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Design and Implementation of an automated gravity-fed irrigation water management system in Burkina Faso

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DEDICACES

To my family, an inexhaustible source of love, support and inspiration. You believed in me, encouraged me to persevere and gave me the strength to overcome obstacles. This memoir is the fruit of your love and sacrifice.

To my friends, fellow travelers on this adventure. Thank you for the shared laughter, the calmed moments of doubt and the constant encouragement. Your friendship has been a driving force along the way.

To all those who believe in a future where agriculture and technology come together to build a more prosperous and sustainable Burkina Faso. May this memoir contribute, however modestly, to that vision.

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ABSTRACT

This thesis focuses on the design and implementation of an automated irrigation water management system, specifically tailored to the agricultural context of Burkina Faso. Faced with the major challenges posed by water scarcity and the inefficiency of traditional irrigation techniques, this project aims to introduce an innovative solution to improve water resource management in agriculture. The proposed system relies on the use of an Arduino Uno board to automatically control irrigation based on the actual needs of crops, measured by soil moisture sensors. Gravity irrigation, which uses the force of gravity to distribute water, is optimized by solenoid valve controlled by the system, thus reducing water losses while increasing agricultural productivity.

Key words:

1. Gravity irrigation

2. Automated management

3. Arduino Uno

4. Water resources

5. Sustainable agriculture

RESUME

Le présent mémoire traite de la conception et de la mise en œuvre d'un système de gestion automatisée de l'eau d'irrigation gravitaire, spécifiquement adapté au contexte agricole du Burkina Faso. Face aux défis majeurs que posent la rareté de l'eau et l'inefficacité des techniques d'irrigation traditionnelles, ce projet vise à introduire une solution innovante pour améliorer la gestion des ressources hydriques dans l'agriculture. Le système proposé repose sur l'utilisation d'une carte Arduino Uno pour contrôler automatiquement l'irrigation en fonction des besoins réels des cultures, mesurés par des capteurs d'humidité du sol. L'irrigation gravitaire, qui utilise la force de la gravité pour distribuer l'eau, est optimisée par une électrovanne contrôlée par le système, réduisant ainsi les pertes d'eau tout en augmentant la productivité agricole.

Mots clés :

1. Irrigation gravitaire

2. Gestion automatisée

3. Arduino Uno

4. Ressources hydriques

5. Agriculture durable

TABLE OF CONTENTS

LIST OF ACRONYMS AND ABBREVIATIONS

BIT: Burkina Institute of Technology

LCD: Liquid Crystal display

GND: Graund

IDE: Integrated development environment**.**

ETP: Evaporation transpiration potential

DO: Analog output interface

AO: Digital output interface

ICU: water consumption for irrigation purposes

LIST OF TABLES

LIST OF FIGURES

GENERAL INTRODUCTION

Irrigation is the age-old practice of artificially supplying water to crops. It plays a crucial role in optimizing the growth and quality of harvests, freeing them from the vagaries of the weather and guaranteeing year-round agricultural production. However, with water becoming increasingly scarce worldwide, irrigation faces a major challenge : how to reconcile the need to ensure food security with the preservation of this vital resource ?

Water is essential to life. It is at the heart of all human, animal and plant activities. Agriculture, in particular, is a particularly water-hungry sector, requiring large volumes to ensure the growth and development of crops. Given this situation, it is imperative to develop more efficient and sustainable irrigation methods, capable of meeting the growing needs of agriculture while preserving water resources.

Our study will be divided into two main parts**:**

The first part, entitled **"Theoretical study",** contains two chapters and lays the foundations for the research. **Chapter I** presents the context of irrigation in Burkina Faso, highlighting the importance of agriculture, the challenges of traditional irrigation and the crucial role of water in the country's socio-economic development. It highlights the specific problems of irrigation and justifies the relevance of the automation project. The objectives of the study, as well as the research hypotheses, are clearly stated. **Chapter II** explores different water management technologies, comparing surface and pressure irrigation techniques. It focuses on the principles and advantages of gravity-fed irrigation, as well as on available automation technologies. Current irrigation practices in Burkina Faso and crop water requirements are also examined to contextualize the project.

The second part, entitled **"Design and implementation of the automated gravity-fed irrigation system"**, also containing two chapters, focuses on the practical dimension of the project. **Chapter I, "System design"**, presents the proposed system in detail, justifying the choice of components and describing the hardware architecture and software used. **Chapter II, "System Operating Principle"**, explains how the system works, with a flow chart, block diagram and assembly diagram. Where available, experimental results are presented and analyzed.

The dissertation concludes with a synthesis of the main findings, a discussion of the system's limitations and recommendations for future research or improvements.

PART I: THEORETICAL STUDY

CHAPTER I: GENERAL INFORMATION

I. IRRIGATION CONTEXT IN BURKINA FASO

Agriculture plays a key role in Burkina Faso's economy. It accounts for around 32% of gross domestic product (GDP) and employs over 80% of the working population. The predominantly rural country relies heavily on rain-fed agriculture, making the production of key crops such as vegetables and cereals particularly vulnerable to climatic hazards, including frequent droughts and variable rainfall. In this context, efficient water management becomes a crucial issue for ensuring food security and improving farmers' livelihoods.

II. ISSUES

In Burkina Faso, water plays a vital role in life and agriculture, which is a major component of the economy and livelihoods of rural populations. However, the irrigation methods used remain archaic and inefficient, relying mainly on submersion or sprinkler irrigation. Although these practices have persisted, they cause significant losses of scarce water and lead to low agricultural productivity, threatening food security. Flood irrigation can saturate soils and encourage disease, while sprinkler irrigation leads to evaporation losses, especially in hot, dry climates. Climate change is exacerbating these challenges, with prolonged droughts and unpredictable rainfall, making water management more complex and increasing the risk of agricultural losses.

Faced with these constraints, gravity-fed irrigation, which uses the force of gravity to distribute water, appears to be an attractive alternative due to its simplicity and low cost. However, it also has its limitations in terms of irrigation efficiency and control. The automation of this system, in particular through the use of solar energy, could help overcome these challenges by optimizing water use, improving agricultural productivity and strengthening the resilience of farms in the face of climatic hazards.

III. CHALLENGES OF TRADITIONAL IRRIGATION

Traditional irrigation methods are widespread in Burkina Faso. They are mainly based on techniques such as submersion or sprinkler irrigation. Although rooted in local farming practices and relatively inexpensive to implement, these methods have significant limitations that hamper their effectiveness and sustainability.

Submergence irrigation, for example, involves completely flooding the field, resulting in excessive water use. Much of this water is lost through evaporation, deep infiltration or runoff, particularly in areas with sandy or low-permeability soils. What's more, this method can lead to waterlogging of the soil, encouraging the development of disease and hindering plant growth. As for sprinkler irrigation, although more controlled than submersion, it is still subject to significant water loss through evaporation, particularly in the hot, dry climates of Burkina Faso.

In addition to being inefficient in terms of water use, these traditional methods are often labor-intensive and physically demanding. Transporting water, opening and closing sluices and monitoring plots of land are all time- and energy-consuming tasks, limiting farmers' ability to devote themselves to other productive activities.

On the other hand, traditional irrigation can have adverse effects on soil quality. Flood irrigation, in particular, can lead to salinization, making the soil unsuitable for long-term cultivation. Soil erosion is also a risk, particularly on sloping land where water is not properly channeled.

Finally, traditional irrigation management is often complex and imprecise. Controlling water flow and distributing water to individual plots is difficult, which can lead to uneven watering and yield losses.

IV. THE ROLE OF IRRIGATION AND ITS SOCIO-ECONOMIC EFFECTS

The purpose of irrigation is to supply water to crops when natural rainfall is insufficient to meet production targets. By compensating for water shortages, irrigation makes it possible to :

Increase yields: A regular supply of water, adapted to the plants' needs, promotes their growth and development, leading to more abundant harvests.

Improving product quality : A good water supply contributes to the quality of agricultural products, improving their appearance, taste, nutritional value, etc.

Stabilizing production : By reducing dependence on the vagaries of the weather, irrigation helps to regulate agricultural production. This ensures a constant supply to markets and agri-food industries, stabilizes farmers' incomes and facilitates access to credit.

