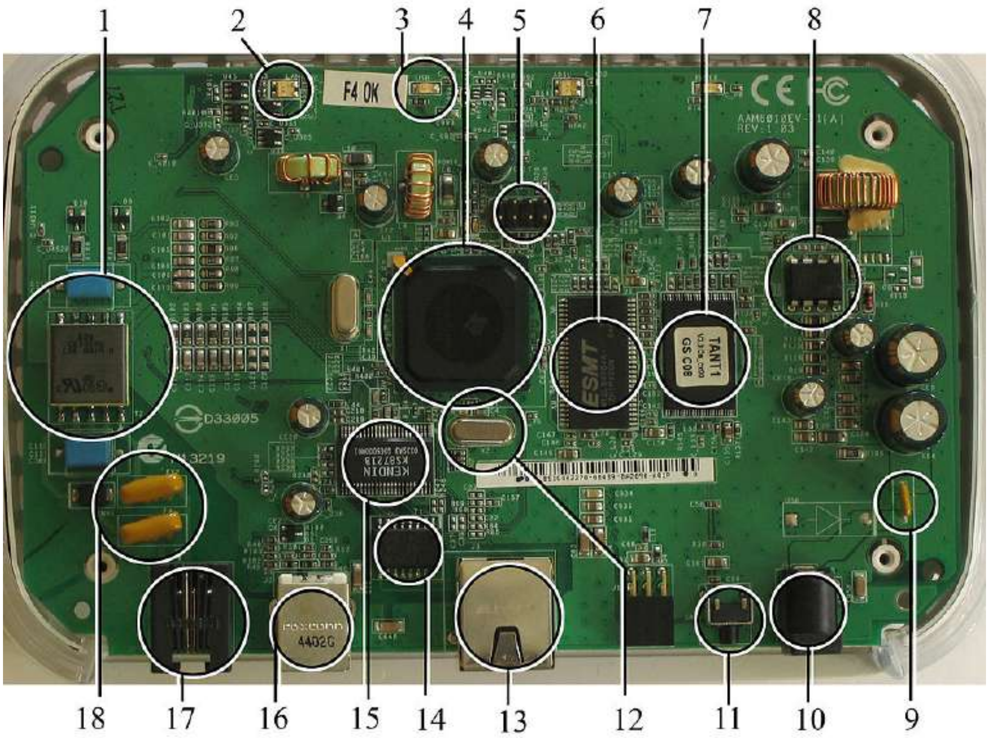

Figure 2.4: Netgear DG 632 board

The labeled parts are as follows:

- Telephone decoupling electronics (for Asymmetric Digital Subscriber Line (ADSL))
- Multicolour LED (displaying network status)
- Single color LED (displaying Universal Serial Port (USB) status)
- The main processor, a TNETD7300GDU, a member of Texas Instruments' AR7 product line
- JTAG (Joint Test Action Group) test and programming port
- RAM, a single ESMT M12L64164A 8 MB chip
- Flash memory, obscured by a sticker
- Power supply regulator
- Main power supply fuse
- Power connector
- Reset button

- Quartz crystal
- Ethernet port
- Ethernet transformer, Delta LF8505
- KS8721B Ethernet PHY transceiver
- ADSL port
- Telephone (RJ11) port
- Telephone connector fuses

10 Challenges of an embedded system

Embedded systems certainly have their benefits, but equally, there are lots of limitations to a component that is so dependent on other elements of a totally enclosed system:

For starters, they are very hard to upgrade as their 'embedded' nature means they are sometimes in very deep or inaccessible places within the overall machine.

The deep level of embedded system integration also means it's hard to fix something when it goes wrong. Unlike modular systems, embedded systems are hard to re-program when in situ. This means it's very difficult to upgrade any software if a fault is found and even if it can be tweaked, it may have a knock-on effect on some of the other parts [9].

For a replacement to be successful and to effectively overcome issues, it's likely the entire device will need to be totally deconstructed with other components removed, with the part replaced and reprogrammed in order to work.

Often, it's more cost-effective for the whole machine to be replaced rather than a single part when labour costs and new component costs are combined.

However, in some cases, the embedded system's dependency on other components means that sometimes tweaks can be applied via other, more accessible parts [9].

11 Conclusion

Embedded systems are more and more apartments in industrial fields (control of industrial processes, etc.), professionals (post office and bank counters, credit cards chips, insurance cards, ...) or domestic (household appliances, games, ...). We depend on it more and more and they are expanding. Miniaturization, micro-computing, and developments in software engineering make it possible to have increasingly reliable systems and more efficient.

Chapter 3

Realization

1 Introduction

The realization phase is crucial in the development of embedded systems because it shows us the system from different aspects and in plain details. In this chapter, which is devoted to the realization of the system, we are going to explain in detail the different stages of the realization of our smart irrigation system.

Indeed, the realization of the smart irrigation system can be divided into two main parts which are the electronic part and the central processing unit.

2 Electronic part

This part of the project mainly aims to establish the link between the software and the external environment. The electronic part determines the optimal position of the sensors, ensures that they can accomplish their task, and ensures the communication between the nodes and the central processing unit.

2.1 Components

2.1.1 Arduino Nano R3

The Arduino Nano R3 (Figure 3.1) is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.x). It has more or less the same functionality of the Arduino Duemilanove but in a different package. It lacks only a Direct Current (DC) power jack and works with a Mini-B USB cable instead of a standard one [11].

