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Design of automatic irrigation system for greenhouse based on solar energy

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In front of jury composed of

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Abstract

Irrigating agricultural plants is a sensitive and costly process both financially and materially, and it significantly affects the annual crop yield. Therefore, in our project, we propose a smart irrigation system that relies on solar energy as a power source. Through this system, the timing and amount of water needed for greenhouse irrigation are determined, which facilitates water and energy conservation for farmers and enhances the quality of their products.

ملخص

يعتبر ري النباتات الزراعية عملية حساسة ومكلفة في نفس الوقت من الناحية المالية والمادية ويؤثر على المحصول السنوي للزراعة، لذلك نقترح في مشروعنا نظام ري ذكي يعتمد على الطاقة الشمسية كمصدر للطاقة يتم من خلاله تحديد الوقت وكمية المياه اللازمة لري الدفيئة، مما يسهل على المزارعين ترشيد استهلاك المياه والطاقة وتحسين جودة منتجاتها.

Résumé

L'irrigation des plantes agricoles est considérée comme une opération délicate et coûteuse à la fois sur le plan financier et matériel, et elle affecte le rendement annuel de l'agriculture. C'est pourquoi nous proposons dans notre projet un système d'irrigation intelligent basé sur l'énergie solaire comme source d'énergie, qui permet de déterminer le moment et la quantité d'eau nécessaire pour l'irrigation des serres. Cela facilite aux agriculteurs la rationalisation de la consommation d'eau et d'énergie, ainsi que l'amélioration de la qualité de leurs produits.

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R. Mohamed Ali, T. Abdellah Habib Erahmane

Dedication

First and foremost, praise be to Allah who has granted me the opportunity and strength to pursue my studies. I dedicate this humble work to everyone without exception: to my mother and father, to all my brothers and sisters, to all members of my family, to my colleague and dear friend Habib Taleb, to all my friends and comrades, to all my teachers and educators who have accompanied me in my educational journey.

I would also like to dedicate it to my teachers Khalida Bousdira and Abdelhak Bouchakour, and to my dear friends Hamza Rebbouh, Nouri Ahmed and Nasro lakas, Azeddine Krami, Sam HSR, Mohammed Abdelbassit Kherrafi , Asaad Taha, and Chihab Eddine Nettari.

Also the General Union of Free Students School.

R Mohamed Ali

Dedication

Praise be to Allah until praise reaches its utmost limit. I am pleased to extend my sincere thanks, dedicating this thesis to everyone who accompanied me at every stage of my academic journey, to all those who supported and stood by me. To my dear parents, my brothers and sisters, to every member of my family, from the eldest to the youngest. To my companion on the university path, my friend Rebbouh Mohamed Ali.

To everyone who taught me a letter in elementary, middle, high school, and university. To my classmates, to the residents of Ain

Deheb municipality, to the General Union of Free Students. To everyone who contributed, even with kind words, to the success of this humble work and supported us in completing our academic path.

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T Abdellah Habib Erahmane

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General introduction

Water is considered one of the essential and vital factors in the process of irrigation and watering in agriculture. Adequate quantities of water are provided to plants to ensure their healthy growth and high-quality crop production. The availability of water for irrigation is a fundamental requirement for improving production, as irrigated areas are more productive compared to non-irrigated regions [1].

Irrigation is strongly linked to food security, which is significantly affected by the water crisis. Algeria, like other countries, is greatly impacted by water scarcity[2]. To address this crisis and in light of the increasing need for a smart and suitable human living standard[3], it was necessary to find new solutions to solve this irrigation problem by implementing an intelligent irrigation system through the use of sensors, allowing us to test soil conditions before providing water to the fields. This mechanism will reduce the workload on farmers and help maintain suitable soil conditions for enhanced and high-quality agricultural production. Consequently, with the advancement of technology in the field of computing and electronics, such as wireless sensor networks, it has become possible to design smart irrigation systems that eliminate direct farmer involvement [2].

To implement automatic irrigation, the ARDUINO board was chosen to control the water pump, enabling water movement, and a soil moisture sensor. The program automatically regulates irrigation cycles and prevents water wastage by cutting off irrigation automatically in case of rainfall. This water-saving measure will be achieved through the utilization of a well-conducted preliminary study [4].

The irrigation system we will be working on will make it easy to track and determine the amount of water consumed by the greenhouse, as well as reduce water wastage while providing the appropriate amount of water for irrigation to ensure plant comfort. Additionally, it will utilize clean solar energy as a power source in the system.

We will summarize our project in three main chapters:

- The first chapter provides an overview of greenhouses and the associated problems.
- The second chapter presents different irrigation systems along with previous work on this topic.

- The third chapter focuses on the materials, methodology, and results of our project.

I. Introduction

The technology of agricultural greenhouses, or "environmental chambers," is a modern agricultural technique that helps to significantly increase crop productivity. It allows for the creation of a controlled environment for plant growth, as well as the conservation of water resources, climate control, and the reduction of the impact of climate change. In this chapter, we will discuss the nature of agricultural greenhouses, the advantages they provide in agricultural production, and also review the main climatic parameters that must be taken into account when establishing a greenhouse. We will also discuss the types of agricultural greenhouses and their classifications, the basics of choosing the appropriate agricultural greenhouse, including the cover for agricultural greenhouses, and the problems that may arise in greenhouse farming.

I.1.What is greenhouse?

A greenhouse is a structure designed to provide an ideal micro-climate for growing crops with a lifespan of around 25 years. Those containing high-value equipment and crops should have a longer lifespan of at least 10 years. Agricultural greenhouses are generally made up of four distinct and homogeneous environments: the soil, the plants, the indoor air, and the wall separating the interior from the exterior. To promote plant growth, a greenhouse must provide appropriate levels of light, humidity, and warmth, and maintain a reasonably stable climate. The primary source of heat in a greenhouse is sunlight, which passes through transparent materials

Like glass or clear plastic. When the sunlight hits an opaque surface, some of it is converted into heat. However, some heat loss still occurs despite the fact that heat is retained inside a mostly glass or plastic structure. Therefore, additional heat sources are required to keep the plants, ground, and soil comfortably warm. Maintaining a stable environment is critical for most plants, and this is the key to running a successful greenhouse. Ventilation, heating, cooling, and misting systems are critical considerations when constructing a greenhouse to ensure its durability and longevity. Greenhouses must conform to the same design and construction standards as those used for homes and other small buildings worldwide. Over the past four decades, growers, entrepreneurs, and plant enthusiasts have redesigned greenhouses using various materials. Stress limits should be considered to prevent potential risks to human life and structural damage [5-7].

I.2. Advantages of greenhouse production

Greenhouse production helps overcome problems encountered in outdoor farming:

- Crop needs are limited in the local climate.

- External weather conditions hinder production in open fields.

The greenhouse allows for easy management of climatic factors, which is not the case for outdoor farming. Among the major advantages of greenhouse production, we cite:

- Higher production thanks to the possibility of controlling the climatic conditions of the crop and promoting production all year round.
- Increased yield and quality of the harvest.
- Early production.
- Reduced consumption of fungicides and insecticides.

The agricultural greenhouse contributes greatly to the modernization of the agricultural sector through the implementation of new technologies. Note that the translation may not be word-for-word but conveys the same meaning in both languages [8].

I.3. Main climatic parameters in the greenhouse

I.3.1. Temperature

Temperature in greenhouses is the most important parameter for crop production under greenhouse conditions. It can be broken down into three types:

- Soil temperature.
- Plant temperature.
- Ambient temperature around the crop.

Temperature has a major influence on vegetative growth, as it is involved in many biological processes such as photosynthesis and respiration. The reaction rate easily increases with ambient temperature. For example, photosynthesis almost doubles when the temperature increases by 10°C [8].

I.3.2. Humidity

The relative humidity (RH) is the ratio, expressed as a percentage, of the actual water vapor pressure to the maximum (saturating) pressure. It affects the growth and health of crops in various ways. A high relative humidity favors fungal diseases, which is due to temperature fluctuations and evapotranspiration that occurs mainly during the first hours of the day. Water condensation easily covers plants, creating ideal conditions for fungal spores to germinate quickly. It can also weaken the crop and make it more susceptible to changes in climatic parameters. However, in a greenhouse, there are many methods that can be used to control humidity levels more effectively than in open-field cultivation. For instance, plants do not get wet when it rains. Ventilation brings in fresh and less humid air, and increasing the indoor temperature reduces the relative humidity. On the other hand, low relative humidity can be unfavorable to growth and promotes excessive crop transpiration. In this case, necessary measures can be taken, such as misting, watering, using shading sheets, ventilation, and interior cooling. A low RH has an advantage in high-temperature climates as it supports greenhouse cooling. Such situations require decision-making that favors crop growth. The average RH data only represents a general indication of humidity. Generally, RH has high values early in the morning and low in the middle of the day. These are critical moments for controlling and regulating the greenhouse climate. Continuous monitoring of indoor climatic conditions is essential to counter these uncertainties and ensure successful production [5].

I.3.3. Light

The growth and development rate of plants greatly depend on the solar radiation that the crop receives per day. The duration of sunlight is a crucial factor, although some crops react to short days, and others to long days (crop periodicity). Hence, it is important to know the day length throughout the year. Day length can be prolonged using artificial light or shortened by using shading materials (black plastic film). This is especially practiced in tropical countries to allow crops to reach the final stage of development. We need to know the day length to choose the type of crop to plant. The total amount of sunlight determines the growth rate and level of plant development. The variation in day length is strongly linked to seasons. Moreover, the distribution of annual rainfall and cloud cover are also determining factors. The topography of the land and especially the presence of mountains have an effect on the rate of cloud condensation and shading consequences [9].

I.3.4. CO2 content

He content of CO2 is one of the necessary factors for photosynthesis, and the higher the presence of CO2, the better the photosynthesis. During the night, compared to outside, the effect of the shelter will result in an increase in the CO2 content. Plants continue to breathe during a 24-hour cycle. During the day, CO2 is absorbed through the chlorophyll function, and the carbon dioxide

Content increases in the early morning and decreases in the late afternoon. In order to maintain the activity of the crops, it is necessary to maintain a high CO2 level. The diffusion of CO2 towards the areas near the plant due to their lower concentration of CO2 is not sufficient to ensure the necessary supply for the needs of the crops. Therefore, it is necessary to promote air renewal with ventilation. It should be noted that for certain crops, air enrichment with CO2 is practiced to increase production yields" [10].

I.4. Fundamentals for Choosing Your Greenhouse

I.4.1. design of a greenhouse

The design of a greenhouse depends on the crop type, crop quantity, and the method used for climate control. The greenhouse's dimensions and geometry, particularly its width, length ratio, affect the temperature and humidity distribution profile along the greenhouse. The ratio is an indication of the surface area exposed to solar radiation and the prevailing wind. Fig 1 illustrates different shapes of greenhouses with varying width, length ratios. For greenhouses designed for desalination processes, the dimensions have the greatest influence on water production and energy consumption. The authors investigated a range of (width, length) ratios and concluded that the higher the ratio, the higher the water production and the lower the energy consumption. In Oman, a greenhouse with a (width, length) ratio of 0.27 produced about 297 L/day of freshwater. For maximum solar energy collection, a greenhouse with a 0.1 (width, length) ratio was proposed. The cooling energy requirements of a greenhouse depend on solar radiation. A greenhouse with a 0.3 (width, length) ratio requires a cooling power of 110 kW. For greenhouses with (width, length) ratios ranging from 0.08 to 0.16 built on reclaimed coastal lands, where wind characteristics affect the greenhouse microclimate, the stability and turbulence are more dependent on the height of the ridge and the slope angle rather than the (width : length) ratio. A long greenhouse should be designed with a (width, length) ratio close to 0.5 to avoid irregular distribution profiles of air velocity and temperature throughout its length [11].

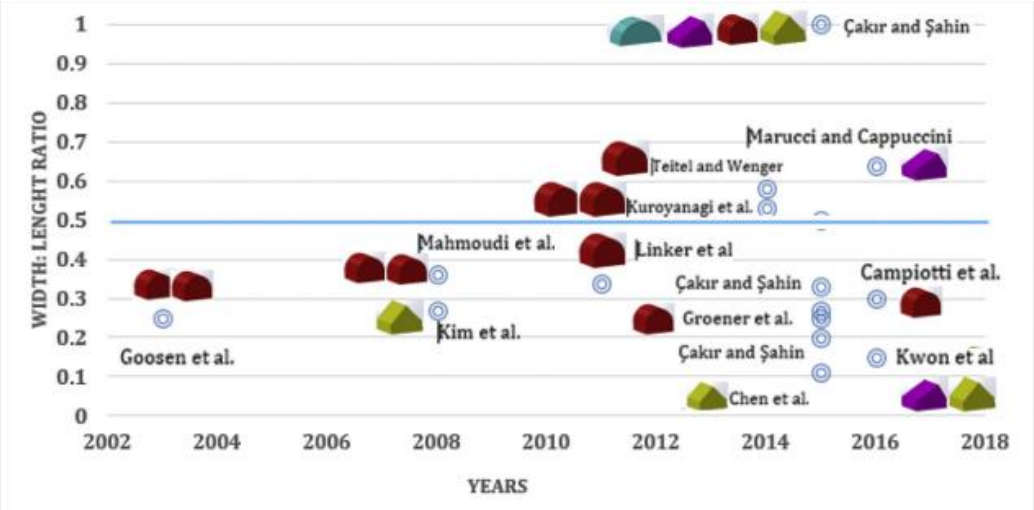

Fig. I. 1. Chronological greenhouse width : Length ratio.

I.4.2 Greenhouse Site Selection and Choice of Structure and Cover

When selecting a site for a greenhouse complex, several factors should be taken into consideration. The site should be level to minimize grading costs and have proper drainage to accommodate the high water usage in greenhouse operations. If drainage is a concern, installing drainage tiles below the surface prior to building the greenhouses is recommended. A natural windbreak, such as a treeline or hill, on the north and northwest sides is also advisable, while trees on the East, South, or West sides should be placed at a distance of 2.5 times their height to prevent overshadowing the crop. In areas with snowfall, trees should be kept 100 ft (30.5 m) away from the greenhouses to prevent snowdrifts. Additionally, the site should have sufficient space for future expansion to ensure long-term economic viability [1].

When it comes to choosing the structure and cover of the greenhouse, the main criteria are:

- The transmission of radiation useful for photosynthesis, as it determines the potential production.
- The strength and durability, especially in areas with climate risks.
- Functionality and ease of maintenance, which play a role in labor costs.
- Energy savings when heating is required.
- Price [12].