Diversify crops : Irrigation makes it possible to grow a wider variety of plants, even in areas where they would not grow naturally. This allows us to better respond to market demand.

Strengthen food security : By increasing and diversifying national agricultural production, irrigation helps to reduce dependence on imports and ensure the country's food self-sufficiency.

Improving the balance of trade : Increased agricultural production thanks to irrigation can generate exportable surpluses, helping to improve the country's balance of trade.

Increase farm incomes : Irrigation enables production to be intensified on existing land, thus increasing farmers' incomes without the need to acquire new plots.

Promoting rural development : By creating economic opportunities in rural areas, irrigation helps to maintain the population and generate employment.

V. PROJECT JUSTIFICATION AND RELEVANCE

V.1 STUDY OBJECTIVES

V.1.1 GENERAL OBJECTIVE

In this project, we aim to design and implement an intelligent agricultural water management system in Burkina Faso, integrating automatic irrigation technologies and renewable energy sources, to improve water use efficiency and agricultural productivity while minimizing environmental impact. This will involve interfacing various sensors and pumps with a controller. To save water, we have decided to use drip irrigation with pump control.

V.1.2 SPECIFIC OBJECTIVES

- Carry out a comparative analysis of traditional irrigation techniques (such as submersion or sprinkler irrigation) in terms of water consumption, agricultural productivity and environmental impact.
- Design a system using sensors to monitor soil moisture and automate irrigation according to crop needs, while integrating sustainable energy solutions such as solar power.

- Adapt system parameters to maximize irrigation efficiency and ensure compatibility with traditional farming techniques used by local farmers.
- Develop awareness-raising and training strategies to facilitate farmers' appropriation of the system, emphasizing the economic and environmental benefits of this technology.

V.2 RESEARCH HYPOTHESES

In this study, we formulate the following research hypotheses :

- **Hypothesis 1: Water efficiency.** Automation of gravity-fed irrigation, compared with traditional methods, will significantly reduce water consumption for the market garden and cereal crops studied in Burkina Faso.
- **Hypothesis 2: Yield improvement.** The installation of an automated gravity-fed irrigation system will lead to an increase in the yield of vegetable and cereal crops, by providing the optimum amount of water at the right time.
- **Hypothesis 3: Reduced workload.** Automated irrigation will considerably reduce farmers' workload, particularly in terms of time and physical effort devoted to the task.
- **Hypothesis 4: Ease of use and maintenance.** The automated gravity-fed irrigation system will be perceived as easy to use and maintain by farmers, thus promoting its adoption.
- **Hypothesis 5: Economic viability.** Investment in an automated gravity-fed irrigation system will be economically viable for Burkina Faso farmers, with a reasonable return on investment.
- **Hypothesis 6: Resilience to climate change.** The adoption of automated gravity-fed irrigation will improve the resilience of farms to climatic hazards, particularly drought, by guaranteeing a more regular and controlled supply of water.

CHAPTER II: LITERARY REVIEW

I.DEFINITIONS

Irrigation : the practice of artificially applying water to crops, meadows or other vegetation to compensate for insufficient natural rainfall or soil water reserves. This ensures optimal plant development, increases yields and stabilizes agricultural production, even in difficult climatic conditions.

Automation : in the context of automated (or intelligent) irrigation, automation refers to the system's ability to manage and control the supply of water to crops autonomously, without direct human intervention.

II. IRRIGATION WATER MANAGEMENT TECHNOLOGIES

There are currently several irrigation systems available for supplying water to crops. Each method has its own advantages and disadvantages, which need to be taken into account when selecting the most suitable method for local conditions. But before moving on to irrigation techniques, it's important to study the crop's water requirements.

II.1 CHOICE OF IRRIGATION TECHNIQUES

The choice is based on a set of criteria and constraints. We take into account :

-topography

-water resources (quality, quantity and pressure)

soil type (permeable or impermeable, clayey or coarser-textured)

-sociological and cultural factors

-economic factors

-the profitability of the operation

II.2 IRRIGATION TECHNIQUES

There are 2 main modes:

- gravity-fed or surface irrigation
- pressurized irrigation (sprinkler or micro-irrigation)

II.2.1. SURFACE IRRIGATION TECHNIQUES

This refers to all techniques where water is distributed entirely in the open air, simply by flowing over the surface of the soil. Water is distributed by runoff, submersion or furrowing.

II.2.1.1. RUNOFF IRRIGATION

In this method, water is conveyed onto the ground at a gentle slope, creating a controlled flow. The water gradually spreads over the surface of the soil, infiltrating as it goes, enabling the plants to absorb the necessary moisture.

Figure 1: runoff irrigation

Table 1: advantages and disadvantages of runoff irrigation

Benefits	**Disadvantages**
Low installation and export costs	Variable irrigation efficiency
Suitable for sloping terrain	Uneven water distribution
Reduced erosion	Risk of soil salinization
Water of varying quality can be used	Requires careful management

II.2.1.2. IRRIGATION BY SUBMERSION (OR FLOODING)

This method involves covering the soil with a layer of water of varying thickness. The water is held in place long enough for it to infiltrate deeply, reaching the root zone of the crops and enabling the soil to store the water needed for their growth.

Figure 2: Flood irrigation

Table 2: Advantages and disadvantages of flood irrigation

Benefits	**Disadvantages**
Simple, low-cost installation	Low water use efficiency (losses through evaporation, infiltration)
Suitable for waterlogging-tolerant crops (rice, some forage crops)	Risk of soil waterlogging and disease development
Groundwater recharge	Difficulty in precisely controlling the amount of water applied
Salt leaching in saline soils	Negative impact on soil structure (reduced porosity)

II.2.1.3. MIXED TECHNIQUES (SHORT-ROW IRRIGATION)

The feed channel serves a number of short channels, separated by ridges and plugged at the ends. The water first trickles into the furrows, then fills them. The flow rate is regulated to prevent overflow. The short length of the furrows ensures even infiltration along the length of the furrow. The crop can be located on the ridge, on the side of the ridge or in the furrow.

Figure 3: Stingray irrigation

Table 3: Advantages and disadvantages of stingray irrigation

Benefits	**Disadvantages**
Simple, low-cost installation	Variable irrigation efficiency (depends on slope, soil, etc.)
Adapted to different soil types	Non-uniform water distribution (more water upstream of rays)
Easy application of soluble fertilizers	Risk of soil salinization if water contains salts
Less erosion than flooding	Requires site preparation (creation of lines)

II.2.2. PRESSURE IRRIGATION TECHNIQUES

II.2.2.1. SPRINKLER IRRIGATION

This technique reproduces the effect of a fine, regular rainfall, with water propelled in droplets into the air from nozzles or sprinklers. This dispersal ensures uniform distribution of water over a wide area, encouraging absorption by plants and soil.

Figure 4: Sprinkler irrigation

Table 4: Advantages and disadvantages of sprinkler irrigation

Benefits	**Disadvantages**
Adaptable to a variety of soils and crops	Water loss through evaporation
Distribution uniformity (in theory)	Wind sensitivity
Easy automation	Risk of leaf diseases
Possibility of applying fertilizers and pesticides	Pump energy consumption

II.2.2.2. LOCALIZED IRRIGATION OR MICRO-IRRIGATION

This method involves delivering water directly to the roots of plants, very precisely and in small quantities. Thanks to a network of pipes and drippers, water is delivered slowly and regularly, limiting losses through evaporation, runoff or deep infiltration.

Main micro-irrigation techniques :

- Drip system
- Line irrigation system known as the Bas-Rhône system
- Mini-diffuser irrigation system
- Porous boom irrigation system

Table 5: Advantages and disadvantages of localized irrigation

Benefits	Disadvantages
Maximum water savings	High initial installation costs
Reduced weed growth	Sensitivity to water quality
Fertigation possible	Requires regular maintenance
Improving crop quality	Risk of root disease development

II.2.2.3 GRAVITY IRRIGATION : PRINCIPLES AND ADVANTAGES

Gravity irrigation is an ancestral irrigation method based on a simple but effective principle: the use of gravity to transport water from its source to the crops. In concrete terms, water is conveyed by canals, gutters or pipes from a point of higher altitude, then distributed to the plants by runoff or infiltration, thanks to a network of secondary canals, basins or levelled beds. Although less sophisticated than other irrigation methods, this technique offers considerable advantages, particularly in the Burkina Faso context:

Low cost: Gravity irrigation does not require major investment in expensive equipment such as pumps or pressurization systems. It is therefore particularly suited to small farms with limited financial resources.