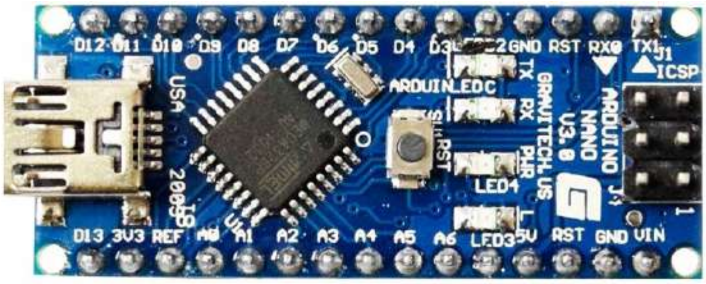

Figure 3.1: Arduino nano R3

- Technical specification

Specification	**Value**
Microcontroller	ATmega328
Architecture	AVR
Operating Voltage	5 V
Flash Memory	32 KB of which 2 KB used by the bootloader
Static Random Access Memory (SRAM)	2 KB
Clock Speed	16 MHz
Analog IN Pins	8
Electronic Erasable Programmable Read Only Memory (EEPROM)	1 KB
DC Current per I/O Pins	40 mA (I/O Pins)
Input Voltage	7-12 V
Digital I/O Pins	22 (6 of which are Pulse With Modulation (PWM))
PWM Output	6
Power Consumption	19 mA
Board size	18 x 45 mm
Weight	7 g

Table 3.1: Arduino nano R3 specifications

2.1.2 DHT22

DHT is very basic and slow temperature and humidity sensors, but are great for hobbyists who want to do some basic data logging. The DHT sensors are made of two parts, a capacitive humidity sensor, and a thermistor. There is also a very basic chip inside that does some analog to digital conversion and spits out a digital signal with the temperature and humidity. The digital signal is fairly easy to read using any microcontroller [12].

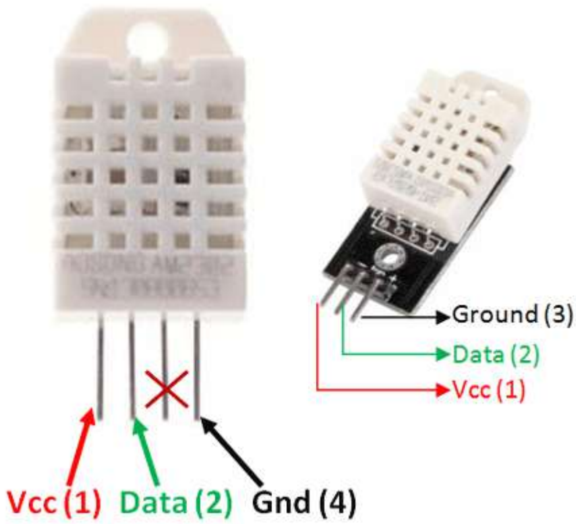

Figure 3.2: DHT22 temperature and humidity sensor

There are two versions of the DHT sensor: DHT11 and DHT22 as in figure 3.2, they look a bit similar and have the same pinout, but have different characteristics. We choose DHT22 because it is more accurate then DHT11.

- Technical specification

Specification	**Value**
Operating Voltage	3 V to 5 V
Humidity	0 – 100 % with 2.5 accuracy
Temperature	-40 – 80*C with +-0.5*C accuracy
Sampling rate	0.5 Hz once every 2 second
Body size	15.1mm x 25mm x 7.7mm
Input Voltage	7-12 V
Power Consumption	Max 2.5 mA
IO pins	4 pins with 0.1ŝpacing

Table 3.2: DHT22 sensor specifications

2.1.3 Capacitive soil moisture sensor

Capacitive Soil Moisture Sensor (Corrosion Resistant) is a soil moisture sensor based on capacitance changes (Figure 3.3). Compared with resistive sensors, capacitive sensors do not require direct exposure of the metal electrodes, which can significantly reduce the erosion of the electrode [12]s.

Figure 3.3: Capacitive soil moisture sensor

- Technical specifications

Specification	Value
Operating Voltage	3.3 V to 5.5 VDC
Output Voltage	0 3.0 VDC
Interface	2.0-3P
Dimension	98mm * 23mm (3.86in x 0.905in
Weight	15g

Table 3.3: Capacitive soil moisture sensor specifications

2.1.4 Nrf24l01 wireless transceiver

NRF24L01is (Figure 3.4) a popular 2.4GHz RF wireless Transceiver Module among Arduino Users. Regarded highly for its cost to performance ratio, it features specs that's one of the best in its league [13].

The operating voltage of the module is from 1.9 to 3.6V, but the good news is that the logic pins are 5-volt tolerant, so we can easily connect it to an Arduino or any 5V logic microcontroller without using any logic level converter [13].

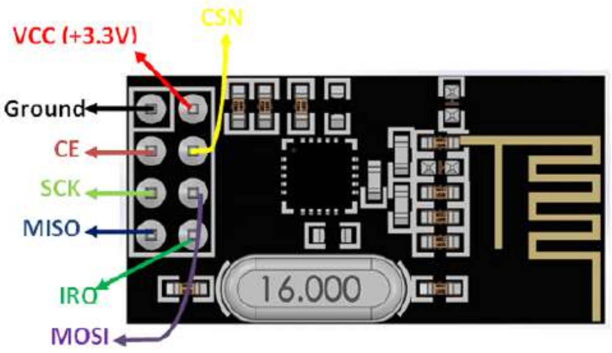

Figure 3.4: Nrf24l01 wireless transceiver

The module supports programmable output power viz. 0 dBm, -6 dBm, -12 dBm or -18 dBm and consumes unbelievably around 12 mA during transmission at 0 dBm, which is even lower than a single LED. And best of all, it consumes 26 µA in standby mode and 900 nA at power down mode. That's why they're the go-to wireless device for low-power applications [13].

- Technical specifications

Specification	**Value**
On the air data rate	1 or 2Mbps
Operating Voltage	3.3 VDC
Operating current	250 mA
Range	0 1000 m
Channel range	125 Radio Frequency (RF) channel operation
Communication Protocol	(SPI) speed 0-8 Mbps
Baud Rate	250 kbps - 2 Mbps.
Maximum Pipelines/node	6
Frequency	2.4GHz
Features	True single-chip GFSK transceiver Complete Open Systems Interconnection (OSI) Link Layer in hardware Enhanced ShockBurst™ Auto Acknowledgement (ACK) and retransmit Short switching time enable frequency hopping