I.4.3. Greenhouse shapes

The shape of a greenhouse is a critical factor in crop cultivation and production, as it determines the amount of solar energy received by the greenhouse. The most common structural form is a straight sidewall and gable roof, which can be used to construct single or multiple span greenhouses. The optimal greenhouse shape in hot and arid climates should minimize solar irradiation in the summer and maximize it in the winter, while tropical regions require protection from rain, wind, and excessive global radiation. The greenhouse volume to ground floor area ratio should also be as high as possible, and the gutter height should be at least 3 meters.

Several studies have been conducted to improve greenhouse shape design, with the even-span greenhouse being the most commonly studied. Other designs that have been studied include the Quonset shape, uneven-span shape, and arch roof shape which are shown in the figure 2 Multi-span greenhouses have also been studied, with results showing that as the number of spans increases, the ventilation rate increases and the differential between windward and leeward roof pressures decreases [13].

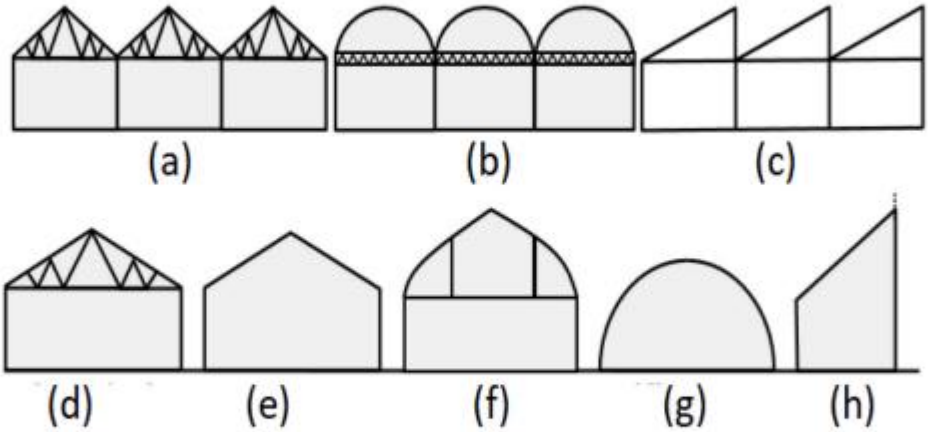

Fig. I. 2. Greenhouse roof shapes : (a) Gable roof, (b) Arch roof, (c) Sawtooth roof, (d) Trussed roof, (e) Gable frame (even span), (f) Gothic house, (g) Hoop house (Quonset), (h) Lean-to house [13].

I.4.4. Greenhouse Orientation

In general, there are two important criteria to consider when deciding on the orientation of a greenhouse :

• The greenhouse should receive adequate and uniform levels of light for optimal crop growth.

• The prevailing winds should not negatively affect the structure or operation of the greenhouse.

Single greenhouses (which are free-standing and have a single span) located above 40◦N latitude in the northern hemisphere should have their ridge running from East to West, so that the low-angle light of the winter sun can enter from the side rather than from an end, where it would be blocked by the frame trusses. Below 40◦N latitude, the ridge of single greenhouses should be oriented from North to South, since the angle of the sun is much higher. Gutter-connected greenhouses or multi-span greenhouses (connected to another greenhouse along their length) at all latitudes should be oriented from North to South to avoid shadows that would occur from a greenhouse lying immediately south of it in an East-West arrangement. Although the North-South orientation has a shadow from the frame trusses, it is much smaller than the shadow that would be cast from a whole greenhouse oriented to the south.

Different researchers have used various greenhouse orientations (East-West and North-South) for growing off-season vegetables or ornamental plants.

The prevailing wind direction of the site also influences the orientation. In naturally ventilated greenhouses, ventilation should open on the windward side. The effect of wind can be reduced by constructing fences of varying heights or growing trees and shrubs as windbreaks. A solid windbreak, which causes turbulence, is much less effective than one that allows a small amount of wind to pass through it.

On the other hand, a greenhouse facility is significantly affected by shading from surrounding terrain, buildings, and plant material. Therefore, greenhouses should not be built near large trees, buildings, or other obstructions. As a general rule, no objects taller than 3.3m should be within 9m of the greenhouse in any direction (East, West, South, or North). The magnitude of shadows depends on the angle of the sun and thus on the season of the year [1].

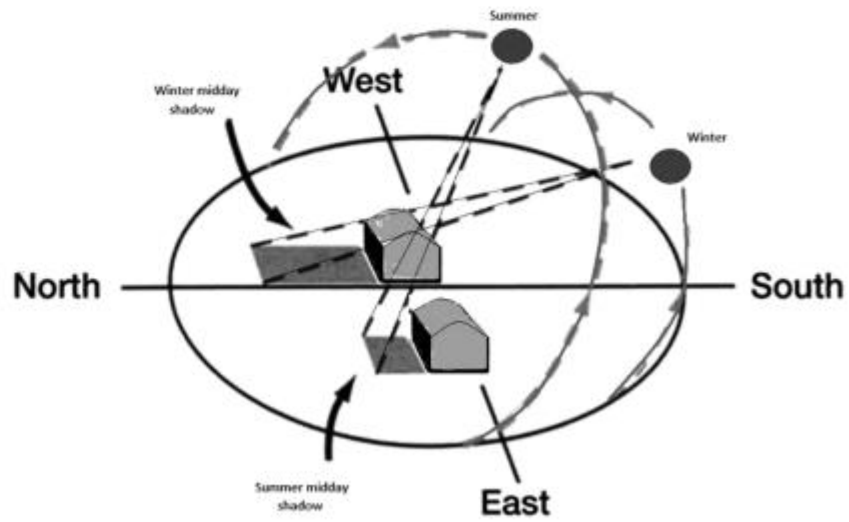

Fig. I. 3. Location Priorities for Greenhouse based on Ambient Sunlight.

I.5. greenhouse cover

The choice of cladding material for a greenhouse is crucial in determining the quality of light and radiation that reaches the crop, as well as the heat loss of the structure. Factors such as strength, consistency, durability, and energy conservation must be considered when selecting a cladding material. Additionally, questions such as the amount of light and heat that will enter and exit the greenhouse, as well as the purchase, installation, and maintenance costs, should be taken into account. Other variables, including transmittance, dust and dirt, gases, and salt, can also affect the cover used for the crop. Glass, plastic films, and rigid plastic panels are the most commonly used types of coverings for greenhouses.

I.5.1. Glass

Transparent or translucent flat mineral glass is a silicate of lime and soda (silica 71 to 74%, lime 10 to 15%, soda 13 to 17%). The different types of glass used in greenhouse cultures are :

transparent or clear glass (called horticultural glass), hammered or cathedral glass (cast horticultural glass), low-emissivity horticultural glass, double glazing, insulated glass, tempered glass, reinforced glass, and laminated glass.

Clear horticultural glass is highly transparent to all solar radiation between 380 and 2500 nm, with visible light transmission typically between 89% and 91% at normal incidence. The transparency to photosynthetically active radiation (PAR) is better than that to short infrared radiation. The light transmission remains high up to an incidence angle of 60°, beyond which reflection losses increase sharply. It is practically opaque, like the majority of glasses in the ultraviolet below 300 nm, and passes about half of the UV radiation between 300 and 400 nm. It is practically opaque to long infrared radiation beyond 5000 nm, i.e., to terrestrial thermal radiation. At the thicknesses used, the glass is poorly insulating, with a fairly high thermal transmission coefficient (5.5 to 6.1 W/m2K). Some of the thermal losses (45%) are due to a fairly high emissivity (emissivity coefficient of 0.9). Its advantages are: excellent light balance, high chemical and physical stability, and great longevity; however, it has three disadvantages: high weight (10 kg/m2 for 4 mm thickness), low resilience, and low resistance to thermal shock.

Hammered or cathedral glass was widely used in the 1960s and has one flat side and one intentionally wavy side. The flat side faces outward. It is much less commonly used nowadays. Its advantages are : this glass diffuses light strongly, which is advantageous for plant illumination. Its disadvantages are very high reflection losses.

Low-emissivity horticultural glass can reduce radiative losses due to a thin layer of tin oxide, which is always applied to the outward-facing surface. Its transmission in the visible (PAR) is 83% instead of 90%. It decreases rapidly beyond 1,000 nm to become zero at around 2,700 nm. Long-wave infrared transmission is virtually zero. Radiation losses are reduced on average by 70%. This type of glass can save 40% of energy on clear sky and weak wind days, but only 5% on overcast and strong wind days. Compared to horticultural glass (clear or hammered glass), despite a reduction in heat losses and a favorable thermal balance, the significant reduction in light leading to yield losses is a notable disadvantage. Its investment cost is slightly higher.

Double glazing is designed to reduce thermal losses, and often on the side walls, a double glazing unit consisting of two glass panes placed (6 to 20 mm) apart is used. The glass panes can have the same thickness (4 mm). The space between the panes contains air (preferably dry). The seal with the interior must be perfect. This type of glazing allows for energy savings in greenhouse heating, but it has a higher investment cost.

Insulated glass is a prefabricated assembly of two glass sheets spaced permanently and sealed, trapping a dehydrated gas (such as a CO2-rich mixture). This type of glazing is highly effective in thermal insulation [14].

I.5.2. Plastic

The use of plastic materials, especially polyethylene (PE) films, has greatly contributed to the development of greenhouses in recent years. PE is a flexible and strong material that is easy to install on lightweight structures. While it has high transparency in the spectral domains of 0.39 to 39 μm, it does not have the greenhouse effect unless it undergoes special treatment or has a condensed water film on its inner surface. Plastic film is the most widely used cladding material in tropical, subtropical, and arid climates due to its cost-effectiveness. Plastic structures are often considered temporary and may have lower assessment rates or be exempt from taxation. Additionally, crops grown under plastic have been found to be of equal quality to those grown under glass. However, the main weakness of PE is its short lifespan due to aging and mechanical breakage problems, as well as a decrease in light transmission due to dirt. It is important to evaluate plastic materials at various levels, including their optical and mechanical properties, to ensure optimal performance we mention several types of the:

I.5.2.1. Polyethylene (PE)

PE is a popular greenhouse material due to its flexibility and strength, but it has drawbacks like faster heat loss at night. UV-inhibited PE reduces heat loss but deteriorates with sun exposure. Double-walled blown PE reduces heat losses and condensation, but lacks the greenhouse effect of glass. PE's main weakness is its short lifespan due to aging, breakage, and reduced light transmission. Evaluating plastic materials' properties is crucial for optimal greenhouse performance.

I.5.2.2. Low density polyethylene (PE)

PE film is a cost-effective option for DIY greenhouses. Clear PE is used for most plants, while white PE is suitable for low-light plants. It stretches up to 2.6-3% and the optimal tension is 1.3-1.5% of its length.

PE film has advantages like low cost, flexibility, tear-resistance, and resistance to chemicals. However, it has drawbacks such as a short lifespan of around 2 years, degradation over time, poor heat conduction, and susceptibility to tears if not properly installed. It is also degraded by UV radiation and oxygen.

I.5.2.3. Polyvinyl Chloride (PVC)

PVC is a cost-effective and easily accessible material for building Quonset-style greenhouse frames. It can be bent into hoops to secure polyethylene film, with plywood or fiberglass sheets used for the frame ends. PVC retains heat well at night, preventing temperature inversion, and is resistant to cracking and tearing. However, it is not widely used in greenhouse construction, comprising only 2% of covering materials. PVC creates a stronger greenhouse effect due to its lower heat conductivity, but it produces less condensation and can accumulate surface dust. Attaching fiberglass sheets can provide additional cover.

I.5.2.4. The Vinyl sheet

Vinyl sheets are commonly used at the ends of the greenhouse for visibility but are not suitable for covering the top. They have a lifespan of about four years. The advantages of Vinyl sheets include their heavier weight, durability, and longer lifespan, especially when made with an ultraviolet inhibitor. They can last up to five years. However, similar to polyethylene, they tend to accumulate dust due to their electrostatic properties, which can reduce the amount of light transmission.

I.5.2.5. Rigid plastic panels

Rigid plastic panels, specifically polyester films like Mylar, are durable and lightweight, making them a popular choice for greenhouse construction. They have a thickness of about 5mm and share characteristics with glass, such as light transmission and resistance to hail and extreme temperatures. However, they can be expensive and may be less effective on unstable frames exposed to wind.

I.5.2.6. Fiberglass Reinforced Panels (FRPs)

Fiberglass Reinforced Panels (FRPs) are durable, rigid plastic panels made from acrylic or polycarbonate materials. They have high resistance to breakage and UV radiation, making them long-lasting for 10 to 15 years. FRPs are lightweight, retain heat well, and provide soft, shadowless illumination in greenhouses. However, a major drawback is their susceptibility to burning when exposed to flames or extreme heat, requiring caution to prevent fire.

I.5.2.7. Acrylic semi-rigid panels

Acrylic semi-rigid panels are popular in greenhouses for their strength, lightweight nature, sunlight resistance, and good light transmission. They can withstand snow, strong winds, and hail, providing long-lasting service. However, they are prone to scratching. Despite being expensive, they are considered cost-effective in the long run, particularly in commercial greenhouses where they can reduce heating costs by up to 30%. These panels have a lifespan of up to 20 years.

I.5.2.8. Polymethyl methacrylate (PMMA or PMM)

Polymethyl methacrylate (PMMA or PMM) is a rigid, transparent plastic commonly used as a glass alternative in various applications. It offers advantages such as high transparency to UV rays and opacity to nocturnal radiation. PMMA has a strong structure, resistant to tearing and aging. However, it has a low broadcasting power and is prone to scratching, which can diminish its optical qualities over time.

I.5.2.9. Polypropylene

Polypropylene is a material that offers advantages such as increased strength, stiffness, and higher temperature resistance compared to polyethylene. It is commonly used in fiber production due to its good specific strength. One benefit of polypropylene is its ability to be treated with a non-stick coating, preventing dust accumulation and facilitating handling during installation. However, a drawback is that it is transparent to long wavelength infrared radiation. Additionally, its porous surface can lead to water dripping if the structure lacks proper slope.

I.5.2.10. Ethylene-vinyl-acetate

EVA (Ethylene-vinyl-acetate) is a thermic film used in areas with low nighttime temperatures for crops. It offers advantages over polyethylene (PE) film, including higher thermal effectiveness in keeping plants warm. EVA is also more flexible, impact-resistant, tear-resistant, and has better light transmission than PE. However, a major disadvantage of EVA is its high level of expansion, which can lead to water pooling and vulnerability to wind damage [1 6 10].