Simplicity: Setting up and maintaining a gravity-fed irrigation system is relatively straightforward, requiring no advanced technical skills. This makes it easy for farmers to adopt, even in the most remote rural areas.

Low energy consumption: Gravity irrigation operates without the need for external energy, making it independent of electricity grids, which are often unreliable or non-existent in rural areas of Burkina Faso. This helps reduce operating costs and the environmental impact of agriculture.

Adaptability to terrain: This technique can be used on a variety of terrains, including those with a slight slope, which is common in Burkina Faso. It can also be used on land that would be difficult to irrigate using other methods.

Use of alternative water sources: Gravity irrigation can be supplied by a variety of water sources, such as rivers, reservoirs, natural springs or even collected rainwater. This flexibility is a major asset in a country where water resources are often limited and seasonal.

Reduced erosion: By encouraging a slow, controlled flow of water, gravity-fed irrigation reduces the risk of soil erosion, thus preserving the fertility of farmland.

Gravity irrigation also has certain limitations. Its efficiency may be lower than that of other methods, due to water losses through evaporation and infiltration. In addition, water distribution may be less uniform, requiring careful design and management of the system. Finally, it is dependent on the topography of the land, and may need to be adapted for use on flat terrain.

Despite these limitations, gravity-fed irrigation remains an attractive option in Burkina Faso, particularly for small-scale farmers.

III. IRRIGATION AUTOMATION: TECHNOLOGIES AND APPLICATIONS

Irrigation automation relies on the integration of various technologies to control and manage the supply of water to crops more precisely and efficiently. These technologies offer considerable potential for improving agricultural productivity, reducing water consumption and facilitating farmers' work, particularly in a context of limited water resources and climate change.

III.1 MAIN AUTOMATION TECHNOLOGIES

Table 6: Characteristics of the main automation technologies

Technology	Role	Examples	Benefits	Limits
Sensors	Collect environmental and crop data	Soil moisture sensor, weather sensor, water level sensor	Provide real-time information for informed decision-making.	Can be costly, require regular maintenance, can be sensitive to environmental conditions.

Actuators	Control water flow in the system	Solenoid valves, motorized valves, pumps	For precise, automated water flow regulation.	Can be expensive, require a power source, can fail.
Controllers	Analyze sensor data and send commands to actuators	Time controllers, microcontrollers (Arduino), programmable logic controllers (PLCs)	Centralize system management, enabling irrigation to be adapted to requirements.	Can be complex to program and configure, require maintenance.

III.2 APPLICATION OF IRRIGATION AUTOMATION

Automated irrigation offers many advantages for agriculture, including :

Precision irrigation : By adjusting water supply to actual crop needs and environmental conditions, automation optimizes water use, improves yields and reduces water losses through evaporation or runoff.

Remote management : The ability to control and monitor the irrigation system remotely offers greater flexibility and considerable time savings for farmers.

Water savings : Automation prevents over-watering and optimizes irrigation schedules, contributing to more efficient use of water, a precious and often limited resource, particularly in Burkina Faso.

Reduced labour costs : By automating certain irrigation tasks, farmers can reduce their dependence on labour, which can be particularly beneficial in regions where farm labour is scarce or expensive.

Improved crop quality : A precise, regular water supply promotes optimum plant growth and reduces water stress, resulting in improved crop quality and yield.

IV. IRRIGATION PRACTICES IN AGRICULTURE IN BURKINA FASO

In Burkina Faso, irrigation water management in agriculture is marked by a combination of traditional and modern practices, with challenges and opportunities specific to the local context.

We have listed a few current irrigation practices in Burkina Faso:

Gravity irrigation: This is the most widespread method, particularly in state-developed irrigation schemes. It relies on the use of canals and gullies to convey water by gravity from a source (dam, river) to the plots. This method is relatively inexpensive, but can lead to significant water losses through evaporation and infiltration.

Pumped irrigation: mainly used for off-season crops and smallholdings, pumped irrigation involves drawing water from streams or underground aquifers using motor-driven pumps. This method is more flexible than gravity-fed irrigation, but requires an investment in equipment and energy.

Figure 5 : Pump irrigation

Traditional irrigation : In some regions, farmers use ancestral techniques such as flood irrigation of the lowlands or the use of traditional wells. These practices are often adapted to local conditions, but can be inefficient in terms of water use.

Micro-irrigation : Although less widespread, micro-irrigation (drip irrigation, micro-sprinklers) is gaining in popularity thanks to its water-saving efficiency. It is encouraged by some agricultural development projects, but its initial cost can be an obstacle for smallholders.

V. CROP WATER REQUIREMENTS

Rainfall, particularly its effective part, provides part of the water required to satisfy crop evapotranspiration needs. The soil, acting as a buffer, stores part of the rainwater and releases it to crops in times of deficit. In humid climates, this mechanism is sufficient to ensure satisfactory growth in non-irrigated cropping systems. In arid conditions, or in the event of a prolonged dry season, irrigation is necessary to compensate for the evapotranspiration deficit (crop transpiration and evaporation from the soil) caused by insufficient or irregular rainfall. Water consumption for irrigation is defined as the volume of water needed to compensate for the deficit between potential evaporation on the one hand, and effective rainfall during the crop growth period and the change in soil water content on the other. It varies considerably according to climatic conditions, seasons, crops and soil types. For a given month, the crop water balance can be expressed as follows :

$ICU = Etc - P - \Delta S$

Where : ICU = water consumption for irrigation needed to meet crop demand (mm)

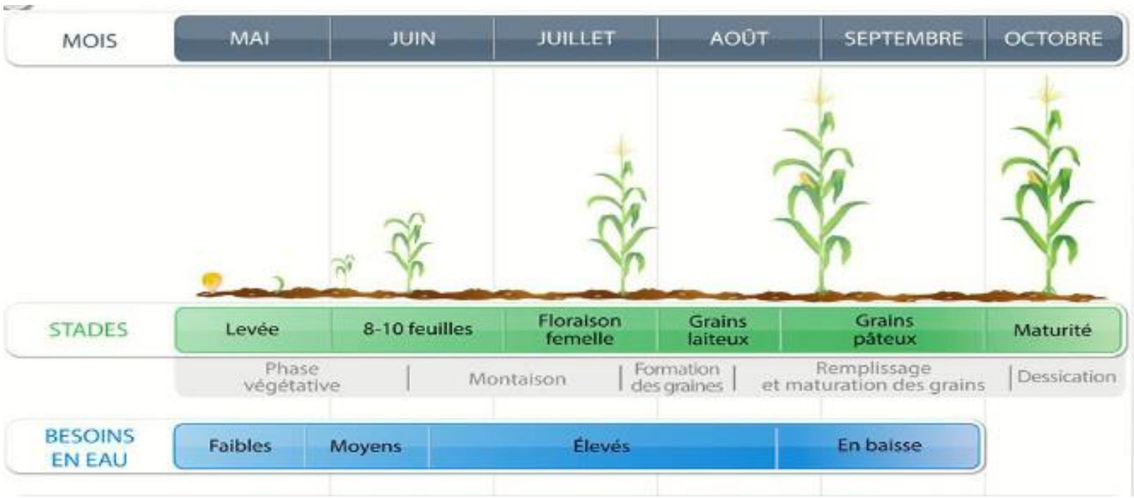
Etc = potential crop evapotranspiration (mm)

P = effective rainfall (mm)

ΔS = change in soil moisture (mm)

To calculate crop water requirements, i.e. the potential evapotranspiration of irrigated crops (Etc in mm), the reference evapotranspiration (Eto) is multiplied by a coefficient specific to the crop and growth stage (Etc = Kc x Eto).

The water requirement of a crop is the height of water, in mm, needed to compensate for the evapotranspiration of a crop in good health, established in a large field, under non-limiting soil conditions in terms of water availability and fertility, and leading to the potential crop yield under given climatic conditions.[1]



Source : FAO

Figure 6: Cultural coefficient

PART II: DESIGN AND IMPLEMENTATION OF THE AUTOMATED GRAVITY-FED IRRIGATION SYSTEM

CHAPTER I : SYSTEM DESIGN

I. PRESENTATION OF THE AUTOMATED GRAVITY IRRIGATION SYSTEM

The implementation of an automated water management system in agriculture relies on the harmonious integration of various hardware components. These components play an important role in ensuring the automation, precision and efficiency of the irrigation system.