Table 3.4: Nrf24l01 wireless transceiver specifications

2.1.5 Relay

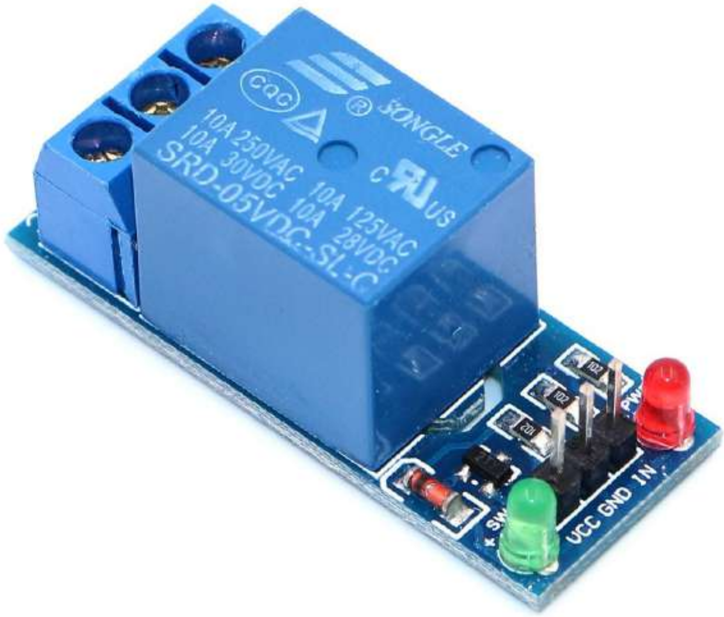

Figure 3.5: Relay

Relay is a switch that controls (open and close) circuits electromechanically. The main operation of this device is to make or break contact with the help of a signal without any human involvement in order to switch it ON or OFF. It is mainly used to control a high powered circuit using a low power signal. Generally, a DC signal is used to control circuit which is driven by high voltage [12].

- Technical specifications

Specification	**Value**
Working voltage	5 VDC
Maximum load	Alternating Current (AC) 250V/10A, DC 30V/10A
Trigger current	5 mA
Dimension	50 x 26 x 18.5mm (L x W x H)
Weight	31g

Table 3.5: Relay specifications

2.1.6 Power circuit

Figure 3.6: Power management board

The most important thing when designing an embedded system is the power consumption optimization, especially when the system is not connected to a direct power source as in our system which uses batteries as the main power source, thus power consumption optimization is needed to extend the duration of nodes operations, also batteries are charged from solar panel so the batteries charge at day and discharge at night.

To achieve a low power consumption system, we use a board (Figure 3.6) with a 134n3p circuit to charge the 3.7 V batteries and supply 5 V to the system with the help of a voltage booster embedded in the board.

Using renewable energy sources to power the system saves a lot of money for farmers. Solar energy is available everywhere especially in agricultural lands because they didn't have mountains. As a result, we use solar energy as a power source to charge batteries of nodes.

2.2 Nodes

The smart irrigation system consists of groups of nodes working together to ensure safe irrigation. These nodes can be divided into three categories based on their functionality (Figure 3.7)

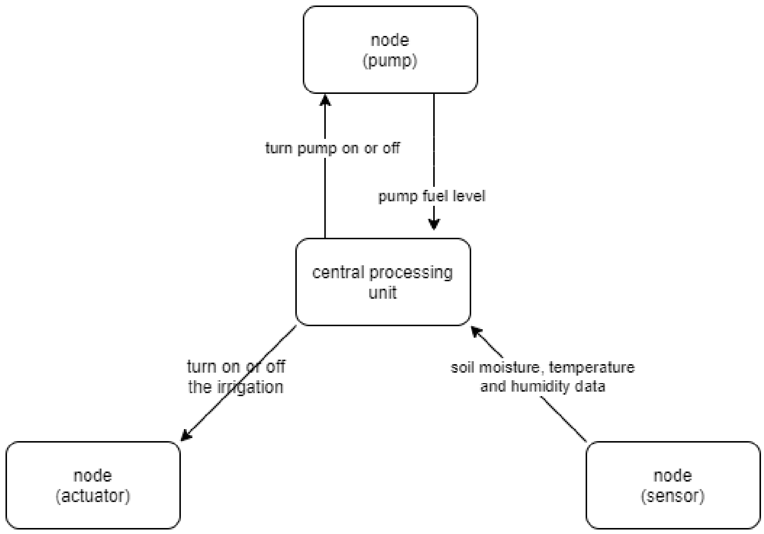

Figure 3.7: Nodes architecture

Each node can either communicates directly to the central processing unit or communicates indirectly to the central processing unit with the help of near nodes (based on their position) as described in the wireless communication topology section.

2.2.1 Sensor node

The main task of these types of nodes is measuring the soil moisture, temperature, and humidity periodically and send it back to the central processing unit with the help of near nodes. It consists of the basic power circuit, soil moisture sensor, dht22 sensor, and the wireless modular which is nrf24l01 as in figure 3.8.

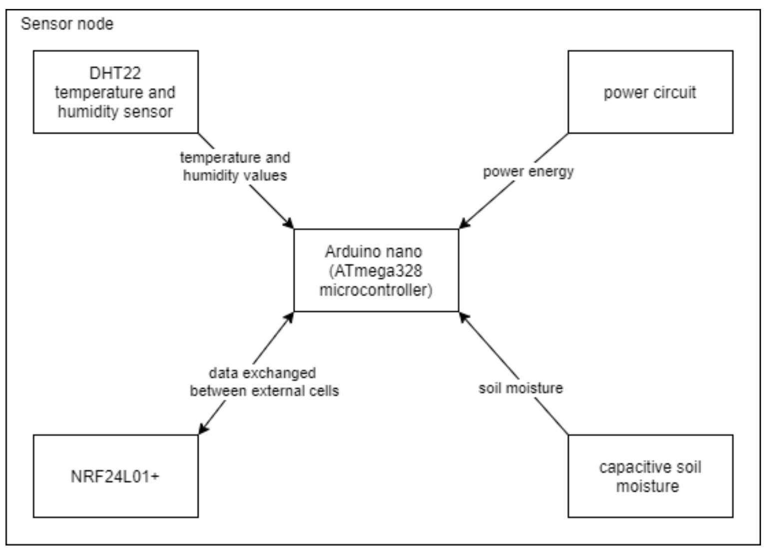

Figure 3.8: Sensor node schema

2.2.2 Pump node

The pump node is responsible for turning the pump on or off and ensures that the action received from the central processing unit is correctly executed. It can also measure the fuel level in case of a pump powered by fuel or checks whether the electrical energy is available in case of a generated electrical source.