I.6. Type of greenhouse

The classification of greenhouses is very complex and difficult, and is often based on the shapes given by the supporting frames that make up the assembly. There are two main types belonging to two large families of 4greenhouses : Chapel greenhouses and tunnel greenhouses. They can also be distinguished according to the shapes of their roofs, such as flat-sloped chapels with vertical posts, asymmetric chapels, chapels without vertical posts, chapels with sloping side walls, etc. There are also other types of smaller greenhouses called "petit tunnel", which have quickly developed in Mediterranean countries due to their low cost. Its base width is 1.5 meters and its height is 0.45 meters, and its length does not exceed 20 meters [5].

Fig. I. 4. Small tunnel greenhouse.

Fig. I. 5. Multiplication greenhouse.

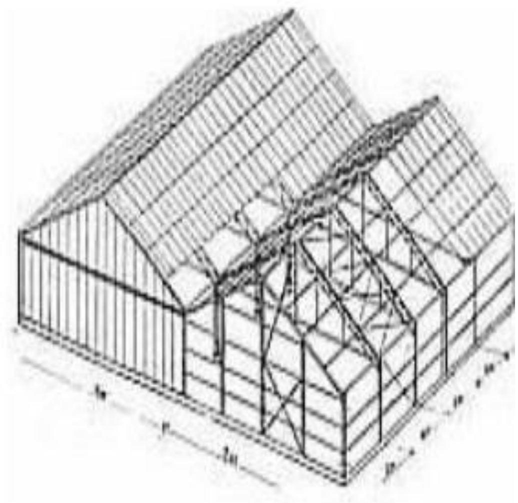

Fig. I. 6. Double chapel greenhouse.

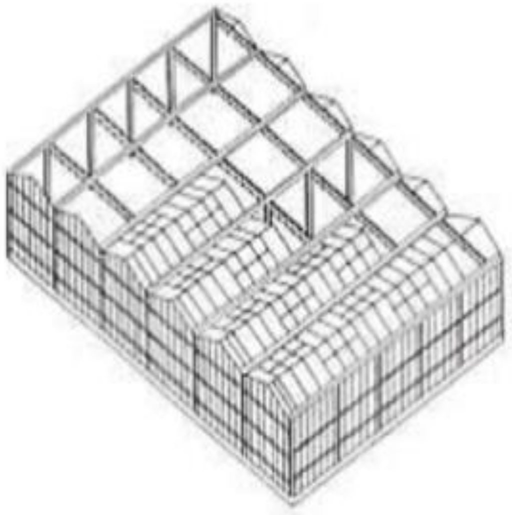

Fig. I. 7. Double chapel greenhouse.

I.6.1. The round arched tunnel greenhouses

The round arched tunnel greenhouses are widely used in developing countries with mild climates, but they come with several disadvantages that impact yield and quality. Although they are relatively easy to construct and can resist wind with proper foundations and strong steel tubes, they have a small net floor area for plant cultivation compared to the space they occupy. The plastic-film consumption is also higher per net floor area, and the greenhouse volume is too small for proper climate control. Additionally, there is a wide nearly horizontal zone at the top where condensation drops fall down from the covering material, and 6-30 wires are stretched in longitudinal direction that can damage the plastic film. Even if No-Drop films are used, water droplets cannot run off along the inner surface of the film [15].

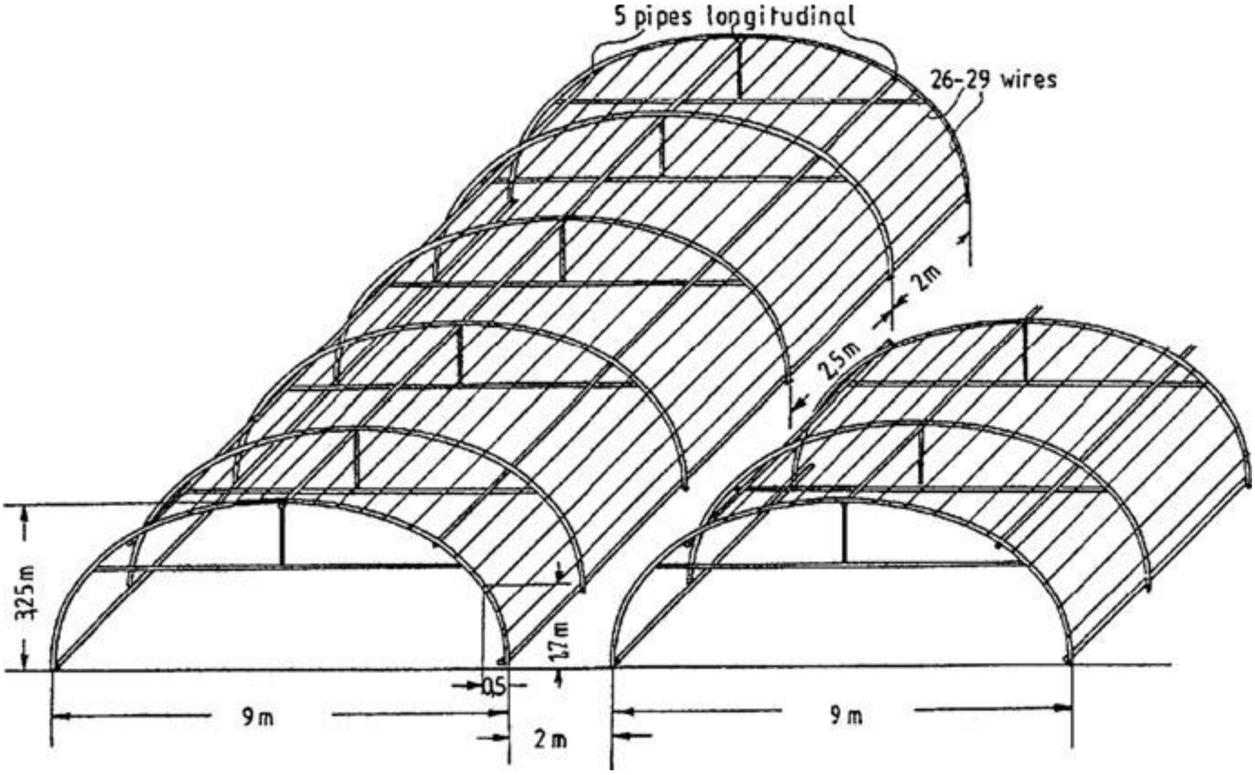

Fig. I. 8. Round-arched tunnel greenhouse.

I.6.2. Horticultural greenhouses

Horticultural greenhouses are constructed using building units called chapels, which consist of two vertical (or slightly inclined) side walls and a symmetrical double-pitched roof. The common dimensions of chapels are approximately 3, 6, 9, 12, and 16 meters in width. When two consecutive chapels are not separated by an internal wall, they form a multi-chapel or twin-chapel greenhouse. Farms are the main load-bearing structural elements of the chapel and are repeated at regular intervals. The length between farms determines the type of greenhouse. The module is a characteristic surface of the greenhouse obtained by multiplying the width of the chapel by the length of the inter-farm space. The gables are the vertical walls that form the two ends of a chapel, while the ridge is the line formed by the top of the chapel. The portico is a load-bearing structure constituted in older greenhouses by the foot of the farm and a beam joining the tops of the uprights, but there are fewer and fewer portico greenhouses. The uprights are the vertical side walls of a chapel. Figure ...will provide à better visualization of these different elements in volume.

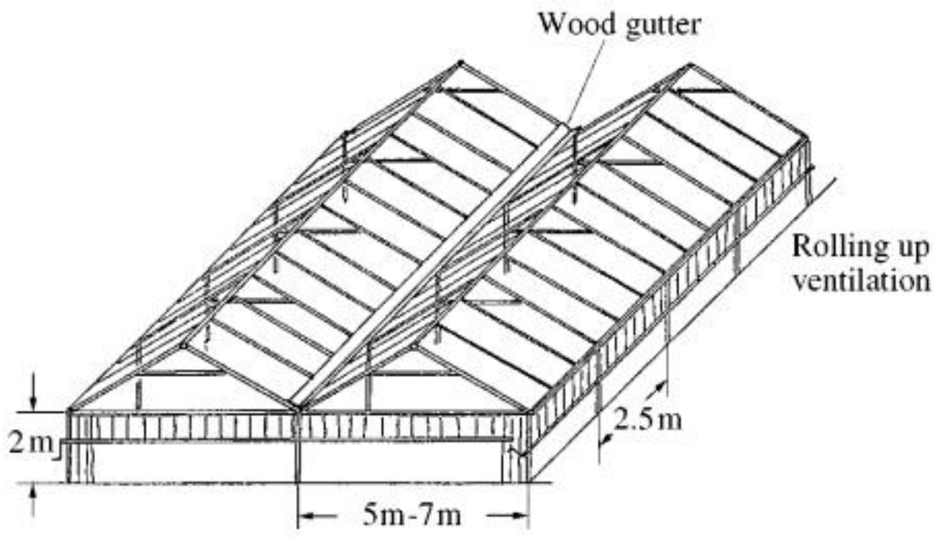

Fig. I. 9. Pitched roof construction covered with plastic.

I.6.3. Multi-span gutter-connected plastic-film greenhouses

Multi-span gutter-connected plastic-film greenhouses are a popular choice due to their advantages. They offer a larger greenhouse volume and better climatic conditions, with sidewalls that should be at least 3 meters high. Ventilation with sidewall and gable ventilators can prove efficient, but for multi-span units wider than 18 meters, roof or ridge ventilation may be required, especially if the outside temperature exceeds 27°C. However, these ventilation systems are costly, representing 25-30% of the total investment. Without roof vents, the investment cost for greenhouse structures, including plastic film, is around €10-16/m2, while with roof vents it can be as high as €27/m2. Pointed-arched roofs can be built to reduce dripping. Small units with two to three spans can be built with side-wall and gable ventilation only if the gutter height is 3 meters or more, but roof or ridge ventilation is necessary for multi-span greenhouses with four or more spans [15].

Fig. I. 10. Multi-span pointed-arched greenhouses.

I.6.4. Chinese greenhouses

What sets Chinese greenhouses apart from conventional greenhouses is their unique design. Unlike traditional greenhouses, Chinese greenhouses are not spacious, which means less cubic feet of space to heat and cool, resulting in more affordable maintenance of optimal growing conditions. Additionally, they have less surface area of glass or plastic exposed to the elements, reducing surface area for heat loss on cold winter nights and overheating during summer. Moreover, Chinese greenhouses are well-insulated and contain lots of thermal mass to store and release heat, which maintains thermal stability during cold months. They are also oriented on east-west axes, capturing the low-angle "winter sun" to increase heat gain in the late fall, winter, and early spring while reducing heat gain throughout the rest of the year. Finally, many Chinese greenhouses are earth-sheltered, which means they naturally stay cooler in the summer and warmer in the winter. These design features make it possible for Chinese greenhouses to be heated solely by sunlight, eliminating the need for additional heating sources like wood, natural gas, or propane, or expensive electricity to run space heaters. This energy-efficient design eliminates heating and cooling systems found in conventional greenhouses, making Chinese greenhouses sustainable and self-sufficient. With all these features combined, Chinese greenhouses are an efficient and comfortable place to grow plants [16].

Fig. I. 11. Chinese greenhouse.

I .7. Greenhouse problems

I .7.1. Problem of high temperature

Air temperature is a crucial factor in determining the microclimate within a greenhouse. The temperature inside a greenhouse varies due to complex interactions between different elements, including the structure, vegetation, outside air, weather conditions, and solar radiation. High temperatures during the warmest months of the year can negatively impact the growth of crops in greenhouses, particularly in regions with temperate, subtropical, and semi-arid climates. In some Mediterranean countries, temperatures above 35 °C and 3 kPa VPD are common during the summer. High temperatures are also a problem in hot arid and tropical climates year-round, where maximum temperatures can reach up to 75 °C. Without proper ventilation or cooling systems, greenhouse temperatures in such climates exceed outside conditions. Yield potential in many common vegetable crops reduces at temperatures above 26 °C, with fruit set being one of the first processes negatively affected by temperatures greater than 32 °C during the day and 26 °C at night. Generally, plants grown under protected cultivation are particularly adapted to average temperatures ranging from 17 to 27 °C. Optimal temperatures for tomato cultivation, for instance, are between 25 and 30 °C during the photoperiod and 18 to 25 °C during the dark period. The mean absolute maximum temperature for most greenhouse crops should not be higher than 35 to 40 °C [17].

I .7.2. Adverse impact of humidity

Dehumidification is essential in greenhouses for the following reasons:

1. Prevention of Condensation: High humidity levels in greenhouses increase the likelihood of condensation forming on leaves, particularly at night. This creates a favorable environment for the development of fungal diseases like Botrytis. By removing excess moisture through dehumidification, the chances of condensation and fungal growth are reduced.
2. Promotion of Optimal Plant Growth: Maintaining greenhouse air humidity within the range of 60-80% is crucial for healthy plant growth. Low humidity levels can inhibit plant growth by causing reduced stem lengths and smaller leaf sizes. Conversely, excessive humidity impedes water evaporation from plant leaves, limiting nutrient uptake and potentially resulting in deficiencies of vital nutrients such as boron and calcium.
3. Enhancement of Solar Radiation and Photosynthesis: Condensation on the greenhouse cover can significantly reduce the amount of solar radiation entering the greenhouse, up to 23% in some cases. This reduction in light interception negatively impacts photosynthesis,

leading to a decrease in the leaf area index and overall plant growth. Dehumidification helps maintain optimal humidity levels, ensuring sufficient solar radiation for effective photosynthesis.

4. Prevention of Fungal Diseases: High humidity levels create favorable conditions for the growth of fungi, which can be harmful to plants. By controlling humidity and reducing moisture in the air, the proliferation of fungal diseases can be mitigated, safeguarding the health of greenhouse crops.
5. Challenges in Closed Greenhouses: Closed greenhouses, which are increasingly popular in colder climates, face specific challenges in controlling excessive humidity levels. Limited airflow in closed systems necessitates the implementation of effective dehumidification measures to maintain the desired humidity range.

In summary, dehumidification plays a vital role in establishing an optimal growing environment for plants in greenhouses. It prevents condensation, reduces fungal diseases, maximizes photosynthesis, and enhances crop productivity [18].