The system is based on the principle of gravity irrigation, using the natural force of gravity to deliver water from an upstream source to the cultivated plots. Automation, made possible by the integration of sensors, a microcontroller and a solenoid valve, enables the flow of water to be controlled according to soil moisture, guaranteeing optimum water supply for the crops.

The use of solar energy to power the system reinforces its autonomy and sustainability, making it particularly well-suited to rural areas of Burkina Faso where access to electricity is often limited. What's more, the system's simplicity of design and use makes it easy for farmers to adopt, even those with limited technical skills.

II. COMPONENT SELECTION AND JUSTIFICATION

II.1 HUMIDITY SENSOR

A sensor is a device that detects and measures a physical quantity in the environment and converts it into an electronic signal. The physical quantity can be humidity, temperature, movement, light or any other physical phenomenon.

The digital soil moisture sensor determines the water content of the soil. It is placed in the soil at a given depth. It gives a digital output of 5V when the soil moisture level is high, and 0V when the soil moisture level is low.

Figure 7: soil moisture sensor

The sensor includes a potentiometer for setting the desired humidity threshold. When the sensor measures more moisture than the set threshold, the digital output switches to a high level and an LED indicates the output. When soil moisture is below the set threshold, the output remains low. The digital output can be connected to a microcontroller to detect the moisture level. The sensor also produces an analog output that can be connected to a microcontroller's analog-to-digital converter (ADC) to obtain the exact level of moisture in the soil. This sensor is ideal for automated gardening projects, water detection, etc. See the table below for moisture sensor specifications.

Table 7: Humidity sensor specifications

Operating voltage	3.3V~5V
Vdc power supply	3.3V-5V
PCB dimensions	Approx. 3 cm x 1.5 cm
Soil probe dimensions	Approx. 6 cm x 3 cm
Cable length	Approx. 21 cm
DO	Digital output interface (0 and 1)
AO	Analog output interface
GND	Connected to earth

<u>How to use :</u>

The soil moisture module is the most sensitive to the environment, generally used to detect soil moisture content.

When the module cannot reach the threshold value, the DO port output is high; when soil moisture exceeds a defined threshold value, the DO module output is low.

The D0 digital output of the small board can be directly connected to the MCU, which detects high and low values for soil moisture.

The digital output DO of the small card can directly drive the buzzer module or the relay module in our store, which can form a soil moisture alarm equipment. The analog output AO of the small card and the AD module, connected via the AD converter, enable more precise soil moisture values to be obtained.

II.2 SOLENOID VALVE

II.2.1. DEFINITION

A solenoid valve *(figure 8 below)* is an electromechanical device that regulates the flow of fluids (liquids or gases) by means of an electrical command. There are two main types of solenoid valve : pilot-operated solenoid valves, which use the pressure of the fluid itself to open and close the valve, and direct-acting solenoid valves, where the main orifice is directly controlled by the solenoid. Direct-acting solenoid valves are preferred for low-flow systems, or when the pressure difference across the valve is limited.

The solenoid is electromechanically actuated and is also electrically controlled. It is used to minimize manual work to activate or deactivate valves separately. The two-port valve is used for ON/OFF processes. Multiple-port valves have one inlet and several outlet valves.[2]

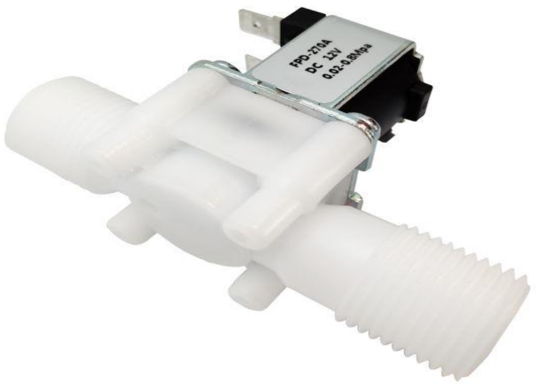


Figure 8: Solenoid valve

II.2.2. SOLENOID VALVE OPERATION

The function of a solenoid valve is to control the flow of liquids or gases in positive, fully closed or fully open mode. They are often used to replace manual valves, or for remote control. The operation of a solenoid valve involves opening or closing an orifice in the valve body, allowing or preventing flow through the valve. A plunger opens or closes the orifice by rising or falling inside a sheath tube, energizing the coil.

Solenoid valves consist of a coil, plunger and sleeve assembly. In normally closed valves, a plunger return spring holds the plunger against the orifice and prevents flow. Once the solenoid coil is energized, the resulting magnetic field lifts the plunger, allowing flow. When a normally open valve is energized, the plunger seals the orifice, preventing flow.

II.2.3. UTILITY OF THE SOLENOID VALVE

In most flow control applications, it is necessary to start or stop the flow in the circuit to control the fluids in the system. An electronically controlled solenoid valve is generally used for this purpose. Being solenoid-operated, solenoid valves can be placed in remote locations and can be conveniently controlled by simple electrical switches.

Solenoid valves are the most frequently used control elements in fluidics. They are commonly used to close, release, dose, distribute or mix fluids. For this reason, they can be found in a wide range of applications. Solenoids generally offer fast, safe switching, long service life, high reliability, low control power and compact design.

The various solenoid valve specifications are shown in the table below:

Table 8: Solenoid valve specifications

Rated voltage	The supply voltage required for optimum operation of the solenoid valve.	12 or 24 V DC
Rated current	The current drawn by the solenoid valve when activated.	300 to 500 mA

Rated power	The electrical power consumed by the solenoid valve during operation.	3.6 to 12 W
Response time	The time required for the solenoid valve to open or close completely after the voltage has been applied or removed.	10 to 50 ms
Operating pressure	The fluid pressure range that the solenoid valve can safely withstand.	0 to 15 bar
Nominal flow	The maximum fluid flow rate the solenoid valve can allow when fully open.	10 to 50 L/min
Operating temperature	The ambient temperature range within which the solenoid valve can operate correctly.	-10° to +50°C
Fluid type	The type of fluid compatible with the solenoid valve (water, air, oil, etc.).	Water, Gas
Orifice (solenoid valve size)	The diameter of the solenoid valve opening through which the fluid flows.	1/4", 1/2", 3/4"
Body material	The material used to manufacture the solenoid valve body, influencing its corrosion resistance and durability.	Brass, Stainless steel, Plastic
Connection type	The type of fitting used to connect the solenoid valve to pipes or ducts.	Threaded (NPT, BSP), Splined, Flanged
Function	Indicates whether the solenoid valve is normally open (NO) or normally closed (NC) when not energized.	NO, NC
Service life	The number of opening and closing cycles the solenoid valve can perform before showing significant signs of wear.	1 to 5 million cycles

II.3 VOLTAGE REGULATOR

A voltage regulator acts as a guardian of electrical stability, ensuring that the output voltage remains constant despite fluctuations in input voltage or variations in current demand. If the output voltage falls, the regulator compensates by increasing the voltage delivered, either by reducing the input voltage (linear and buck regulators), or by drawing longer on the input current (boost regulators). Conversely, if the output voltage exceeds the desired value, the regulator intervenes to reduce it, thus guaranteeing a stable and reliable power supply.

II.4. POWER SUPPLY

II.4.1. SOLAR PANELS

Solar cells, also known as photovoltaic cells, are miniature power plants that harness the sun's inexhaustible energy and convert it directly into electricity. Their operation is based on a fascinating physical phenomenon: the photovoltaic effect.

At the heart of these cells are semiconductor materials, usually silicon, which possess special electronic properties. When a photon, an elementary particle of light, strikes the surface of a solar cell, it transfers its energy to an electron in the semiconductor material. If this energy is sufficient, the electron is released from its atom and becomes free to move. The very structure of the solar cell, with its various layers and junctions, creates an internal electric field that guides the movement of these freed electrons. They are then collected and channeled, forming a direct current (DC). This process of converting light energy into electrical energy takes place silently and without any moving parts, making solar cells highly reliable and long-lasting. This makes them a clean, renewable and sustainable source of energy, perfectly suited to today's energy and environmental challenges.