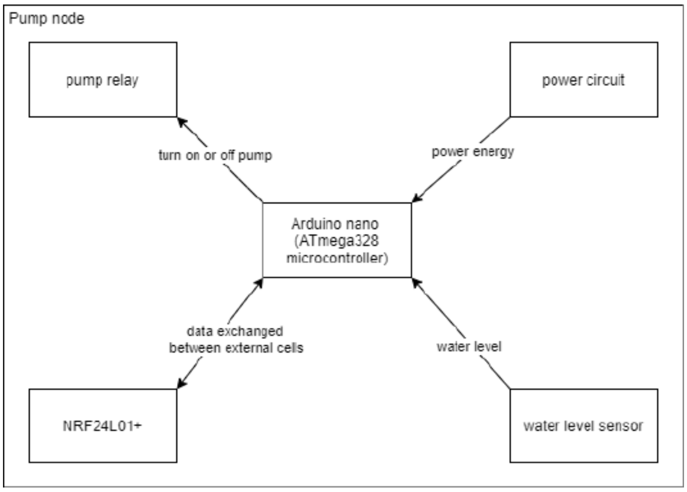

Figure 3.9: Pump node schema

These nodes may be different depending on the type of pump and the source of energy but in general, it consists of power circuit, microcontroller, nrf24l01, relay (Figure 3.9), voltage meter in case of electrical pump or water level sensor and in case of a pump that runs using fuel.

2.2.3 Irrigation node

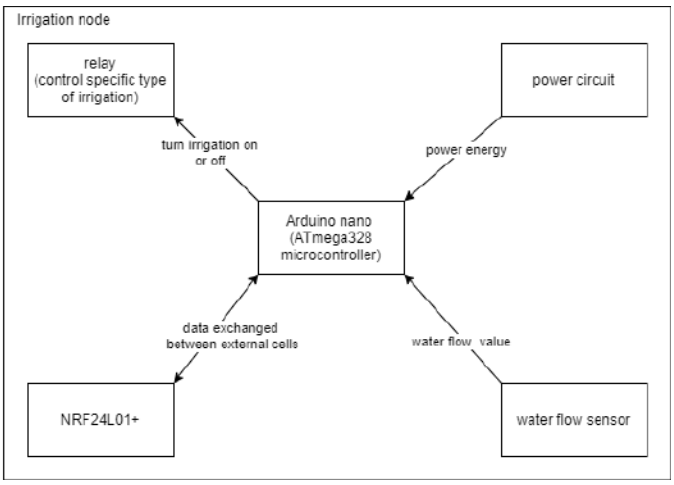

Figure 3.10: Irrigation node schema

This category of nodes is responsible for irrigating the right area of the land by turning the irrigation on or off. Each node has a different architecture than the other, based on the type of irrigation.

To illustrate the schema of the irrigation node, we choose the drip irrigation type which consists of a power circuit, microcontroller nrf24l01, electro vane, and water flow sensor.

In figure 3.10, the relay is the part of the irrigation node that depends on the type of irrigation. It can be used to switch an electro vane in case of drip irrigation or turn rotary pivot motor and electro valve at the same time...

2.3 Wireless communication topology

The agricultural lands are vast, which made us divide the cultivated area into small parts or areas, this division helps us to guaranties the monitoring of land and irrigate it intelligently. As a result, each area has its own monitoring node which can cover a small range (hundreds of meters). So, the idea of a protocol of communication born, and we try to find the best solution to allow communication between all nodes and the central processing unit without data loss.

This topology is like the mash topology, each node can communicate with the near nodes (Figure 3.11) to pass the data to the destination node. Figure 3.12 shows an example of agricultural land divided into 9 areas.

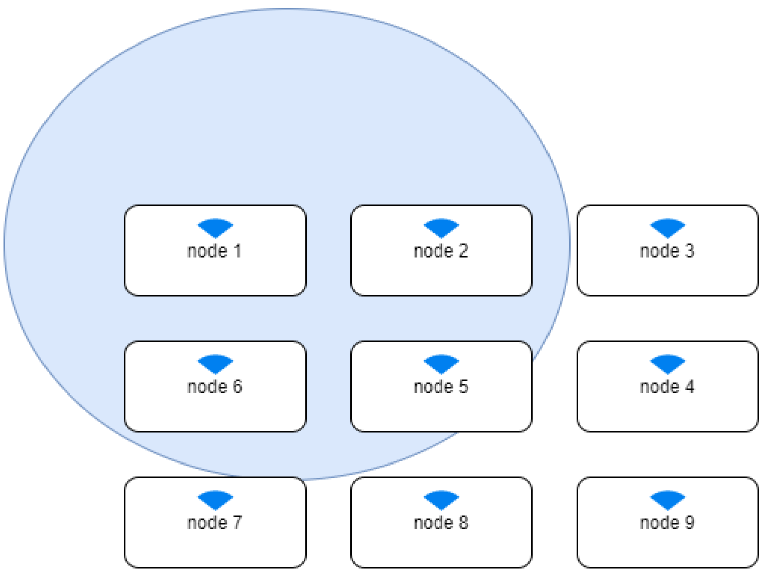

Figure 3.11: Node wireless communication range

The blue circle in figure 3.11 shows the coverred range by the node one. In this case, the node can cominicate with node 2,5, and 6.