I .7.3. Greenhouse cover problems

The main characteristics of various greenhouse covering materials highlight certain factors that become increasingly evident over time. These factors have a significant impact on the greenhouse's thermal effect. The most important factors include:

I .7.3.1 Water condensation on the greenhouse wall

When the relative humidity is high, water condenses on the inner surface of the greenhouse, creating dew as soon as the external temperature drops. The amount of condensed water is practically the same on the inner surface of the covering, but its evacuation differs. It either condenses into droplets that increase in volume and fall on the spot, or it creates a very thin and more or less mobile continuous water film, depending on the geometric shape and slope of the covering.

I .7.3.2. Soiling of the greenhouse covering

The dirt that accumulates on the greenhouse wall consists of atmospheric dust and industrial residues, including soot and oil from burners used in agriculture. This deposit causes a significant loss of light transmission and, of course, affects the greenhouse's crop yield. Some studies estimate an average annual light loss of 10% under normal conditions of use and even more for materials with non-smooth surfaces.

I .7.3.3. Aging of the covering materials

Among the optical problems caused by aging, yellowing of the covering material resulting from the shift of absorption bands that appear in ultraviolet light is a significant concern. This yellowing is particularly noticeable in polyethylenes and polyvinyl chlorides and can intensify to almost complete opacity. Additionally, micro cracks on the surface exposed to solar radiation promote diffuseness and impair the transparency of the material. And other aging curves of widely used covering materials in greenhouses are presented.

According to some studies, electromagnetic radiation energy is inversely proportional to its wavelength, explaining why ultraviolet rays are the primary culprits of material alteration. Short ultraviolet rays are more absorbed by the atmosphere than long ultraviolet rays, which are the true aging agents of the materials [19].

I. Conclusion

Greenhouses are crucial in providing protected agricultural spaces from external conditions, and they are affected by a number of climatic factors. Temperature, relative humidity, lighting availability, and ventilation are among the most important factors, and they have a significant impact on plant growth and productivity within the greenhouse.

Greenhouses allow for the opportunity to cultivate during times of the year when external conditions do not allow for cultivation, and they provide better conditions for plants, such as protection from diseases and pests, and control over the availability of water and nutrients necessary for proper plant growth.

When choosing a greenhouse, suitable conditions for its operation must be met, including a good location, availability of water resources, and heating and ventilation sources to provide suitable indoor conditions for plant growth.

There are various types of greenhouses used in agriculture, and they are classified based on different agricultural needs. The type of cover used to cover the greenhouse also varies, such as plastic or glass, which affects the temperature and lighting availability inside the greenhouse.

Despite the benefits of greenhouses, there are a number of problems that agriculture inside greenhouses can face, such as the accumulation of pests and diseases, and the need for appropriate management practices to ensure their sustainable operation.

II. Introduction

Irrigation is the practice of applying water to plants, crops, or soil to ensure optimal growth and productivity of plants. It is a vital component of modern agriculture and plays a crucial role in food production and food security worldwide.

Irrigation systems come in various forms, including traditional techniques such as flood and furrow irrigation, as well as modern methods such as drip irrigation, center-pivot irrigation, and sprinkler systems. Each method has its advantages and disadvantages and is suitable for different crops, soil types, and climatic conditions. Irrigation practices have evolved over time, and today, modern irrigation systems include advanced technologies such as remote sensing, precision irrigation, and automation, allowing for more efficient water use and improved crop yields.

Therefore, in this section, we will discuss various types of irrigation along with how to practice smart irrigation using solar energy.

II.1. Irrigation

II.1.1. Definition of irrigation

Irrigation is a process of artificially providing water to cultivated plants to increase their production and promote normal growth in areas experiencing insufficient rainfall, excessive drainage, or declining water tables, particularly in arid and semi-arid zones.

Irrigation can be defined as a human process that compels farmers to provide water to agricultural crops in times of water scarcity. In this regard, farmers must use water rationally according to the water needs of each irrigated crop. However, a broader definition of irrigation includes the application of water to the soil for several purposes, including:

- Adding water to the soil to ensure essential moisture for plant development.
- Cooling the soil and atmosphere to create a favorable environment for plant growth.
- Reducing the risk of frost.
- And facilitating soil cultivation[20].

II.1.2. Advantages and disadvantages of irrigation

II.1.2.1. Advantages

Irrigation increases crop yield and regulates it in many regions of the world. It is not just a supply of water to cultivated lands to compensate for the lack of rainfall and allow for the full development of crops. Rather, it is a set of integrated development measures for agricultural and rural areas that should lead not only to increased production and improved living standards for farmers, but also to environmental preservation in a particular agricultural land, by providing irrigation water, which in itself translates into energy savings.

II.1.2.2. Disadvantages of irrigation

Irrigation consumes a lot of water and can accelerate desertification in certain areas, as it accounts for over 85% of human-controlled water. Irrigated agriculture faces new problems such as the risks of salinity that can be assessed through Electrical Conductivity (EC) and soil alkalinity. The latter, due to ion exchanges, is primarily related to sodium, calcium, and magnesium. There are other land drawbacks (structure destruction, reduced structural stability, etc.) [20].

II.1.3. Elements of Irrigation Improvement

It involves managing and precisely defining, for each irrigation, the optimal date and dose, as it ensures the satisfaction of the water needs of the crops. This optimization is based on three criteria:

a) Agronomic: aims to maximize crop yield.

b) Hydraulic: aims to maximize water efficiency.

c) Economic: aims to maximize farm income.

To achieve this improvement, some modern methods have been implemented, such as the Tensiometric Management Method [21].

II.1.4. Different types of irrigation systems

II.1.4.1 Drip irrigation or micro-irrigation

II.1.4.1.1. Definition

Drip irrigation or micro-irrigation is a localized pressurized water distribution system that delivers water to the base of plants through emitters via a network of pipelines. The pipelines are composed of plastic pipes (opaque PE or PVC) assembled together. A master pipeline feeds perforated lateral pipelines or pipelines equipped with special emitters, allowing water to be delivered at a predetermined flow rate of between 1 to 10 liters per hour. Lateral pipelines usually have a diameter of 10 to 25 mm, and the water pressure is typically between 0.5 and 2.5 atmospheres. Water comes out as drips because the pressure decreases due to friction when it flows through the emitter's orifice or passage. The alteration of pressure flow rate at the outlet can be limited if the emitters have pressure regulators. A manual valve or a sequence of programmable valves controls the irrigation timing and interval. Once the predetermined volume is distributed, the flow is automatically stopped. Water can be distributed through various means such as drip emitters, mini-sprinklers, bubblers, micro-jets, etc[22].

Fig. II. 1. Drip irrigation.

II.1.4.1.2. Advantages and disadvantages of drip irrigation

1) Advantages :

- ❖ Drip irrigation has the ability to conserve water, improve crop quality, and increase crop production through controlled doses and frequencies of irrigation.
- ❖ Drip irrigation enhances water use efficiency by reducing water loss caused by deep percolation, soil evaporation, and surface runoff.
- ❖ With drip irrigation, weed growth can be minimized, salinity problems can be alleviated, and fertilizer use can be optimized.
- ❖ Drip irrigation is generally more energy-efficient than sprinklers and can be adapted to difficult soils and terrains.

2) Disadvantages of drip irrigation :

- ❖ The high costs of initial installation and intensive maintenance requirements (such as emitter clogging, etc.) are a drawback of drip irrigation.
- ❖ In addition, drip irrigation limits plant root growth, and salt accumulation near the plants is preferred, which reduces the soil's ability to absorb carbon dioxide [23].

II.1.4.2. Spray irrigation

II.1.4.2.1. Definition

Irrigation using spray systems is a method of watering where water is sprayed into the air in small droplets resembling natural rain to improve water usage in sloping fields, as well as to overcome problems of water saturation. However, "most water losses occur from the water leaving the nozzle until it reaches the soil roots"(can eng), perhaps through wind drift, evaporation, and runoff. Farmers must carefully choose suitable wind conditions for irrigation. Additionally, they can avoid further losses from evaporation and runoff by irrigating at night, which can reduce these losses to negligible levels. Furthermore, matching the spray rate can ensure a more uniform entry of irrigation water into the root zone. The wetted area is circular, and the nozzles should be operated close to each other to achieve at least a 65% overlap of the wetted diameter. Some sprayers are designed to improve the use of different inputs to enhance or boost the production of economically viable crops using precision agriculture techniques. Others are provided through remote sensing devices to monitor water status in the field simultaneously to improve water use efficiency [24].

Fig. II. 2. Central irrigation is one of the types of irrigation by sprinkling.

II.1.4.2.2. Research and Development (R&D) for the use of Sprinkler Irrigation

The development of sprinkler irrigation devices is consistent with the increase in agricultural crops and the development of necessary rates for their application. We mention here the known types of sprinkler irrigation:

A. Sprinkler :

Sprinkling is an important element in the sprinkler irrigation system. The performance of sprinklers has a direct impact on the overall quality of the sprinkler irrigation system.

B. Pipeline sprinkler irrigation system :

Sprinkler pipe line systems are more energy efficient and easier to operate, and irrigation uniformity has been improved. In addition, some systems are equipped with automatic measuring and control devices.

C. Linear and Pivot Irrigation Systems :

With the gradual development of agricultural production, the use of linear and pivot irrigation systems with sprinklers has increased due to their advantages of high irrigation efficiency, large coverage area, high automation, and low labor costs.

D. Hose Reel Irrigation Machines :

The hose reel irrigation machine has advantages such as strong adaptability, ease of maneuvering, low cost, and so on. The hose reel irrigation machine is suitable for irregular field blocks and is widely used [25].

II.1.4.3. Surface Irrigation

Three of the most common types of surface irrigation systems are border, graded furrow (Figure 1.), and level basin - where furrow irrigation represents half of all surface irrigation systems. Other types include contour furrows and corrugation irrigation. Many farms now use furrows and close borders as the best strategy to achieve high efficiency and uniformity. The four basic design parameters in surface irrigation systems are slope, field length (which is difficult to change), flow rate, and stop time. These parameters can be improved using the USDA-ARS WINSRFR surface irrigation model. This study describes how the advanced stage can be modeled using the two-point volume balance method. The infiltration stage is modeled using a numerical flow model that includes a decrease in flow rate over distance and spatial variability of soil properties [26].

II.2. Smart irrigation

II.2.1. Definition

Smart irrigation refers to an automated and independent irrigation system that uses modern technologies to improve the efficiency of water use in irrigation. The smart irrigation environment helps improve water usage in the field and provides remote control and monitoring of the irrigation system. Using Internet of Things (IoT) concepts, the system connects and processes data from sensors and uses an Arduino application as a user interface. This system relies on the use of moisture sensors to detect soil moisture levels and determine the appropriate amount of water to be sent to the plants automatically according to their needs. Renewable energy systems such as photovoltaic panels are also used to provide the necessary energy for operating the pumps. Smart irrigation helps improve water usage in the field and monitor the irrigation system using smartphone applications and the internet to facilitate the irrigation process and save effort and water by large proportions [27].

II.2.2. PROPOSED METHOD

The smart agricultural irrigation and plant disease monitoring system consists of four main units: the final device node, the coordinator node, the web and mobile server node (control unit), and the wireless sensor network. The final device node comprises an Arduino control unit, GSM, a motor, a soil moisture sensor for plant imaging, a temperature sensor, and a humidity sensor. The microcontroller device serves as a final device in addition to the coordinator device in the wireless sensor network, used for data communications within the network. Data is continuously collected from the sensors and sent to the coordinator node, which is connected to the web server system via the RS232 serial data carrier. The data is obtained from the server and displayed on an Android phone for real-time monitoring of agricultural land parameters. Then, the control signal is automatically sent to the coordinator node from the Android application. When the final device node receives a signal from the coordinator node, it operates according to the received signal, whether the motor is in the on or off position. The motor operation and stop process for irrigation was framed using fuzzy logic. The control unit was programmed based on vague rules. Accordingly, the system helps farmers control the use of the motor and water according to the requirements of the agricultural land, even through remote field monitoring. The arduino and GSM/GPRS modems are configured once the power supply is turned on. After configuration, the system prompts users to select manual mode or automatic mode. When the automatic mode is selected, Arduino initially checks for the availability of solar power. In the absence of solar power, the system runs on batteries. A water level sensor attached to the system is used to signal the water level in the agricultural field tank. The relay is connected to the pump, which starts pumping water into the agricultural field once the soil moisture sensor detects dry soil. The moisture sensor is used to sense soil moisture in crop lands. The temperature sensor detects the ambient temperature of the agricultural field. When it starts raining, the pump automatically stops pumping water to the field to save electricity, and updates the information for the user using GSM/GPRS. The data collected from the sensors is displayed on an alpha numeric digital display. Figure 5 illustrates the working principle of the proposed system [28].

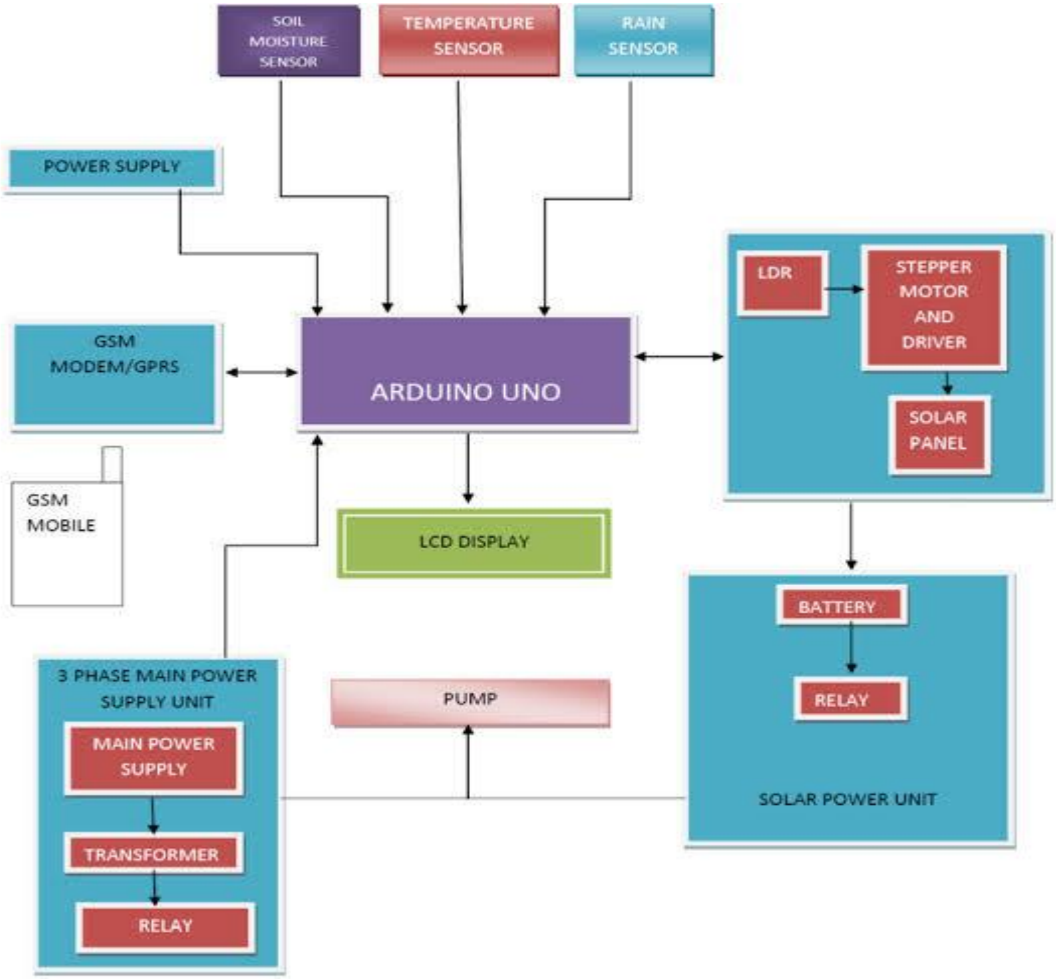

Fig. II. 3. The proposed smart irrigation system.