Today, solar cells are widely used to power a multitude of applications, from small electronic devices to large-scale photovoltaic installations. They help reduce our dependence on fossil fuels and limit greenhouse gas emissions, paving the way for a cleaner, more sustainable energy future.

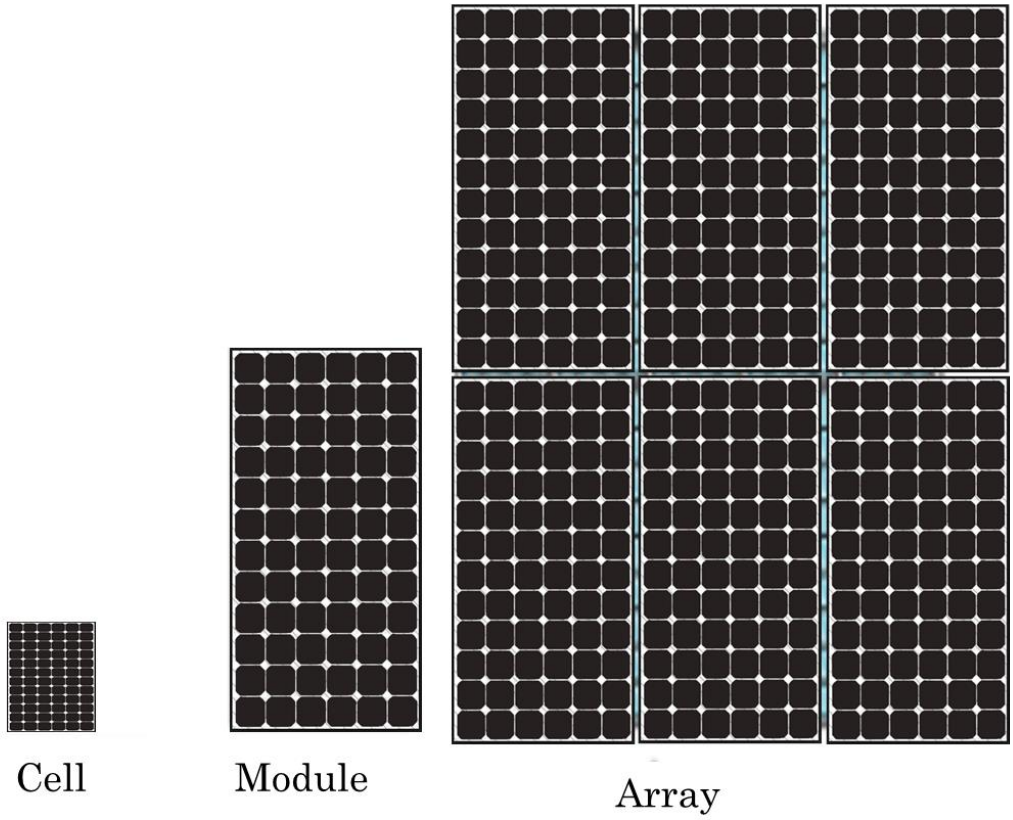


Figure 9: solar panels

II.4.2. SOLAR LANDING

Batteries play an essential role in renewable energy systems by acting as energy reservoirs, capable of storing electricity produced intermittently by sources such as the sun or wind. In this way, they smooth out energy production, making it available even when weather conditions are unfavorable.

At the heart of this storage capacity is a reversible chemical reaction. When the battery is charged, electrical energy is converted into chemical energy and stored in the battery's active materials. When discharged, this chemical energy is converted back into electrical energy, ready to be used to power various devices or systems.

II.5. ARDUINO UNO BOARD

Arduino *(figure 10)* is an open-source platform used to create electronic projects. Arduino consists of both a physical programmable circuit board (often called a microcontroller) and software, or IDE (Integrated Development Environment) that runs on your computer, used to write and download computer code to the physical board.

The Arduino platform has become very popular among electronics beginners, and for good reason. Unlike most previous programmable circuit boards, the Arduino doesn't require separate hardware (called a programmer) to load new code onto the board - you can simply use a USB cable. What's more, the Arduino IDE uses a simplified version of C++, making it easy to learn how to program. Finally, Arduino offers a standard form factor that makes microcontroller functions more accessible.[3]

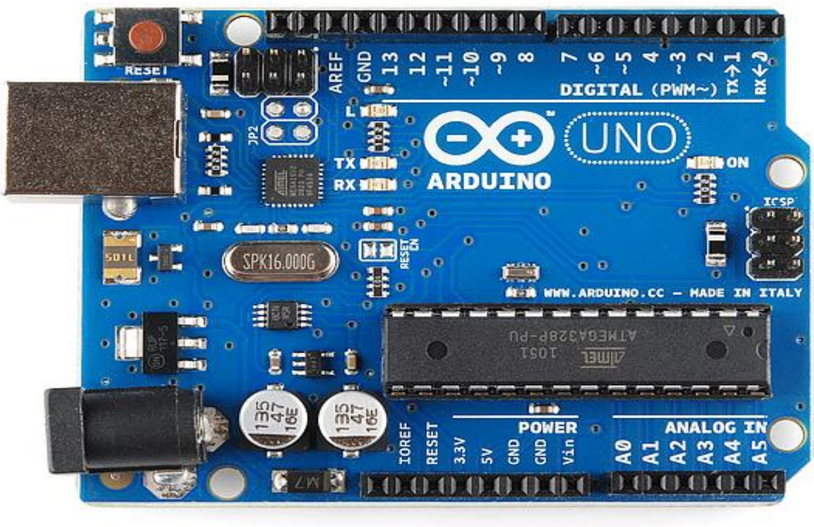


Figure 10: Arduino Uno board

The table below shows the specifications of the Arduino Uno board:

Table 8: Arduino Uno board specifications

Microprocessor	ATMega328
Operating voltage	5V
Supply voltage (limits)	6-20V
Flash memory	32KB
SRAM memory	2KB
EEPROM memory	1KB

14 I/O pins	6 PWM
6 analog inputs	10Bit
Current per I/O	40mA
Timing	16 MHz
Serial bus	I2C and SPI
Supply voltage (recommended)	5-12V

II.6. LCD DISPLAY, BREADBOARD AND CABLES CONNECTORS

The 16x2 LCD display *(figure 11)* is a must-have for electronic circuits, distinguished by its ease of use and accessibility. It displays information clearly and concisely, thanks to its two lines, each of which can accommodate 16 characters. Its operation is based on the use of two types of registers: control registers, which store instructions intended for the screen (such as cursor position or contrast), and data registers, which contain the characters to be displayed. This combination of simplicity and functionality explains the popularity of the 16x2 LCD in many electronic projects, whether for displaying messages, sensor values or basic animations. It offers a user-friendly, affordable interface, ideal for beginners and more advanced projects alike.[3]

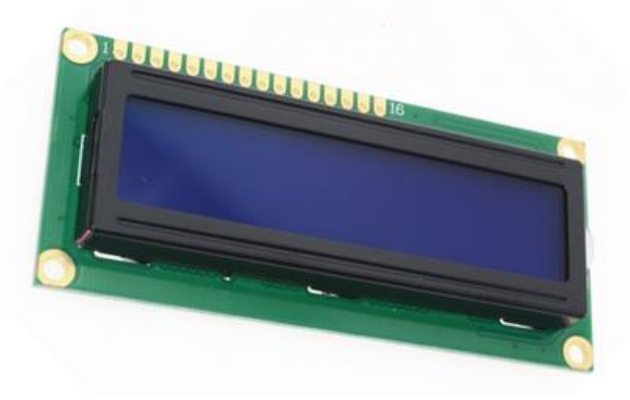


Figure 11: LCD display

The breadboard *(figure 12)* is an indispensable tool for electronic prototyping. It enables you to create temporary solderless circuits quickly and easily, facilitating testing and adjustments before final assembly.