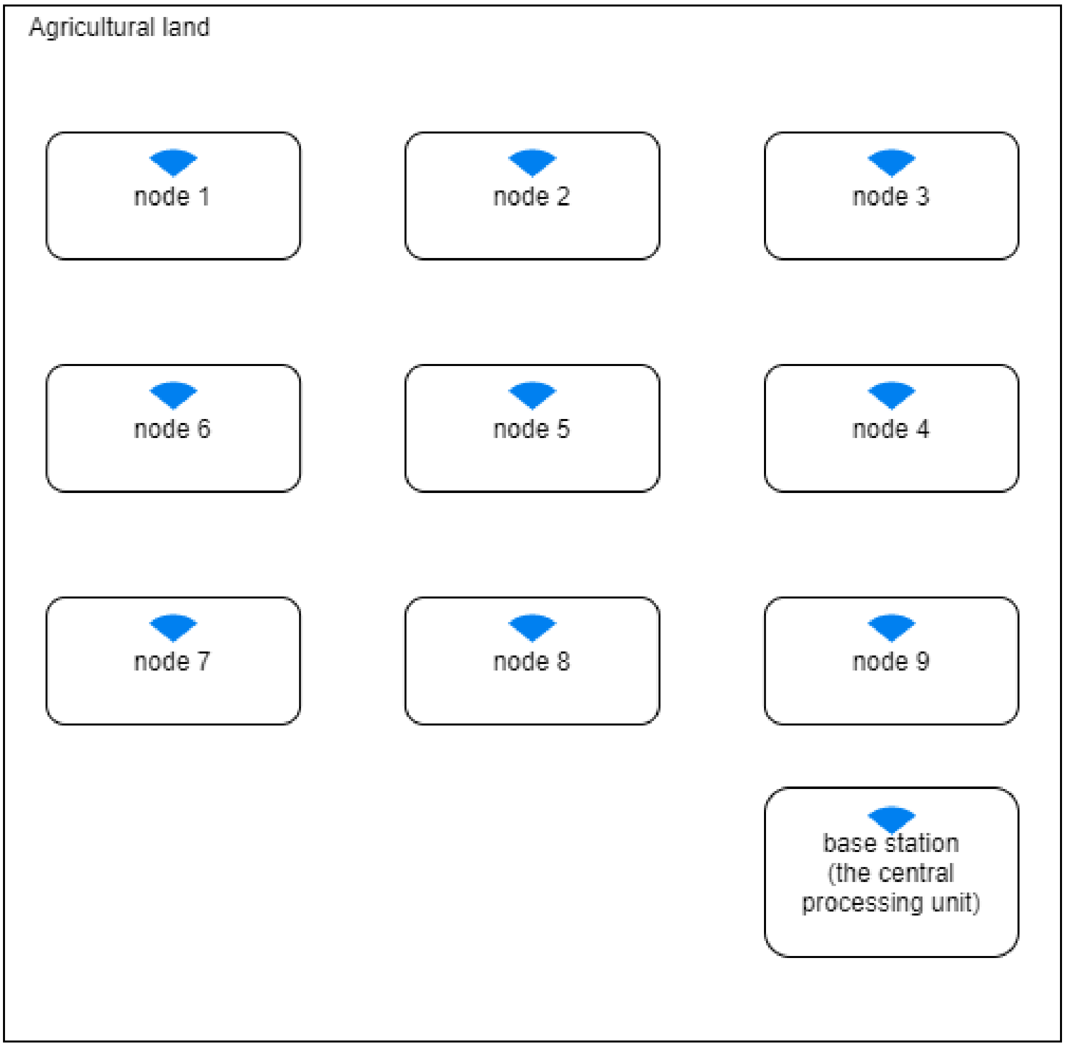

Figure 3.12: Node network organization

Each node in the network has an identification number, the last node is identified with 1 and the number is incremented until the nearest node to the processing unit which is identified with the biggest number. In order to send the measured data to the central processing unit the node that is identified with 1 start sending data periodically and all nodes execute this algorithm to guaranties the transmission and system reliability.

The algorithm below is executed by every node periodically yo transfer the message correctly. In case of failure, the algorithm returns the message to the preceding node and appends the failed nodes.

Algorithm 1: Node communication algorithm

```
Result: Transferring the data to the nearest node
constant:
 int const_time;
initialized_values:
 int node_id;
int[] near_nodes;
  int period = node_id  const_time ;
variable:
 int waiting_time;
  object received_data = null;
  object measured_data = null;
  boolean sent = false;
while waiting_time < period do
    waiting_time++;
    received_data = recieve();
    if received_data != null then
        measured_data = measure();
        if measured_data != null then
            append(measured_data, recieved_data);
            for int near_node_id in near_nodes do
                sent = send(recieved_data, near_node_id);
                if sent == true then
                    break;
            waiting_time =0;
            sent = false;
            measured_data = null;
            recieved_data = null;
measured_data = measure();
if measured_data != null then
    append(measured_data, recieved_data);
    for int near_node_id in near_nodes do
        sent = send(recieved_data, near_node_id);
        if sent == true then
            break;
waiting_time =0;
sent = false;
measured_data = null;
recieved_data = null;
```

3 Central processing unit

The central processing unit is the part that adds intelligent behavior to the system. It analyzes data received from sensors based on some criteria and take the best decision whether irrigating the area or not. Then send the action to the corresponding cell to execute it. In addition, to take decisions, it stores data received from sensors, and the action sent to actuators in databases for future analytics.