II.2.3. System Design

A smart irrigation system has been built as shown in the diagram, illustrating the final stage with all project components; a solar panel, an electronic board with control, a smartphone, an LCD screen, a water pump, humidity sensors, and a GSM for arduino. The control algorithm was programmed on an arduino and uploaded to the microcontroller. The developed smart control enables the irrigation system to automatically start or stop the water pump when it reaches the desired moisture level [29].

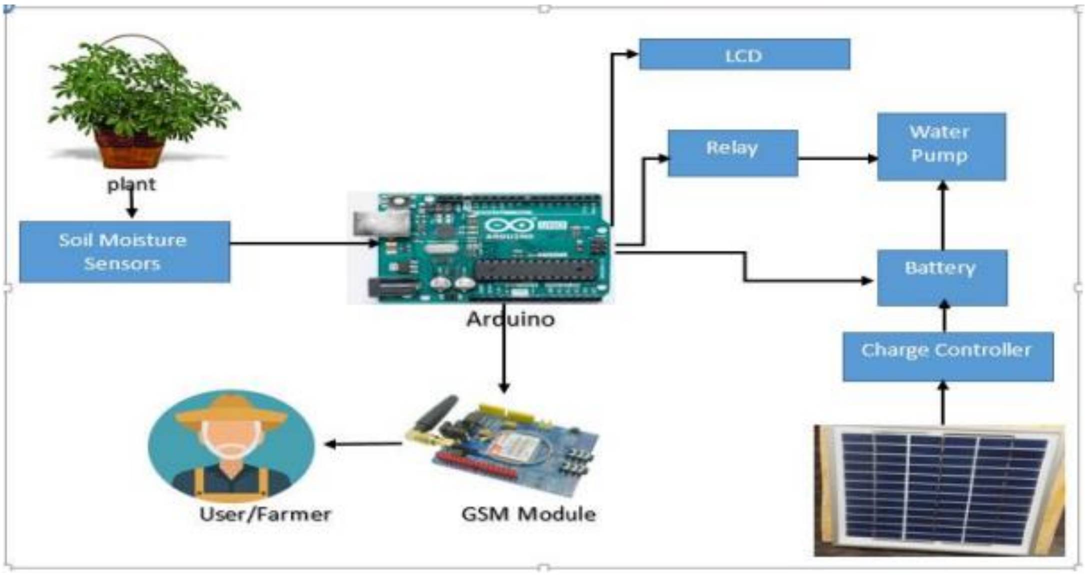

Fig. II. 4. Experimental setup of smart irrigation system.

II.2.4. Advantages of smart irrigation

The smart irrigation system has the following advantages compared to the traditional system :

- This system is a versatile and automated system with many good advantages.
- It can reduce water waste as plants are irrigated based on the soil moisture content.
- Water can be conserved if the soil moisture content is high.
- Integration of various sensors to collect information related to plant care to improve crop productivity.
- As the system is controlled through the web, it can be accessed from anywhere if the internet is suitable.
- This system is compact and cost effective [30].

II.3. A Comprehensive Review about smart irrigation Technologies and Techniques

(Raul Morais, A. Valente, and C. Serôdio) described an implementation of a wireless sensor network for low data-rate applications in agriculture, addressing the limitations of traditional discrete and wired instrumentation. These traditional methods posed challenges in measuring and computing plant physiological responses over large geographical areas. The wireless sensor network utilized solar-powered acquisition stations to measure soil moisture in greenhouses and open field crops, aiming to enhance irrigation efficiency. The dual-probe heat-pulse method was employed to sense soil moisture, while climate parameters such as air and soil temperature, solar radiation, and relative humidity were also measured [31].

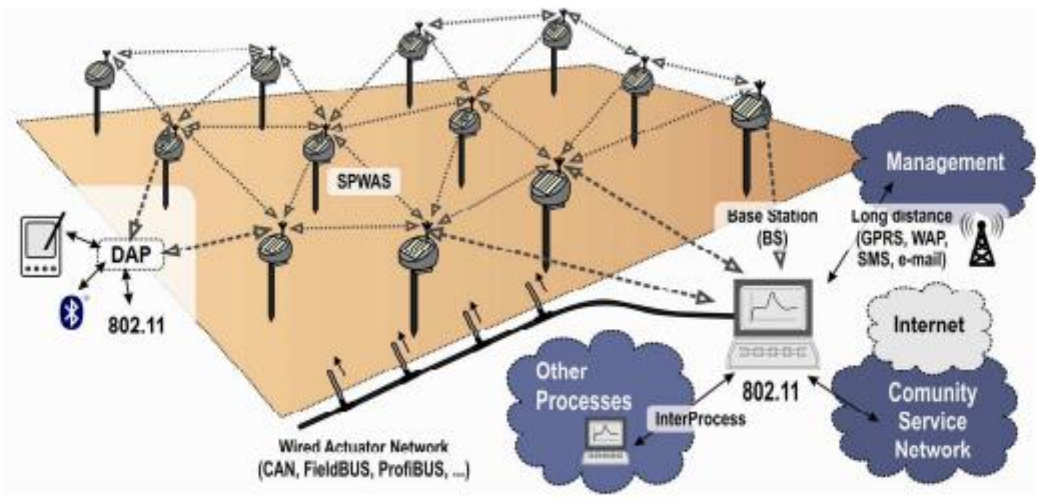

Fig. II. 5. Network architecture.

(William Yiasoumia, Harsharn Grewalb, Basant Maheshwarib, and Bruce Simmons) described a study that focused on the evaluation of two innovative technologies, the Kapillary Irrigation Sub-Surface System (KISSS) and the Irrigation Water Recycling System (IWRS), in peri-urban Sydney. In the area, there were approximately 3,000 commercial irrigators, many of whom relied on town water for their 2-hectare holdings. Due to below-average rainfall in recent years, water use restrictions had been imposed, leading to increased environmental scrutiny from regulators and the public. To address these concerns, the New South Wales Department of Primary Industries (NSW DPI) and the University of Western Sydney secured funding to assess the potential of KISSS and IWRS in reducing potable water consumption and minimizing runoff effects.

The primary objective of the study was to understand the concerns and challenges faced by farmers while evaluating the effectiveness of KISSS and IWRS in real-world conditions. KISSS was a system that delivered water directly to the root zone of plants, minimizing water loss through runoff, evaporation, and deep drainage. By applying water below the ground surface, KISSS significantly improved water application efficiency compared to traditional drip irrigation methods, virtually eliminating evaporation losses. On the other hand, IWRS collected irrigation and rainwater runoff from cropped areas, storing it for reuse in subsequent irrigation to enhance water availability and reduce nutrient runoff from farms.

The study adopted a participatory approach involving eight farmers and various stakeholders. An initial survey identified factors such as ethnicity, technical knowledge, perception of water scarcity, and economic conditions as important indicators of farmers' commitment and motivation to test and monitor the KISSS and IWRS systems on their farms. Farmers faced challenges such as increasing water and fertilizer costs, fluctuating vegetable prices impacting profits, and substantial time investments required for marketing produce. Initially, many farmers were hesitant to adopt IWRS or KISSS over their current overhead sprinkler irrigation system. However, through demonstrations that showcased the benefits of KISSS, including faster wetting zones, uniform crop growth, and water savings, several farmers became interested in evaluating and monitoring either KISSS or IWRS in their farm management practices.

The study highlighted the key lessons learned in engaging farmers to adopt water-saving technologies and discussed the difficulties encountered during the implementation of these technologies in the field [32].

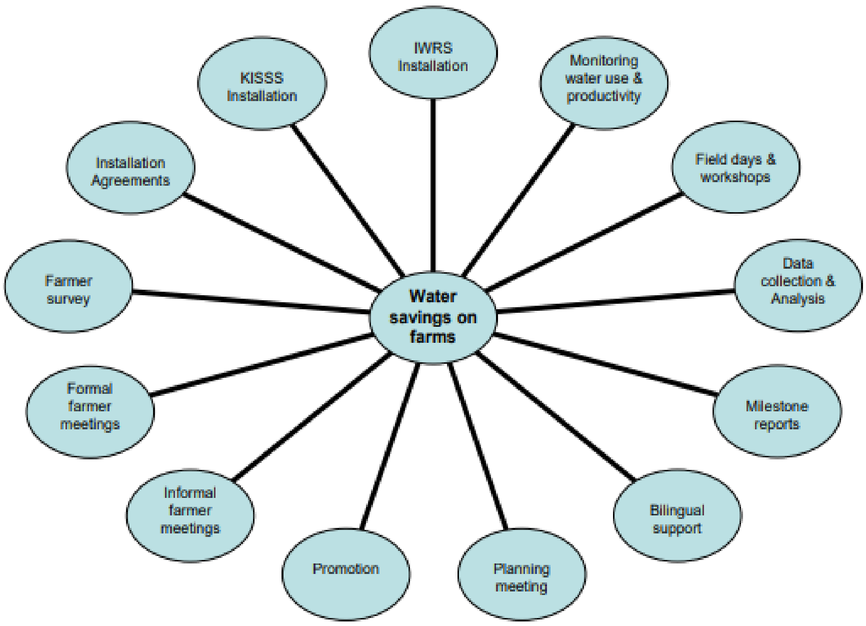

Fig. II. 6. A diagrammatic view of the key participatory steps undertaken in this study.

(M.S. McCready, M.D. Dukes, and G.L. Miller) stated that a range of technologies were available to homeowners for reducing residential irrigation water use. These technologies, referred to as "Smart Irrigation," included controllers based on evapotranspiration (ET) and controllers utilizing soil moisture sensors (SMS). The objective of their research was to assess the effectiveness of these technologies, in conjunction with rain sensors, the evaluation involved testing two types of SMS controllers (LawnLogic LL1004 and Acclima Digital TDT RS500) at three different soil moisture threshold settings. Additionally, six treatments utilizing Mini-Clik rain sensors (RS) were tested with two rainfall thresholds (3 mm and 6 mm) and three different irrigation frequencies (1, 2, and 7 days per week). Two ET controllers, the Toro Intelli-Sense controller and the Rain Bird ET Manager, were also included in the testing. As a comparison, a time-based treatment with irrigation twice a week without any sensor (WOS) was established [33].

(Hassan and Karnataka) stated, They designed a programmable logic controller-based system to control an automatic irrigation system. The system comprised three modules: the programmable logic circuits, sensor system, and the SCADA monitoring. The irrigation system consisted of three samples, simulating three different agricultural fields. The humidity of each field varied according to the requirements of different plantations. It was controlled by two sensors for minimum and maximum humidity, respectively. Each sample was irrigated by a separate valve, which was controlled by the PLC. If the maximum humidity was reached, the PLC would turn off the corresponding valve based on the value provided by the relevant sample. Once all samples had reached their respective maximum humidity levels, the PLC would turn off the main pump. This project was proposed to overcome the difficulties faced by farmers in increasing profits by enhancing productivity and reducing water and electricity consumption. Farmers were able to monitor and control the irrigation system from a single location with the help of SCADA (supervisory control and data acquisition), which performed the controlling actions through the PLC (Programmable Logic Controller) [34].

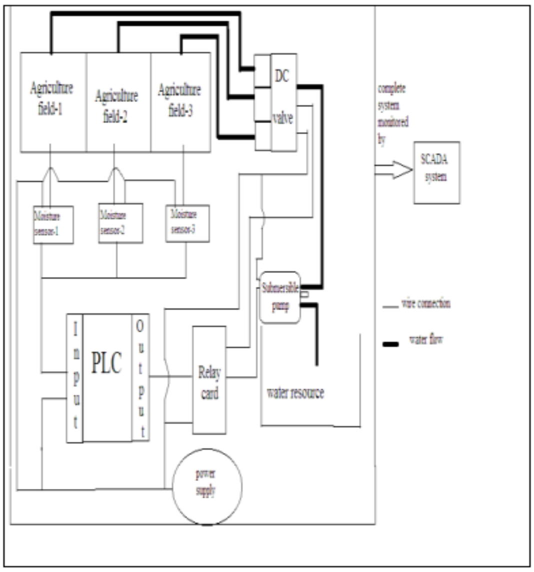

Fig. II. 7. Block diagram of PLC and SCADA based automatic irrigation system.

(Ragheid Atta, Tahar Boutraa, and Abdellah Akhkha) mentioned that irrigated agriculture had long been recognized as one of the largest consumers of water worldwide. The scarcity of water was particularly prominent in semi-arid and arid regions, where average rainfall was minimal, and water scarcity posed the most significant challenge to crop production. Effective management of water irrigation was essential for achieving sustainable productivity and improving water use efficiency in wheat cultivation. Proper timing of irrigation and appropriate water dosage were crucial aspects of irrigation scheduling. Although available equipment, such as soil moisture monitoring devices, provided the necessary information for irrigation management, they often lacked representativeness and reliability. Wireless sensor networks emerged as a new technology that promised more precise monitoring in both time and space at a lower cost compared to current methods. In their paper, the authors developed a new sensor network specifically designed for monitoring soil moisture. The network enabled two-way wireless communication, allowing decisions regarding water irrigation to be transmitted to the sensor nodes. The proposed system was proven to be cost-effective, reliable, and user-friendly. The authors also conducted a study to evaluate the impact of the system on plant growth and soil conditions, while monitoring the increase in water use efficiency [35].