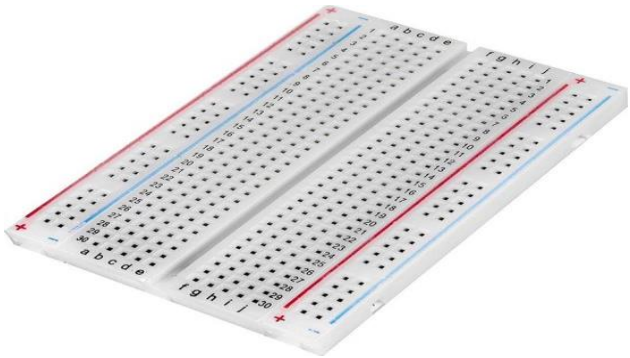


Figure 12: breadboard

Cables *(Figure 13)* are essential for connecting the various system components, such as sensors, relays, Arduino boards and power devices. They ensure the transmission of electrical signals and the distribution of power.[3]

Figure 13: Connector cables

II.7. RELAY

The relay *(figure 14), a* veritable bridge between the digital and physical worlds, enables an Arduino board, delivering a low-power signal, to control more power-hungry electrical devices. It works like an intelligent switch, capable of opening or closing an electrical circuit in response to a command from the Arduino. Specifically, when the Arduino sends a command signal to the relay, usually a 5V voltage, it activates an internal electromagnet. This attracts a moving contact, closing the electrical circuit to which the device to be controlled is connected. Current can then flow, powering and activating the device.

Thanks to the relay, the Arduino can control elements such as motors, pumps or solenoid valves, opening up a wide range of possibilities for the automation and control of a variety of systems.

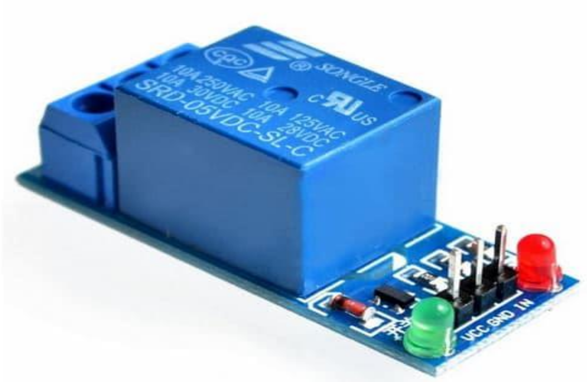


Figure 14 : 5V channel relay

The table below shows the various specifications of the 5V channel relay:

Table 10: Specifications for 5V channel relay module

Controllable digital output	Controllable digital output
Control signal	TTL level
Rated flow current	10A (NO) 5A (NC)
Max. switching voltage	250VAC/30VDC
Max. switching current	10A
Size	50mm x 38mm x 17mm

II.8. CAPACITOR

The capacitor *(figure 15)* is a component with the ability to store energy in the form of electrical charge by producing a potential difference (static voltage) between its plates, much like a small rechargeable battery. There are many different types of capacitor, from very small capacitor balls used in resonance circuits to large power factor correction capacitors, but they all do the same thing: they store charge.

In its basic form, a capacitor consists of two or more parallel conductive (metallic) plates that are not connected or touching, but are electrically separated either by air, or by an insulating material such as wax paper, mica, ceramic, plastic or a liquid gel as used in electrolytic capacitors.

Figure 15: capacitor

II.9. RESISTANCE

A resistor *(Figure 16)* is a passive, two-terminal electronic component that implements an electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, divide voltages, polarize active elements and terminate transmission lines, among other uses. High-power resistors, capable of dissipating many watts of electrical power in the form of heat, can be used in motor controls, in power distribution systems or as test loads for generators. Fixed resistors have resistances that change only slightly with temperature, time or operating voltage. Variable resistors can be used to adjust circuit elements (such as a volume control or light dimmer), or as sensors for heat, light, humidity, force or chemical activity.

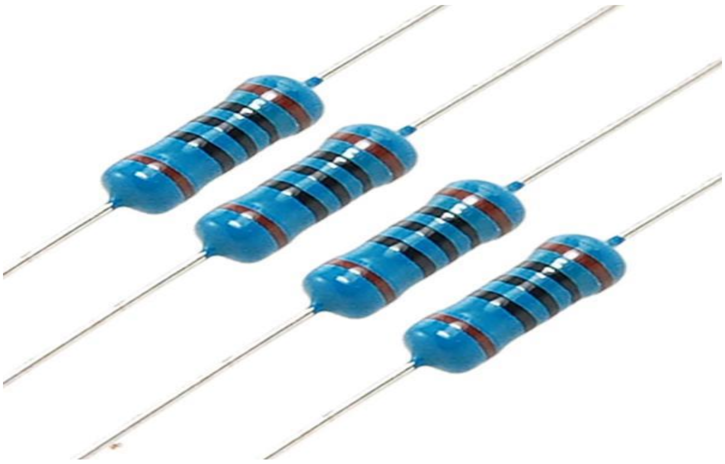


Figure 16: resistors

III.SYSTEM HARDWARE ARCHITECTURE

The figure below *(Figure 17)* shows the system's hardware architecture:

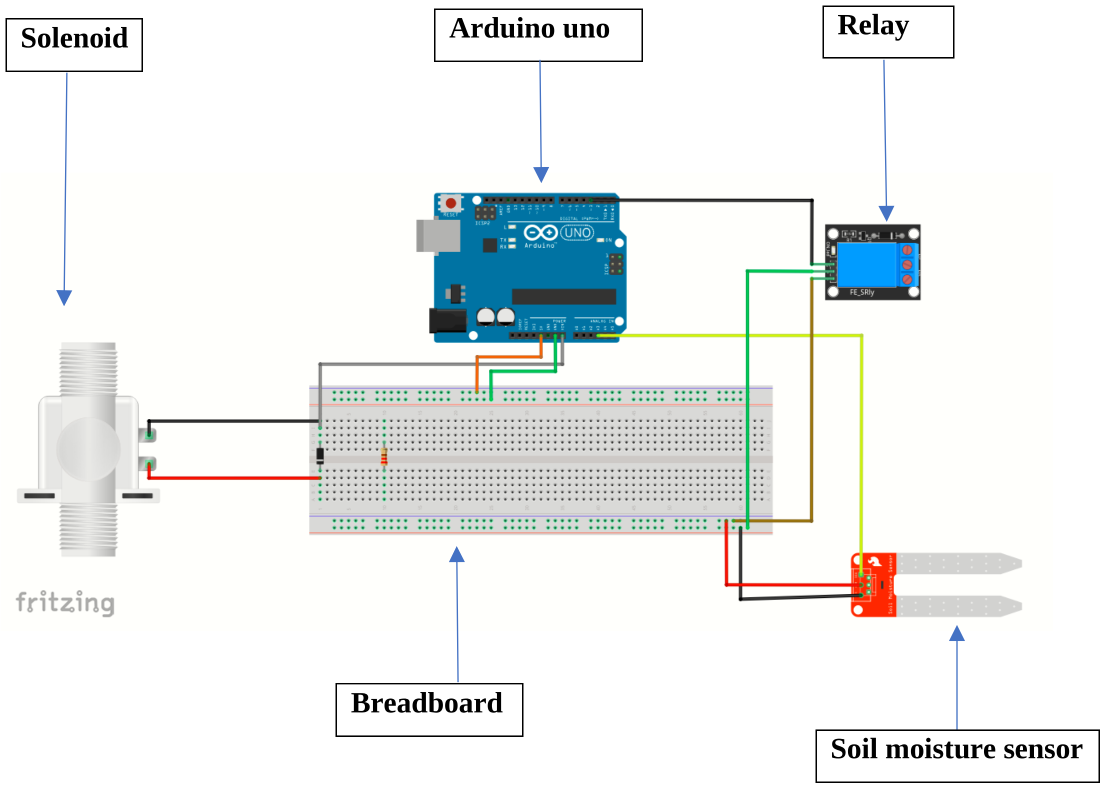


Figure 17: system hardware architecture

IV.SOFTWARE

Arduino IDE :

The Arduino software is a free, open-source development environment (IDE) that can be downloaded from the official Arduino website:

- Edit a program: sketches
- Compile this program in the Arduino's machine language,
- Upload the program to the Arduino's memory,
- Communicate with the Arduino board via the terminal

Fritzing:

Fritzing is an open-source PCB design program that enables fully graphical circuit design. It can also be used to prototype, program and simulate devices using an Arduino microcontroller.