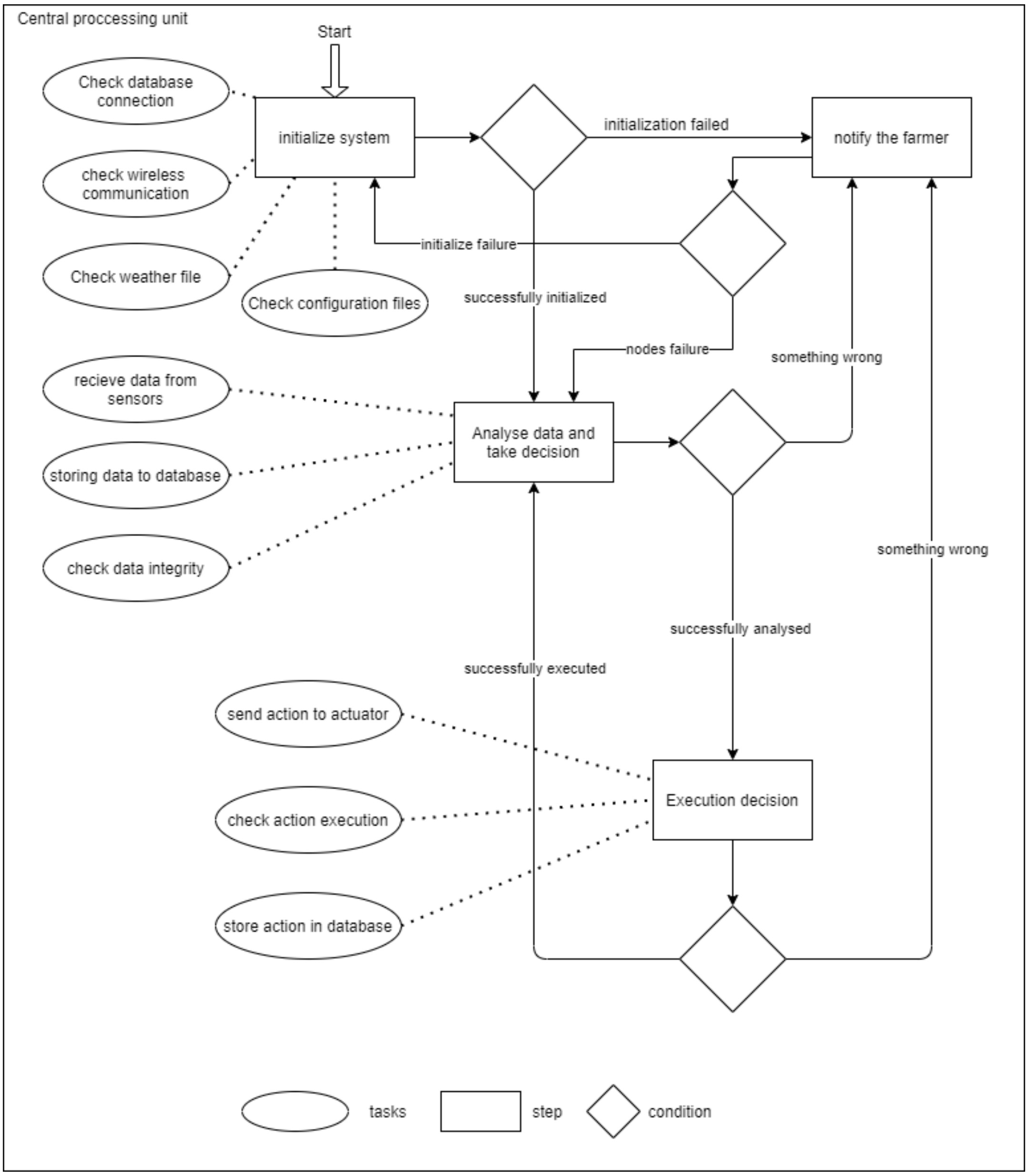

Figure 3.13: How central processing unit work

As in figure 3.13 we can say that the central processing unit is the base station that is responsible of manage the irrigation system.

3.1 How it works

We can resume the tasks of the base station in the steps follow:

- Initialize steps: This is the first step. It checks the system resources and checks nodes communication availability.
- Analyze data steps: here, the system checks the data coherence received from sensors. Next, storing the data in the database. Then, it requests the weather and energy level (fuel or electrical energy). Finally, it takes the decision based on received data, energy level, crop needs, and weather conditions.
- Execute decision steps: In this step, the system sends the decision to the corresponding actuator cell and check whether the action is executed correctly or not.

In case of failure, the system notifies the user instantly via SMS, email, and via the internet.

4 Conclusion

In this chapter, we are discus the electronic part of the smart irrigation system which consists of groups of nodes communicating with the central processing unit with the help of the communication topology and the central processing unit which is devoted to monitoring the system, analyze data, take decisions.

In the next chapter, we are going to present different tools needed to implements the system and we will present the system in action.

Chapter 4

Implementation

1 Introduction

After presenting the different stages of the realization of our system, we will present in this chapter the hardware and software tools used to implement the system, we also going to present some images of the realized system.

2 Used tools

2.1 Hardware tools

We used three computers with the specifications below:

- DELL Latitude E6025 laptop with 6GB RAM, 120 GB solid-state drive (SSD),2.8 GHz Intel (R) Core i5-2520M processor, an Intel HD 3000 graphics card, and a Windows 10 64 Bit operating system.
- Unbranded desktop computer with 8GB RAM, 256 GB SSD,2.6 GHz Intel (R) Core 2 Due processor, a Nvidia GeForce 210 graphics card and a Windows 10 64 Bit operating system.
- Toshibe Satelite laptop computer with 4GB RAM , 500 GB Hard Disk Drive (HDD),1.8 GHz Intel (R) Core (TM) i5-2237U processor, an Intel HD 3000 graphics card and a Windows 10 64 Bit operating system.

2.2 Software tools

2.2.1 Java

Java is defined as an object-oriented language similar to C++, but simplified to eliminate language features that cause common programming errors. The source code files (files with a .java extension) are compiled into a format called java bytecode (files with a .class extension), which can then be executed by a Java interpreter. Compiled Java code can run on most computers because Java interpreters and runtime environments, known as Java Virtual Machines (Virtual Machine (VM)s), exist for most operating systems, including UNIX, Macintosh OS, and Windows. Bytecode can also be converted directly into machine language instructions by a just-in-time compiler (JIT). In 2007, most Java technologies were released under the General Public License (GNU) [14].

2.2.2 Arduino language

The Arduino language is inspired by several languages. We find in particular similarities with C, C ++ and Java. The language imposes a particular structure typical of embedded computing. The setup function will contain all the operations necessary for configuring the board (input / output directions, serial communications rates, etc.). The loop function is executed in a loop after the execution of the setup function. It will continue to loop as long as the card is not powered off, restarted (by the reset button) [11].

Figure 4.1: Arduino logo

2.2.3 PlatformIO

PlatformIO is a cross-platform, cross-architecture, multiple framework, professional tool for embedded systems engineers, and for software developers who write applications for embedded products.

Figure 4.2: PlatformIO home interface

PlatformIO's unique philosophy in the embedded market provides developers with a modern integrated development environment (Cloud & Desktop Integrated Development Environment (IDE)) that works cross-platform, supports many different software development kits (SDKs) or Frameworks, and includes sophisticated debugging (Debugging), unit testing (Unit Testing), automated code analysis (Static Code Analysis), and remote management (Remote Development). It is architected to maximize flexibility and choice by developers, who can use either graphical or command line editors (PlatformIO Core Command Line Interface (CLI)), or both [15].

2.2.4 IntelliJ

IntelliJ IDEA is an IDE written in Java for developing computer software. It is developed by JetBrains (formerly known as IntelliJ), and is available as an Apache 2 Licensed community edition,[4] and in a proprietary commercial edition. Both can be used for commercial development [16].

2.2.5 Microsoft visual studio code

Visual Studio Code is a free source-code editor made by Microsoft for Windows, Linux and macOS. Features include support for debugging, syntax highlighting, intelligent code completion, snippets, code refactoring, and embedded Git. Users can change the theme, keyboard shortcuts, preferences, and install extensions that add additional functionality.