(Hema N, Reema Aswani, and Monisha Malik stated) In those days, due to a busy routine life, people would forget to water their plants. In this paper, we presented a completely autonomous and cost-effective system for watering indoor potted plants placed on an even surface. The system comprised of a mobile robot and a temperature-humidity sensing module. The system was fully adaptive to any environment and took into account the watering needs of the plants using the temperature-humidity sensing module. The paper described the hardware architecture of the fully automated watering system, which used wireless communication to communicate between the mobile robot and the sensing module. This gardening robot was completely portable and equipped with a Radio Frequency Identification (RFID) module, a microcontroller, an on-board water reservoir, and an attached water pump. It was capable of sensing the watering needs of the plants, locating them, and autonomously watering them without any human intervention. The mobilization of the robot to the potted plant was achieved by using a predefined path. For identification, an RFID tag was attached to each potted plant. The paper also discussed the detailed implementation of the system supported with complete circuitry. The paper concluded with the system's performance, including the analysis of the water carrying capacity and time requirements to water a set of plants [36].

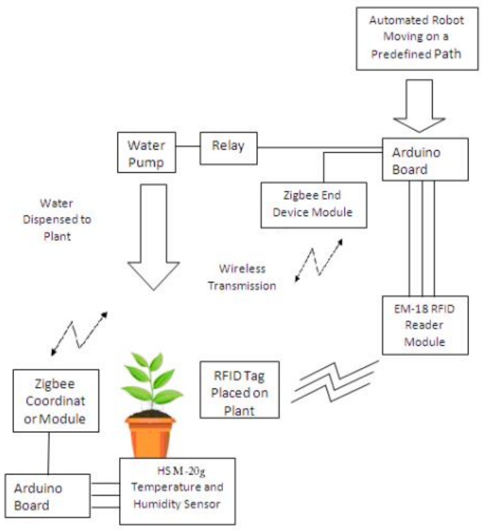

Fig. II. 8. Architecture of the Autonomous System.

(Nilesh R. Patel, Swarup S. Mathurkar, Rahul B. Lanjewar, and Ashwin A. Bhandekar) discussed the rapid technological advancements in the field of agriculture over the past couple of decades. These advancements have led to the installation of various monitoring and control systems aimed at increasing crop yield. However, several factors can contribute to a decrease in yield, with disease being a significant factor. Therefore, the focus of the developed monitoring system was to predict the onset of disease germination.

The system utilized a sensor module to detect different environmental conditions across the farm. The sensed data was then displayed on a Liquid Crystal Display (LCD) using a microcontroller. The microcontroller wirelessly transmitted the environmental data to a central unit, where it was stored and analyzed. The central unit compared the present data with disease conditions and, if a match was found, commanded the microcontroller to operate a relay [37].

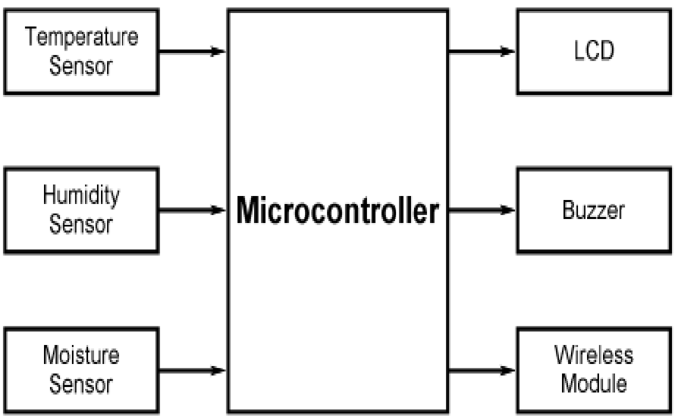

Fig. II. 9. Block diagram of transmitter.

(Mr. Deepak Kumar Roy and Mr. Murtaza Hassan Ansari) stated that the focus of their paper was on achieving effective irrigation and preventing water wastage in uncontrolled irrigation practices. They highlighted that the implementation of new electrical control technologies in irrigation could enhance efficiency, promote water conservation, and reduce environmental impacts. The objectives of their project were to eliminate water wastage and improve irrigation efficiency through the utilization of a PLC-based irrigation system. This system incorporated soil moisture sensors, water level sensors, and a GSM controller. Furthermore, the project aimed to enhance the traditional irrigation system, enabling it to operate with higher efficiency and lower water consumption. They noted that the existing irrigation system was laborious, time-consuming, and highly inefficient in terms of water usage. In contrast, the PLC-based sprinkler irrigation system offered superior features compared to the traditional system [38].

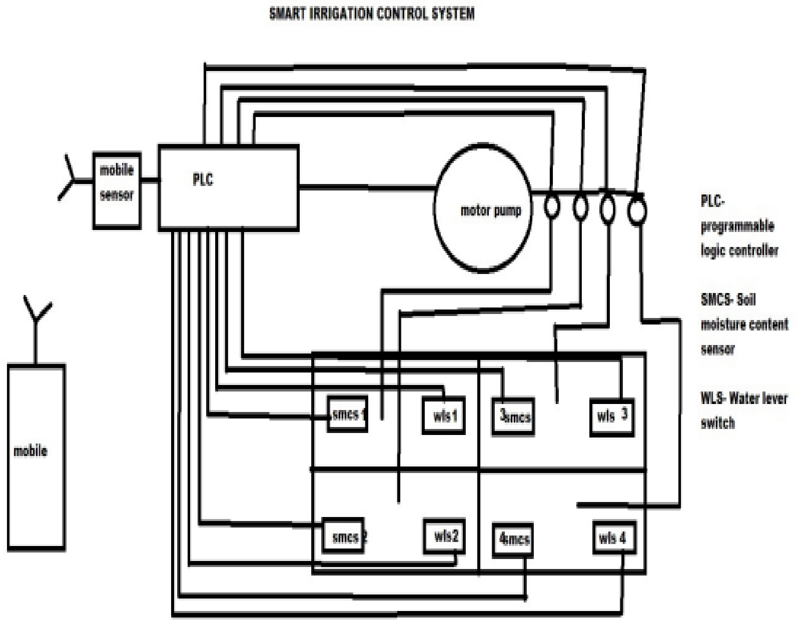

Fig. II. 10. Block Diagram of Smart Irrigation Control System.

(S. Darshna1, T. Sangavi2, Sheena Mohan3, A. Soundharya4, Sukanya Desikan) conducted a study that described a model for automated watering of plants using Arduino. The model utilized a single moisture sensor and temperature sensor to monitor the soil conditions. The moisture sensor reported resistance values that indicated the moisture level, while the temperature sensor reported resistance values corresponding to the temperature. The values were converted into a digital range of 0-1023 using the Arduino's built-in analog-to-digital converter (ADC). Dry soil exhibited higher resistance, whereas wet soil exhibited lower resistance. A servo motor was programmed to rotate a platform, serving as a base for the movement of a pipe. If the soil was dry (high resistance and temperature), a relay was employed to activate the pump and water the plants.

Conversely, if the soil was moist, the pump was switched off. Arduino was utilized as the software for this project, providing libraries for easy programming. The program established a predefined range of resistance values for the moisture and temperature sensors. Any deviation from this range triggered the pump to turn on or off, ensuring appropriate watering of the plants [39].

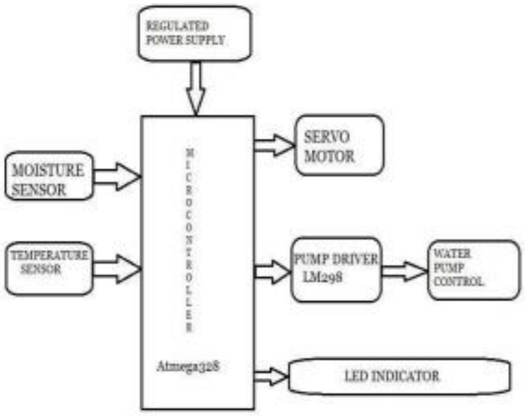

Fig. II. 11. Block diagram of smart irrigation system.

(S.W. Tsang and C.Y. Jim) said that there had been a recent increase in the installation of green roofs, which had led to an increase in irrigation water consumption. This increase was considered wasteful when using conventional watering management protocols. There was a knowledge gap in optimizing irrigation to conserve water, which needed to be addressed. The conventional approach, which involved using weather and soil sensors to calculate watering needs, was found to be impractical and not cost-effective. In this study, artificial intelligence algorithms, specifically artificial neural networks and fuzzy logic, were employed. These algorithms utilized weather data to simulate changes in soil moisture and develop an optimal irrigation strategy. The artificial neural network was trained to predict soil moisture based on four daily weather variables : real-time air temperature, relative humidity, solar radiation, and wind speed. The fuzzy-neural network was used to determine the irrigation time and watering volume. The simulation model successfully replicated the decision-making process of the human brain in irrigation. The use of artificial intelligence in irrigation resulted in maintaining adequate soil moisture levels ranging from 0.13 to 0.22 m3/m3 and reducing water usage by 20% while improving plant coverage. Better plant coverage played a crucial role in the passive cooling mechanism by increasing the thermal-energy performance of green roofs through evapotranspiration from living vegetation. This low-cost and effective technique could encourage the adoption of green roofs by overcoming water consumption challenges [40].

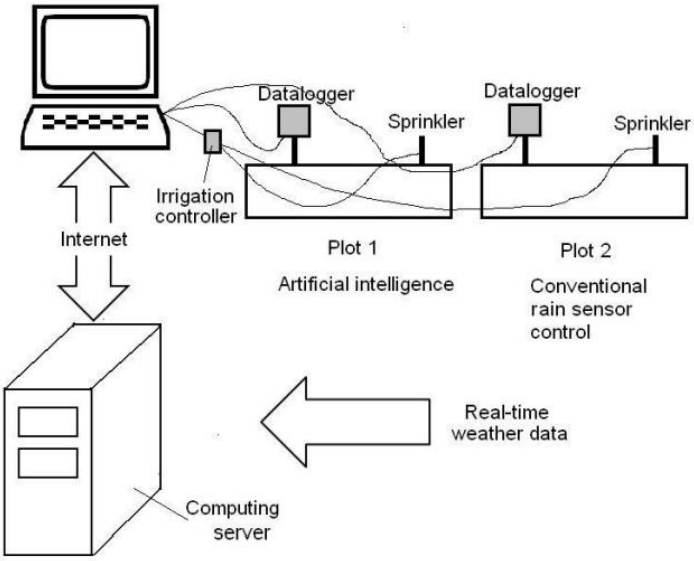

Fig. II. 12. Schematic drawing of the experimental setup.

(In a study conducted by Srishti Rawal) A Remote Measurement and Control System for Greenhouse Based on GSM-SMS was proposed. The system utilized a PC-based database system connected to a base station, which was developed using a microcontroller, GSM module, sensors, and actuators. The central station communicated with the base stations through the GSM module, exchanging messages. The central station set the criterion values for parameters to be measured in each base station, such as air temperature and humidity. The focus of the research primarily revolved around remote monitoring and control, exploring the technology employed and its potential advantages [41].

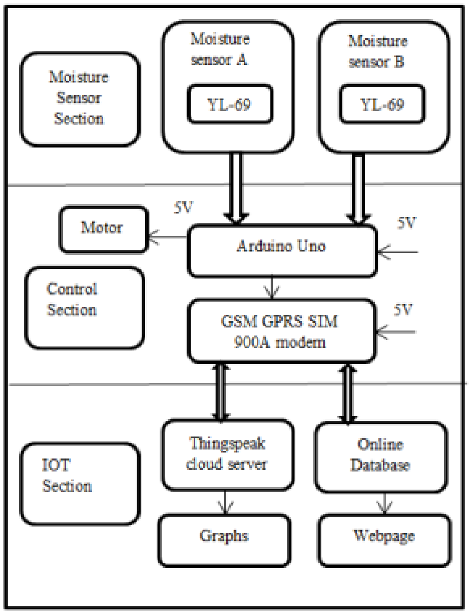

Fig. II. 13. Overall Engineering Design.

(M. Newlin Rajkumar, S. Abinaya, and V. Venkatesa Kumar) mentioned that the Internet of Things (IoT) had been recognized as a new wave of advancements in information and communication technology (ICT). The IoT was a multidisciplinary concept that encompassed various technologies, application domains, device capabilities, and operational strategies. Ongoing research activities in the field of IoT focused on defining and designing standards and open architectures, although there were still unresolved issues that required a global consensus before final deployment. In this paper, an overview of IoT technologies and applications in agriculture was presented, comparing them with other survey papers, and a novel irrigation management system was proposed. The main objective of the work was to improve farming practices by implementing new technologies that promote higher crop growth and efficient water supply. The proposed system utilized automated control features with the latest electronic technology, incorporating a microcontroller that controlled the pumping motor based on the detected dampness content of the soil. Additionally, a GSM phone line was suggested to measure temperature, humidity, and soil moisture levels [42].

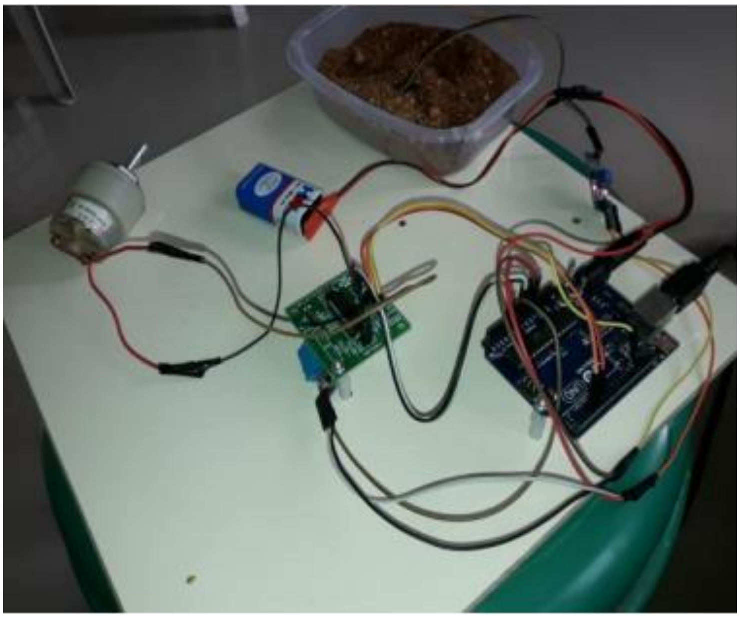

Fig. II. 14. System model.