CHAPTER II: SYSTEM OPERATING PRINCIPLE

The operating principle of our system is essential to ensure efficient and optimal use of water resources. This chapter details the steps and processes involved in automating irrigation, from data collection to activation of the irrigation devices. This methodical approach ensures that our system operates consistently, reliably and in line with crop needs.

I.GENERAL SYSTEM FLOW CHART

The figure *(figure 18)* below shows the system flow chart.

Explanation:

Moisture sensor: The soil moisture sensor measures soil moisture. The value read is compared with a predefined threshold (here 400). If the humidity is below the threshold, the soil is dry and the solenoid valve opens to allow irrigation. If the humidity is above the threshold, the solenoid valve closes to stop irrigation.

Relay and solenoid valve: The relay controls the solenoid valve. When the relay is activated (LOW), the solenoid valve opens. When the relay is deactivated (HIGH), the solenoid valve closes.

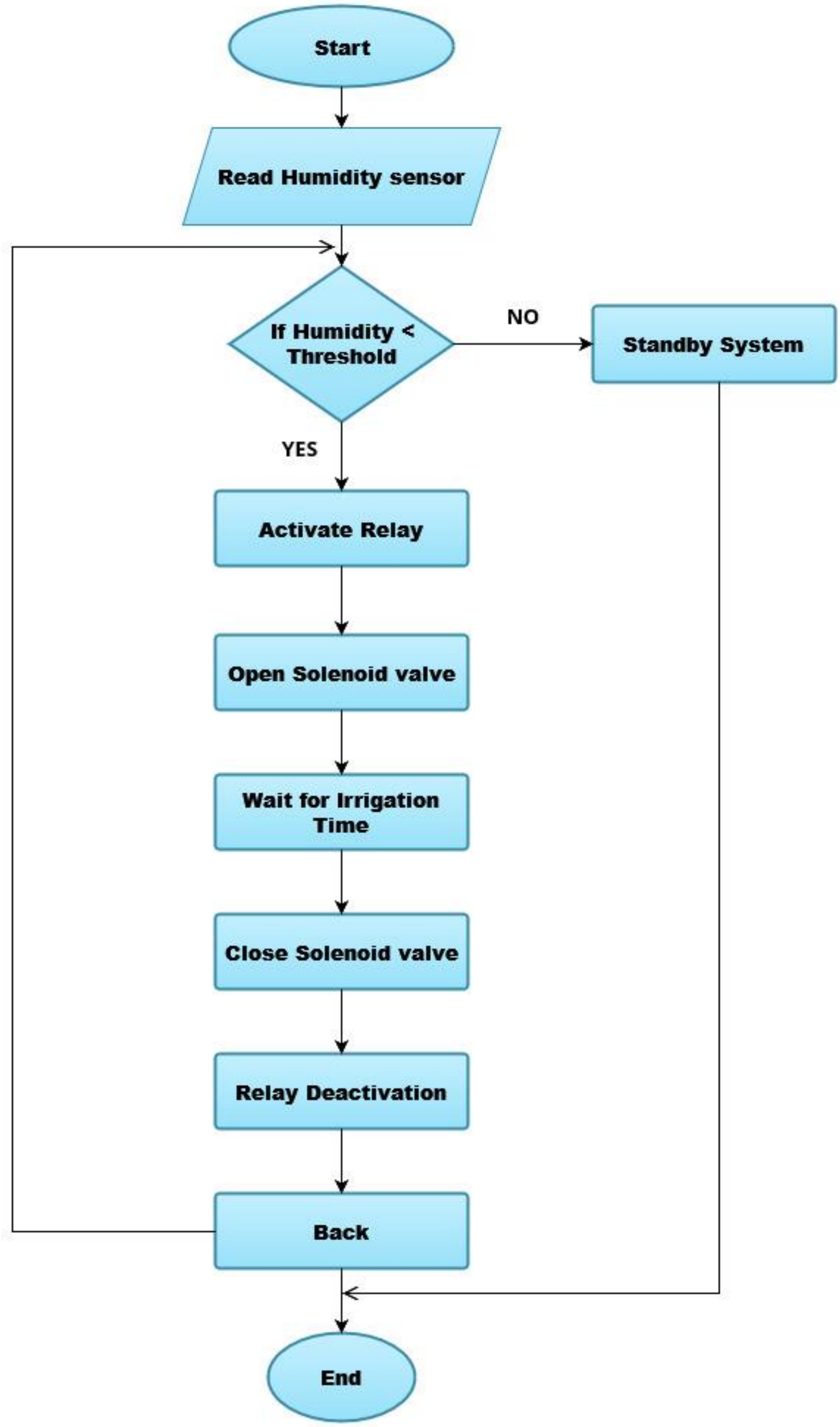


Figure 18: system flow chart

II. SYSTEM BLOCK DIAGRAM

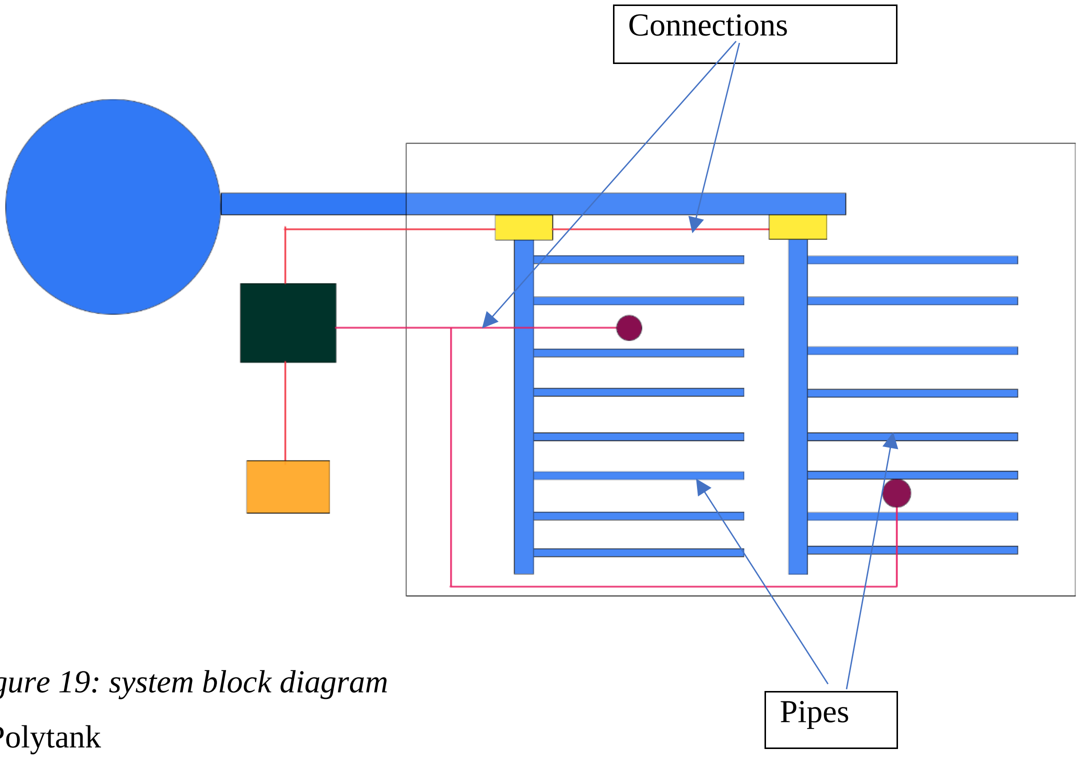


Figure 19: system block diagram

Polytank
Control center
Solenoid valve
Soil moisture sensor
Power supply

GENERAL CONCLUSION

This thesis explored the design and theoretical implementation of an automated gravity-fed irrigation system. Faced with the challenges of water management in a context of climate change and limited resources, this innovative solution offers promising prospects for improving agricultural productivity while preserving the environment.

The theoretical study highlighted the crucial importance of agriculture to Burkina Faso's economy and food security, as well as the limitations of traditional irrigation methods. Automation, by enabling precise control and real-time adaptation of irrigation, appears to be a relevant response to these challenges, particularly for gravity-fed irrigation, a technique adapted to local constraints.

The proposed system, based on the use of moisture sensors, a microcontroller and a solenoid valve, offers a simple, affordable and sustainable solution for optimizing water use and facilitating farmers' work. Although this dissertation has focused on the design and theoretical implementation of the system, it paves the way for future research and development.