Visual Studio Code's source code comes from Microsoft's free and open-source software VSCode project released under the permissive Expat License, but the compiled binaries are freeware for any use. In the Stack Overflow 2019 Developer Survey, Visual Studio Code was ranked the most popular developer environment tool, with 50.7% of 87,317 respondents reporting that they use it [17].

2.2.6 H2 Database

H2 is a relational database management system written in Java. It can be integrated into a Java application or operate in client-server mode. Its jar file is small: about 1 MB [18].

3 Discussions of techniques and mechanisms used in the implementation

3.1 JSON format

JSON (JavaScript Object Notation) is a lightweight data-interchange format. It is easy for humans to read and write. It is easy for machines to parse and generate. It is based on a subset of the JavaScript Programming Language Standard ECMA-262 3rd Edition - December 1999.

3.2 Observer pattern

The observer pattern is a software design pattern in which an object, called the subject, maintains a list of its dependents, called observers, and notifies them automatically of any state changes, usually by calling one of their methods. It is faster rather then pooling which is slow.

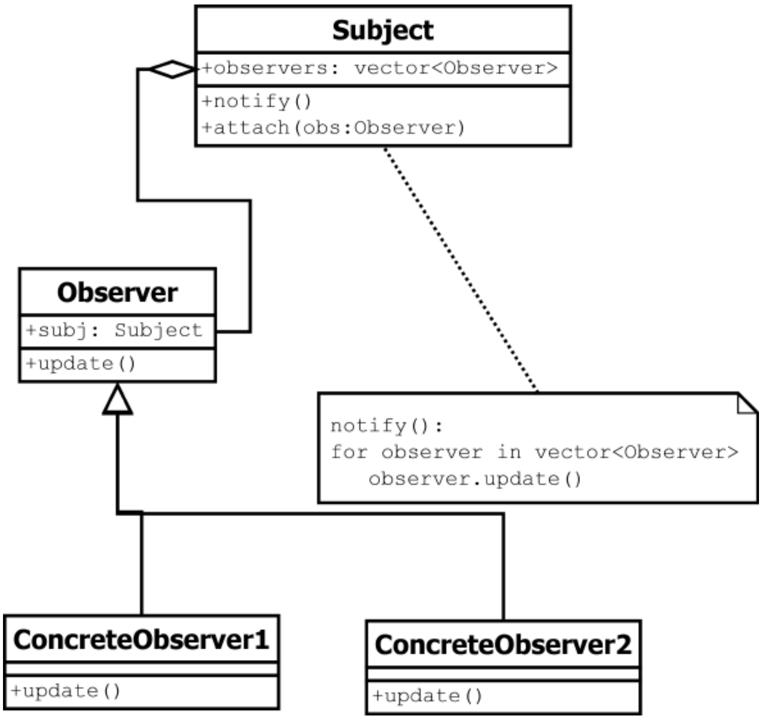

Figure 4.3: Observer pattern schema

It supports the principle of loose coupling between objects that interact with each other. Also, it allows sending data to other objects effectively without any change in the Subject or Observer classes.

Observers can be added/removed at any point in time.

3.3 Modular design

Modular design, or modularity in design, is a design theory and practice that subdivides a system into smaller parts called modules (such as modular process skids), which can be independently created, modified, replaced, or exchanged between different systems.

Modularity offers many advantages. It allows us to work out solutions to common problems independently of projects. This independent work enables us to consistently improve our solutions and it leads to efficiency in development through reuse.

The figure 4.4 shows the modules that the central processing unit have:

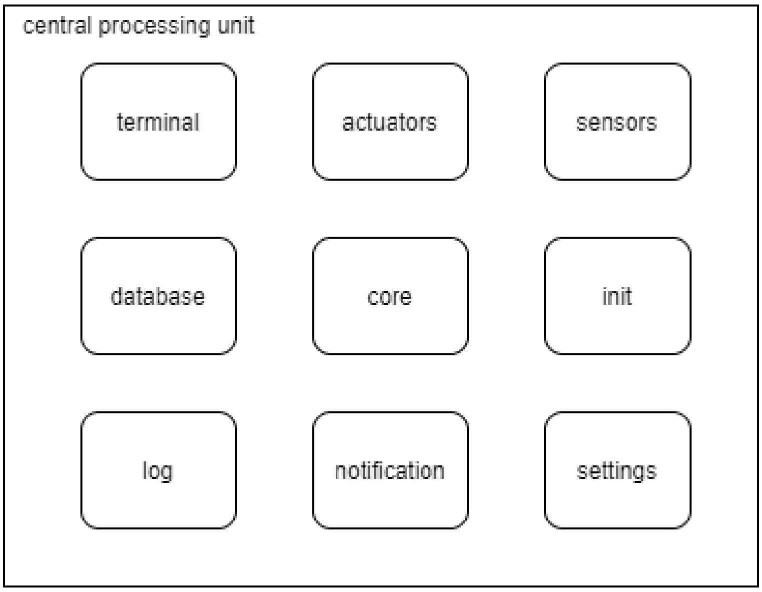

Figure 4.4: Central processing unit modules

4 Presentation of the system

In this section, we are going to present an implementation prototype of our system.