(Trifun Savić and Milutin Radonjić 2018) presented an architecture of a ZigBee wireless sensor network for application in a smart irrigation system in their paper. They provided an overview of the essential features of the ZigBee standard pertaining to Wireless Sensor Network (WSN) operation. Additionally, they described an Arduino-based sensor node capable of acquiring soil moisture and air temperature. This node was equipped with an XBee S2 communication module, enabling its integration into the established WSN.

The authors also discussed the reception of the collected data on the main control unit, which was designed using the Waspmote microcontroller platform and equipped with an XBee S2 coordinator. They detailed the necessary steps involved in establishing communication between the Waspmote platform and the XBee S2 coordinator device, despite the fact that the Waspmote platform was initially designed to communicate solely with XBee routers and end devices [43].

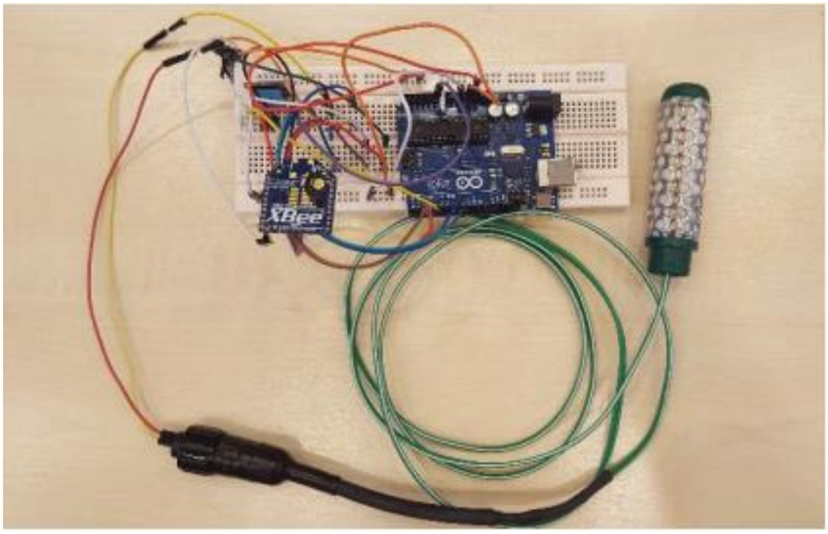

Fig. II. 15. Prototype of the wireless sensor node for soil moisture and air temperature measurement.

(Hajar M. Yasin, Subhi R. M. Zeebaree, and Ibrahim M. I. Zebari in 2019) discussed the current speed and diversity of scientific innovations that have revolutionized individuals' lives and made them more convenient. Among these innovations, irrigation systems play a crucial role in establishing efficient irrigation practices. In their research, they designed a new system for monitoring and operating irrigation using advanced technology.

The system employed the Arduino Mega 2560, integrated with Global System for Mobile communication (GSM) technology, enabling the Arduino platform to send and receive SMS messages from the mobile devices of farmers or homeowners. This communication allowed the system to receive instructions regarding soil moisture requirements or irrigation schedules from the user. Moisture sensors were embedded in the soil to automatically irrigate the plants when the ground became dry, or they could be controlled through SMS commands sent via mobile devices [44].

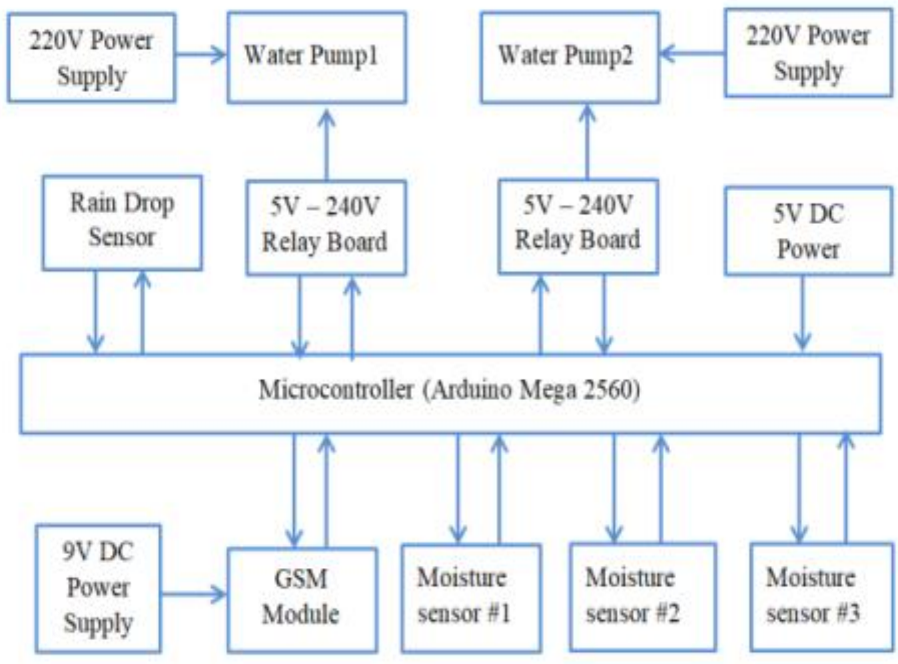

Fig. II. 16. Block Diagram and Proposed System.

(Prakash Kanade and Jai Prakash Prasad) discussed a machine that tracked sensor data and displayed it on an LCD and a PC. They referenced Muhammad's proposal in 2010 for a "Counterfeit Neural Network Controller Automatic Irrigation Control Problem." The researchers found that the ON/OFF regulator had limitations and was not successful, while the approach based on an Artificial Neural Network (ANN) contributed to stronger and more reliable power. These ANN-based regulators did not require previous system experience and had the potential to save significant resources (energy and water) in various farming areas.

Additionally, Sanjukumar proposed an "Advanced Technique for Automatic Motor Pumping for Agriculture Land Purpose Based on Soil Moisture Content" in 2013, which was successfully implemented along with a flow sensor. The main features of this system included a closed-loop automatic irrigation system and control of temperature and water usage. Users could easily set humidity levels and monitor real-time measurements on the LCD display. The researchers also mentioned the possibility of integrating other soil parameters such as pH and electrical conductivity.

In 2018, S. Nalini Durga proposed a "Smart Irrigation System Based on Soil Moisture Using IoT" They highlighted the significance of agriculture in India's GDP and emphasized the need for technological advancements in this sector. They noted that agriculture was the primary occupation in their region and acknowledged the rapid development of technology in various fields, including agriculture and healthcare [45].

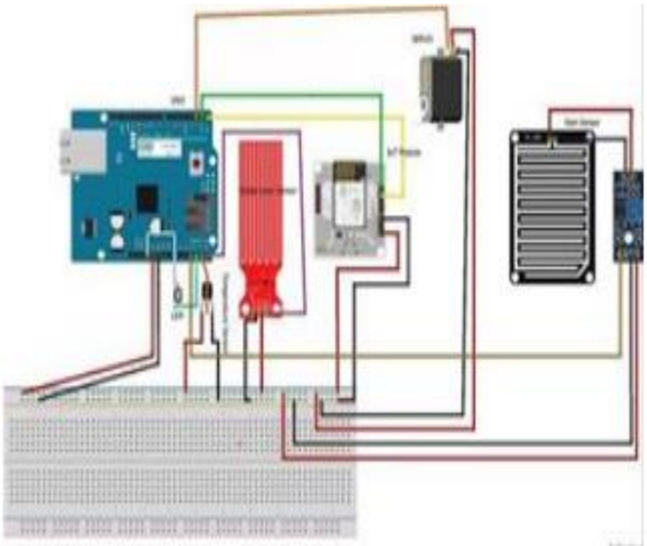

Fig. II. 17. Circuit Diagram.

Rimmi Chaudhary, Gouri Sankar Mishra, Pradeep Kumar Mishra, Rupal Walia, and Aarti (2023) discussed the practice of agriculture as both a science and an art of plant cultivation in their study. They emphasized the importance of adapting agriculture to the modern world and keeping up with new technologies. In smart agriculture, the use of sensors connected to the Internet of Things (IoT) played a crucial role in collecting data to understand agricultural lands.

They highlighted the primary advantage of IoT, which allowed monitoring through remote sensor networks. These networks consisted of multiple sensors placed at various locations, gathering data and transmitting it via wireless protocols. In their IoT system for smart agriculture, they employed Arduino as the power source. The system incorporated components such as a DC motor, moisture sensor, humidity sensor, and temperature sensor.

The system measured humidity and moisture content and automatically initiated watering when the water level fell below a predetermined range, thanks to the sensors. Temperature fluctuations were also taken into account to ensure proper sensor functioning. The IoT system displayed information about humidity and moisture levels, along with the corresponding date and time. Furthermore, the researchers suggested the option of adjusting the temperature based on the specific crops being cultivated [46].

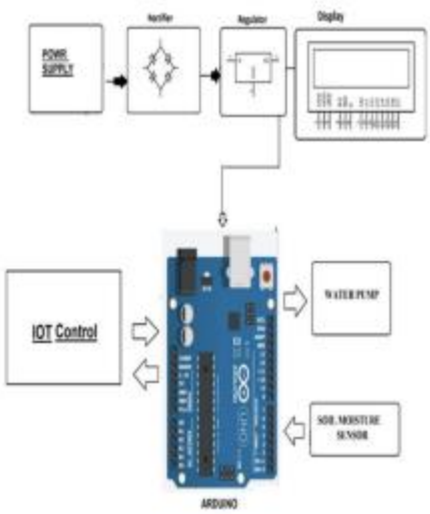

Fig. II. 18. Block Diagram.

II. Conclusion

In conclusion, our comprehensive review has illuminated the wide range of smart irrigation technologies and techniques available in the field. These advancements hold significant potential for optimizing water usage, improving crop yields, and promoting sustainable agricultural practices. Through the utilization of remote sensing, data analysis, automation, and precision irrigation, smart irrigation systems empower farmers to make informed decisions, deliver water precisely to plants based on their needs, and effectively conserve water resources. By harnessing the power of these technologies and techniques, we can pave the way towards sustainable and resilient agricultural practices that ensure optimal plant growth, minimize water waste, and contribute to food security in a rapidly changing world.

III. Introduction

The optimal water usage efficiency is achieved when irrigation provides only the amount of water needed by the crops and the soil is capable of retaining it. When considering the duration of irrigation operations, it is logical to take sufficient time to measure soil moisture in an attempt to improve irrigation decisions. There are several methods for estimating and evaluating soil moisture. Soil moisture can be measured by sending the moisture sensor readings to an Arduino program to display the measurements and activate the pump when moisture levels are low. This system solves the issue of timing and labor by controlling soil moisture and, consequently, agricultural production. The ideal goal is to achieve these objectives, which aim to advance agriculture and increase productivity. The same concept can be expanded to encompass multiple new features for agricultural development and increased production. In this chapter, it is a matter of designing and implementing a system that measures soil moisture. We will provide the steps followed to fully implement the software part and the hardware part in the studied system.

III.1. The Proposed Irrigation System

To overcome the limitations and challenges of traditional irrigation systems, we employ smart irrigation in our project. We offer a new system that establishes a connection between soil moisture needs and the pump to provide the appropriate amount of water for the greenhouse.

We integrate data logging capabilities into the system to record sensor readings, pump activation, and flow meter data over time. By analyzing this data, we can gain valuable insights into irrigation patterns, water usage, and plant behavior. This helps us develop the necessary algorithms and programming logic for precise control of the pump using the Arduino microcontroller based on soil moisture readings. Through this, we can achieve proper calibration and placement of soil moisture sensors and the flow meter to obtain accurate measurements in each irrigation operation.

This proposed system enables automated irrigation based on soil moisture levels, ensuring efficient water usage and targeted irrigation to achieve optimal plant growth while reducing water waste.

III.2. Soil Moisture

Every crop requires a specific moisture content in the soil. Exceeding this threshold can be detrimental to its growth, while a lower value can lead to soil drying out. Soil moisture is key to providing the right amount of water to crops at the right time.

III.2.1. Classification of Soil Moisture

Water in the soil exists in three different states based on their ease of drainage and their utilization by crops. These states are gravitational water, capillary water, and hygroscopic water. They depend on the moisture content and the degree of water film bonding to soil particles, which determine the different forms of soil moisture.

1) Field Capacity Moisture (FCM) :

This refers to the soil moisture level after saturation and subsequent drainage. It varies depending on the soil texture, ranging from a few hours after irrigation for sandy soil to 2 or 3 days for clayey soil. FCM represents the maximum threshold of water available in the soil beyond which plant root activity can be negatively affected.

2) Saturation Point Moisture (SPM) :

It denotes the water content in the soil when all pores are filled with water.

3) Wilting Point Moisture (WPM) :

This is the soil moisture level at which a plant can no longer extract sufficient water for its activities. It can be either temporary or permanent and signifies the minimum threshold of water available in the soil.

4) Equivalent Moisture (EM) :

It represents the percentage of water that a water-saturated soil can retain after centrifugation at 100 revolutions per minute. Its determination provides an indication of the field capacity moisture (FCM).

III.2.2. Methods of Soil Moisture Measurement

Soil moisture can be measured through soil sampling or by using installed moisture recording devices in the ground.

A. Indirect Measurements of Soil Moisture :

It is assumed that with adequate water supply, there is always a balance between the amount of water that may move from the soil to the leaf surface, which can be evaporated through transpiration. This "demand" represents the total water requirements of the crop and primarily depends on the climate and potential evapotranspiration (indicated by the acronym E.T.P). It is a specific value for a particular location during a specific period.

B. Direct Measurements :

The simplest method involves taking soil samples from the root zone (the effective reservoir) and weighing them before and after drying to determine their moisture content.

III.2.3. Presentation of the Soil Moisture Measurement System

Irrigation in agricultural crop systems being the most significant sector in terms of water management and usage, controlling water expenses remains a major challenge for both industry professionals and independent growers. Several researchers have developed solar-powered "smart" automatic irrigation systems. These systems can reduce water consumption in a field by up to 50% and minimize electricity costs. By utilizing a set of solar panels and rechargeable batteries, the platform is equipped with various soil moisture sensors buried in the ground. These sensors calculate the actual water needs of the soil and regulate the water flow accordingly through a small electronic unit. This system allows for constant and real-time monitoring of various atmospheric and soil parameters, as well as plant requirements. Our measurement system is based on an Arduino board connected to specific sensors. To implement our measurement system, the following components are required:

1. Arduino UNO.
2. Sensors:
   - Soil Moisture Sensor.
   - Water flow sensor.
3. Pump.
4. SD Card.
5. Debimeter.

III.3. Hardware Tools, Description of Each Component

Solar panel 12 volt

A 12-volt solar panel refers to a solar panel that produces a direct current (DC) voltage of 12 volts. Solar panels are devices that convert sunlight into electricity using photovoltaic cells. The 12-volt rating indicates the voltage at which the solar panel operates, and it is commonly used in various applications such as charging batteries, powering small appliances, or supplying electricity to off-grid systems. These panels are typically used in solar power systems for RVs, boats, remote cabins, or other similar setups that require a 12-volt DC power source.