Field trials are needed to validate the hypotheses formulated and assess the system's performance under real-life conditions. These trials would provide concrete measurements of water savings, yield improvements and reduced workload for farmers.

In addition, disseminating this technology to farmers in Burkina Faso will require appropriate support and training, to ensure that they take ownership of the system and make optimum use of it. Raising awareness of the challenges of sustainable water management and the benefits of automation will also be essential to encourage adoption of this innovative solution.

In the longer term, it would be interesting to explore other avenues for improvement, such as :

Integration of additional sensors (weather, water level) for even finer irrigation management.

The use of other renewable energy sources, such as wind power, to power the system in areas with limited sunlight.

The development of a remote control interface, enabling farmers to monitor and manage their irrigation system from their cell phone.

This research work has enabled us to acquire new knowledge and skills in the field of automation and irrigation. It can serve as a basis for future research and development work, helping to improve agricultural productivity and preserve water resources in Burkina Faso.

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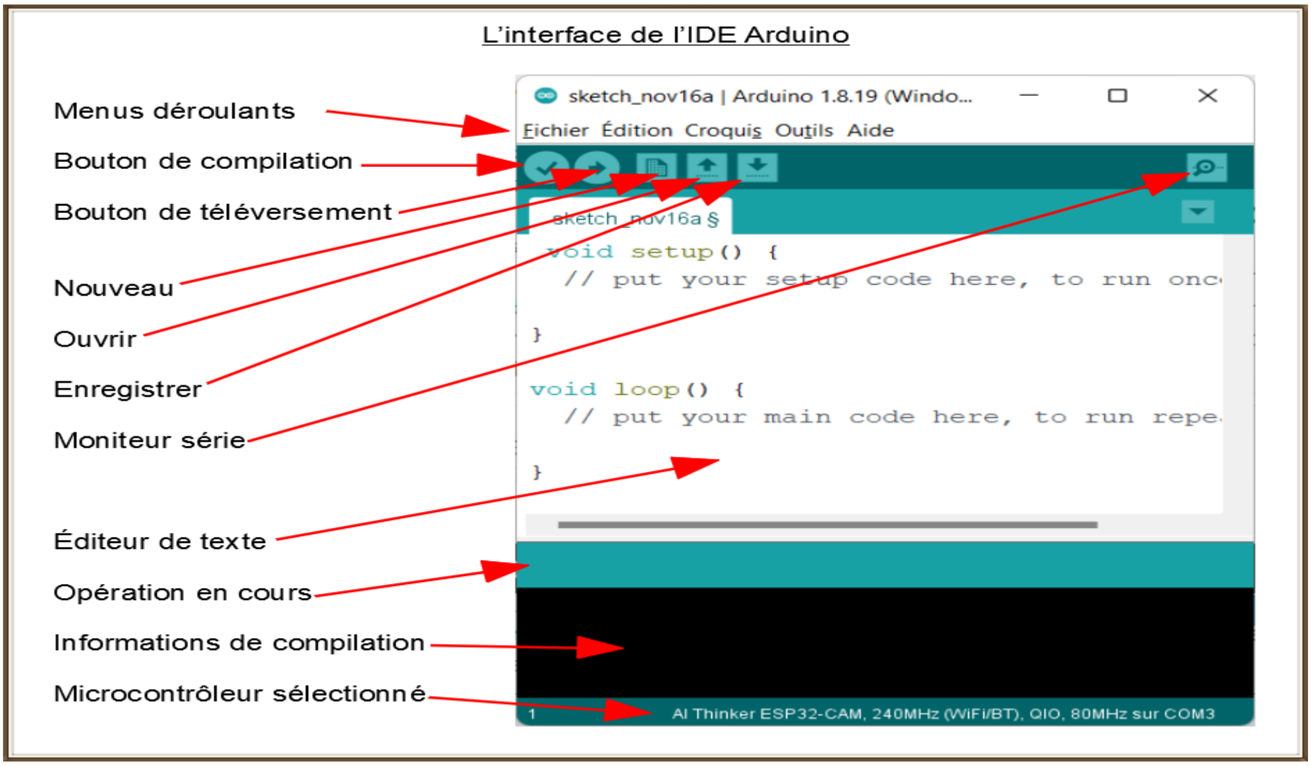
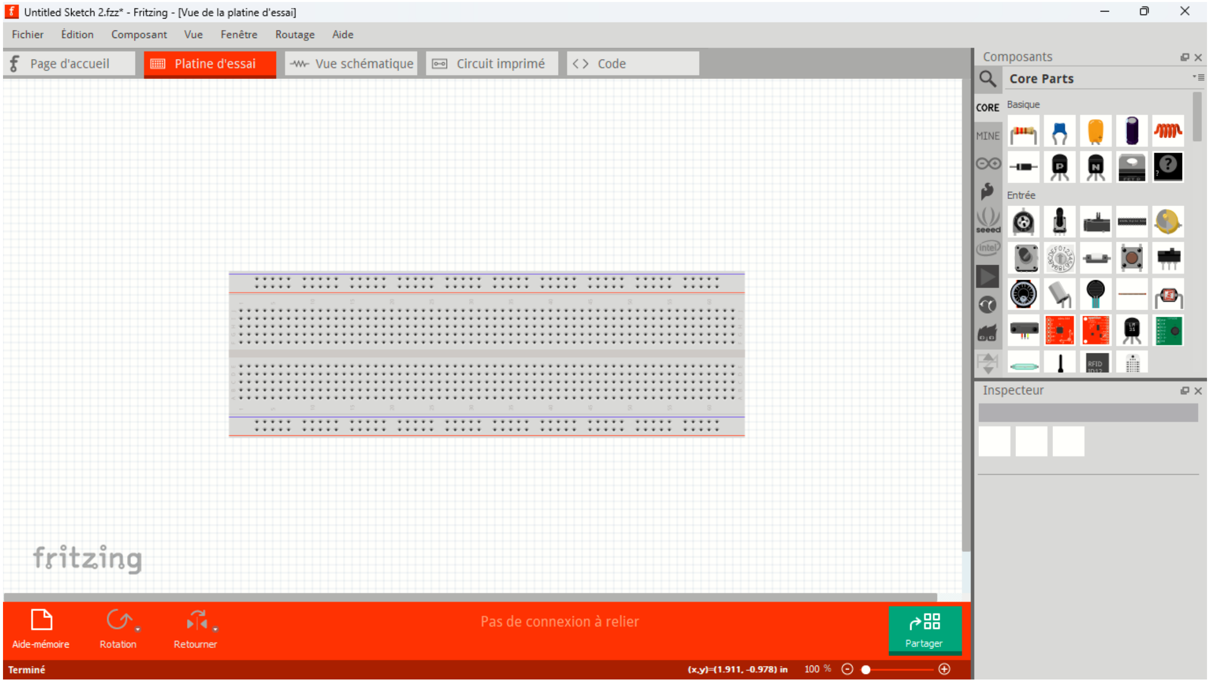
APPENDICES

Appendix I: Arduino software interface



Appendix II: Fritzing software interface



Appendix III: System coding

```
// Pin definition
XVons tint sensorPin = A0; // Analog pin for humidity sensor
XVons tint relayPin = 8; // Digital pin for the relay

// Soil moisture threshold (adjust as required)
const int threshold = 400;

void setup() {
  // Pin configuration
  pinMode(sensorPin, INPUT) ;
  pinMode(relayPin, OUTPUT) ;

  // Relay initialization (solenoid valve closed on start-up)
  digitalWrite(relayPin, HIGH) ;

  // Initialize serial communication for debugging purposes
  Serial.begin(9600) ;
}

void loop() {
  // Read humidity sensor value
  int sensorValue = analogRead(sensorPin) ;

  // Display sensor value for debugging purposes
  Serial.print("Soil moisture: " ) ;
  Serial.println(sensorValue) ;

  // Humidity threshold check
  if (sensorValue < threshold) {
    // Low humidity, solenoid valve open
    digitalWrite(relayPin, LOW);
```

```
    Serial.println("Solenoid valve open");
  } else {
    // Sufficient humidity, close solenoid valve
    digitalWrite(relayPin, HIGH) ;
    Serial.println("Solenoid valve closed") ;
  }

  // Pause before next playback
  delay(1000) ;
}
```