4.1 Irrigation prototype

Figure 4.5: Irrigation system prototype

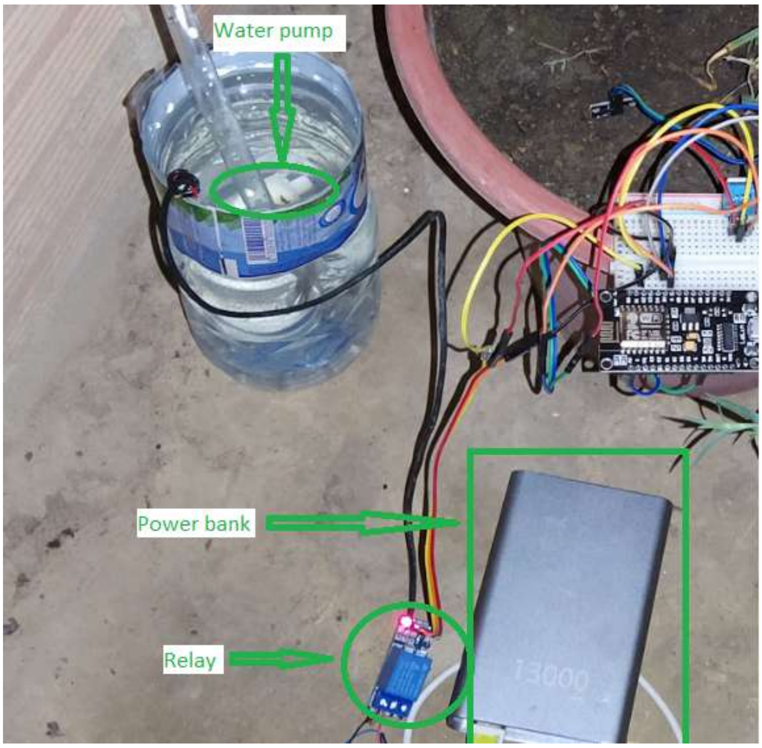

Figure 4.6: Pump part of the irrigation system prototype

This prototype (Figure 4.5) irrigating a flower with an automatic and intelligent way. It measures soil moisture, temperature, and humidity. Then, it makes the irrigation decision and the amount of water needed for irrigation based on the data collected from sensors and weather forecasts.

Figure 4.7: Pump part of the irrigation system prototype

We used a 5V water pump powered by a 5V power bank and triggered by a relay as shown in figure 4.6.

When the soil moisture at a level of 30%, the relay is close and the pump turned on for a small duration based on the moisture level of the soil and the plants need. So the system will irrigating the plant and wait for a small duration and measures the moisture for double-checking if the soil irrigated correctly and with a sufficient amount of water (Figure 4.8).

Figure 4.8: Pump part of the irrigation system prototype

In order to collect data, we use a dht11 sensor for temperature and humidity and a resistance moisture sensor (Figure 4.9)

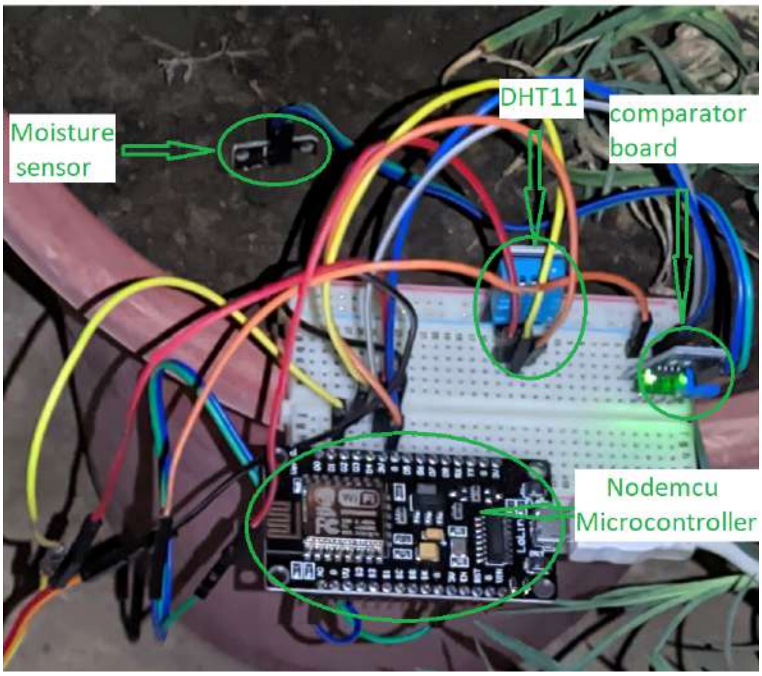

Figure 4.9: Sensor part of the prototype

We used the Nodemcu microcontroller which is Arduino like a microcontroller with Wi-Fi capabilities which make the possibility to communicate with the central processing unit hosted in the cloud.

4.2 Central processing unit

This is the core of the system. it is a computer that has storage and connects to a cellular network and internet (when it available) and has an alarm system to notify the user in case of failure.

```
[ Setting ] : READY
[ Sensors ] : CREATING
[ Actuators ] : CREATING
[ Actuators ] : STARTING
[ Notification ] : STARTING
[ Actuators ] : READY
[ Notification ] : READY
[ Sensors ] : STARTING
[ Sensors ] : READY
[ Core ] : CREATING
[ Core ] : STARTING
[ Core ] : READY
```

Figure 4.10: Central processing unit startup

The configuration of the whole system is done in the central processing unit and all the nodes need to be flashed via this unit at the first usage.

There is a console interface to the unit that makes the user login to the system and then choose from the menu (Figure 4.11) one of the functions that the unit can do.

```
Welcome to Smart irrigation system
Please select a number then press enter.

[1] status.
[2] node configuration.
[3] system configuration.
[4] logs.
[5] refresh system.
[6] restart system.
[7] logout.

choice:
```

Figure 4.11: Main menu of central processing unit console interface

We use the desktop computer as a central processing unit with a local database.

5 Conclusion

In this chapter, we have presented the implementation aspect of our application, while starting with the description of the language and the tool used for the development of the system and we presented the different images of our system with the prototype realized.

General conclusion

The objective of this thesis is to implement a smart irrigation system able to measure the temperature, humidity soil moisture with sensor node. then, it analyses this data based on type of plants, collected data and available energy for pumping the water. As a final step, it takes a decision and monitor the execution process of irrigation.

To achieve our objective, we build a prototype that use a DHT temperature and humidity sensor, soil moisture sensor, wireless communication modular, water pump and Nodemcu microcontroller. Put them together as described in the schema. After that, we powered the system with a 5V power bank. And after completing the build of the prototype, we test it for one month in test phase, which irrigate a flower without any failure.

This work allowed us to deal with practical problems and to verify theoretical knowledge acquired throughout our formation.

Thanks to the continuous work, we were able to reach our goal and satisfy the theorical study, but that doesn't mean it's full. Several things can still be added. The lack of time and material (hardware components) and due to coronavirus, most electronic components not received. This lack did not allowed us to realize the system perfectly. The improvements that can be added are:

- Use high precision sensors like DHT22 and capacitive soil moisture.
- Use a wireless module capable of reach a large distance like HC12.
- Implement the central processing unit into an Single Board Computer (SBC).
- A web user interface for monitoring the system.
- A solar panels system to charge the batteries.

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