Fig. III. 1. Solar panel 12V.

Solar battery

A solar battery, also known as a solar storage battery or solar rechargeable battery, is a type of battery used in solar energy systems. It stores the excess energy generated by solar panels during periods of sunlight and provides power when the panels are not producing electricity, such as during nighttime or cloudy conditions.

Arduino Mega

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It is a popular development board in the Arduino family, known for its extensive range of digital and analog input/output pins and its larger memory capacity compared to other Arduino boards. The Arduino Mega 2560 is commonly used for projects that require a higher number of pins and more processing power, making it suitable for complex and advanced applications. It is compatible with the Arduino software and can be easily programmed using the Arduino IDE (Integrated Development Environment), as illustrated in the following figure.

Fig. III. 2. Carte Arduino Mega.

This electronic board allows its user to easily program and create automated mechanisms without requiring specific programming knowledge. It is a tool designed for inventors, artists, or hobbyists who want to build their own customized automated system by coding it from scratch.

The Operating Principle

- We design or open an existing program using the Arduino software.
- We verify this program using the Arduino software (compilation).
- If errors are detected, we modify the program.
- We upload the program to the board.
- We wire the electronic circuit.
- The program executes automatically after a few seconds.
- We power the board either through the USB port or an external power source.
- It can also operate autonomously with a 9-volt battery, for example.
- We verify that our circuit is functioning properly [1].

Soil Moisture Sensor

A soil moisture sensor is a device used to measure the moisture content in the soil. It is designed to provide accurate and real-time information about the water level in the soil, which is crucial for efficient irrigation and plant health. The sensor typically consists of two or more metal probes that are inserted into the soil. By measuring the electrical conductivity or resistance between these probes, the sensor can determine the moisture level in the soil. This information can be used to automate irrigation systems, ensuring that plants receive the appropriate amount of water and preventing overwatering or underwatering. Soil moisture sensors are commonly used in agricultural, gardening, and landscaping applications to optimize water usage and promote sustainable practices, as illustrated in the following figure.

Fig. III. 3. Soil Moisture Sensor.

Characteristic

- Operating Voltage: 3.3V to 5V DC
- Operating Current: 15mA
- Digital Output: 0V to 5V, with adjustable trigger level from a predefined value
- Analog Output: 0V to 5V based on infrared radiation from the flame falling on the sensor
- LEDs indicating output and power status
- PCB Size: 3.2cm x 1.4cm
- Design based on LM393
- Easy to use with microcontrollers or standard digital/analog integrated circuits
- Small, affordable, and readily available.

LM393 IC Board

The LM393 comparator is used as a voltage comparator in moisture sensor module. Pin 2 of the LM393 is connected to the preset (10KΩ potentiometer), while pin 3 is connected to the humidity sensor pin. The integrated circuit comparator compares the threshold voltage set using the preset (pin 2) with the voltage received from the sensor pin (pin 3), as illustrated in the following figure.

Fig. III. 4. LM393 IC Board.

SD card module

We will demonstrate how to use an SD card module with Arduino to read and write files on an SD card. The SD card module is particularly useful for projects that require data logging. Arduino can create a file on an SD card to write and save data using the SD library. There are different models available from various suppliers, but they all function in a similar way using the SPI communication protocol. The module (Micro SD card adapter) is a Micro SD card reader module that utilizes the SPI interface through the file system driver, allowing the microcontroller system to read and write files on the Micro SD card as illustrated in the following figure.

Fig. III. 5. Sd card.

LCD display

An LCD display, which stands for liquid crystal display, is an electronic screen that controls light using liquid crystals. Unlike traditional light-emitting sources, liquid crystals themselves do not emit light. LCDs are capable of showing various visual elements, both static and dynamic, such as numbers, 7-segment displays, and predetermined text. They can reveal or hide these visuals by manipulating the liquid crystals, similar to how a digital clock operates, as illustrated in the following figure[47].

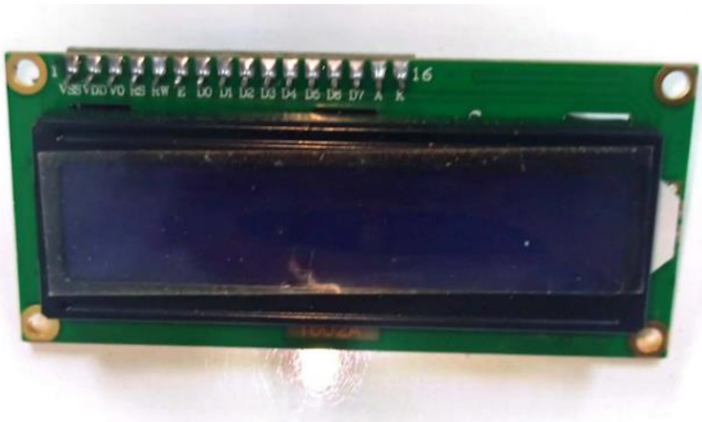

Fig. III. 6. LCD.

Wire jumper

Generally, a cable consists of multiple insulated wires enclosed within the same sheath for protection. These cables are used to connect various components and can be used for transmitting electrical power as well as data, as illustrated in the following figure.

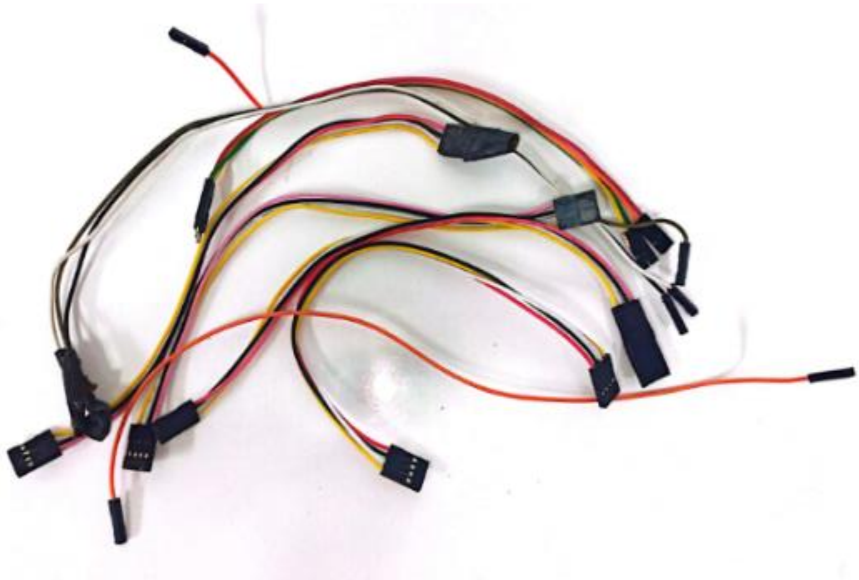

Fig. III. 7. wire jumber.

Relay

It is an electrically operated device, used in this project to control the operation of the water pump, shown in Figure10, as illustrated in the following figure [29].

Fig. III. 8. Relay.

Dc Water pump :

A DC water pump is a device that utilizes direct current (DC) electrical power to facilitate the circulation or transfer of water. It finds widespread use in various applications, particularly in irrigation systems. The pump usually comprises a motor powered by DC electricity and an impeller or rotor that generates the water flow. DC water pumps are renowned for their efficiency, reliability, and quiet operation, as illustrated in the following figure.

Fig. III. 9. Dc Water pump.

Flow meter sensor

A flow meter sensor is a device used to measure the rate of flow of a water. It provides real-time information about the volume or mass of fluid passing through a particular point in a system.

The flow meter sensor typically consists of a sensor element, which measures the flow rate, and a transmitter or display unit that converts the measured data into readable values such as liters per minute or cubic meters per hour. Some flow meters also include additional features such as temperature and pressure compensation to improve accuracy. The data from the flow meter sensor can be used for monitoring and control purposes, as well as for recording and analyzing flow patterns and trends, as illustrated in the following figure.

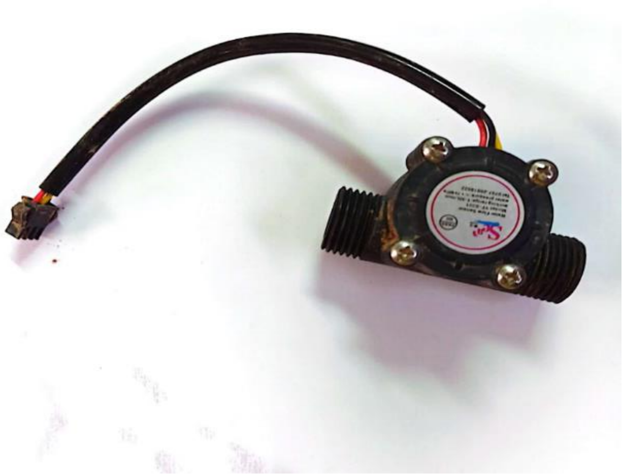

Fig. III. 10. flow meter sensor.

Adapter

The adapter is used to convert the higher incoming voltage to a lower one. It can convert 120V to 12V, which is sufficient enough for tiny electronic equipment. The incoming electrical surge could fry the internal components of the instrument if voltage is not regulated using an adaptor, as illustrated in the following figure.

Fig. III. 11. Adapter.

USB cable

The USB cable serves multiple purposes for an Arduino project. It provides power to the Arduino, allows programming of the board using Arduino IDE, and enables the use of the Serial monitor, as illustrated in the following figure.

Fig. III. 12. USB cable.

III.4. Our Arduino program for our project

Arduino is an open-source electronic prototyping platform that has gained significant popularity in the field of hobbyist and DIY electronics.

Arduino programming allows users to control and communicate with a wide range of electronic components, including sensors, actuators, displays, and communication modules. The Arduino platform provides a rich library of pre-written code, known as libraries, which simplifies the process of interfacing with these components. By including the required libraries in their sketches, users can easily access and utilize the functionality of various hardware modules, as illustrated in the following figure.

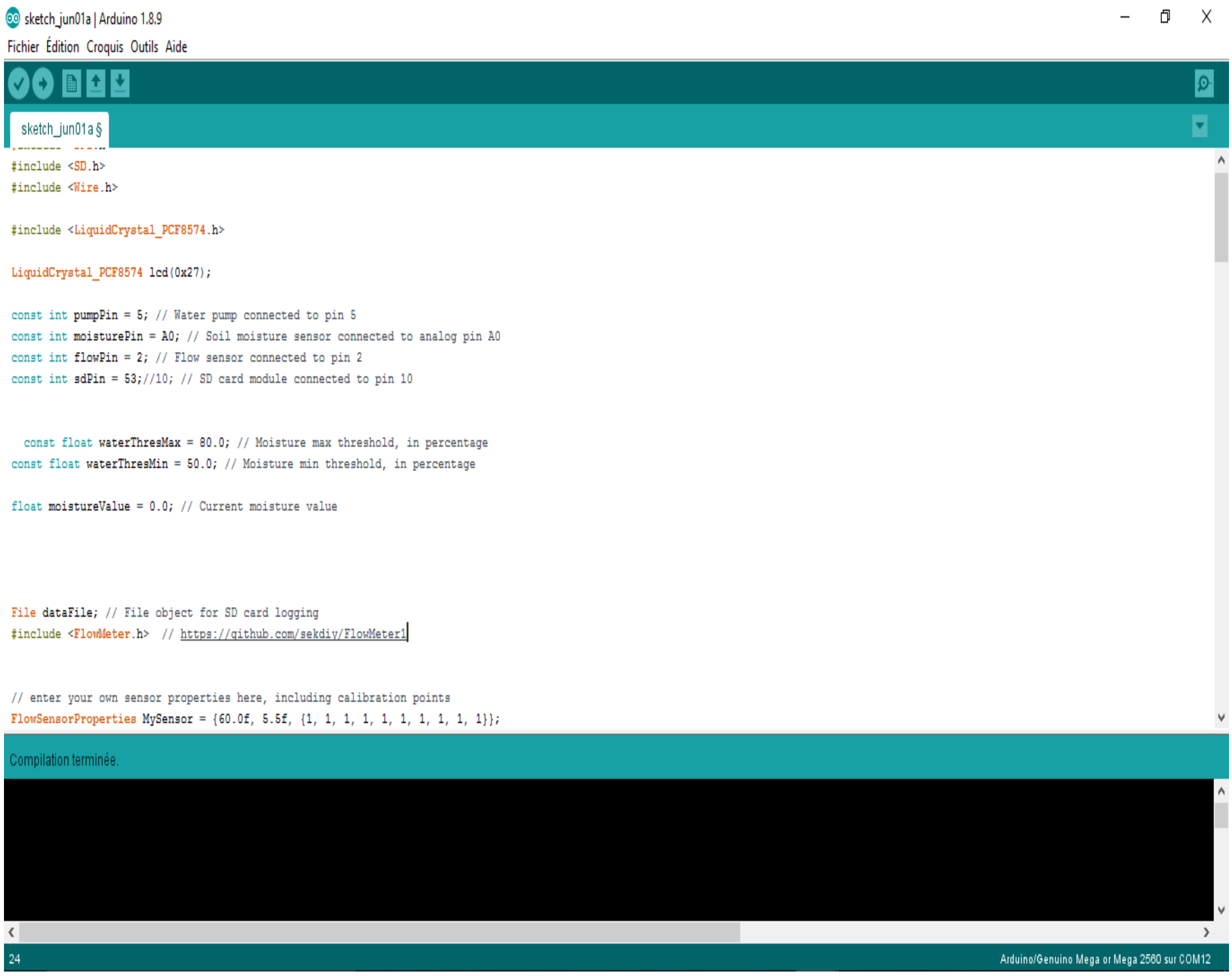

Fig. III. 13. Arduino program for our project.

III.5. Designing our own irrigation system on Fritzing

Smart irrigation technology is considered an innovative solution aimed at increasing water usage efficiency and improving traditional irrigation systems. Now, we are able to apply this smart technology using the Fritzing software for designing and documenting smart irrigation systems.

Fritzing enables us to create detailed and illustrative diagrams of the intended smart irrigation system. We can utilize the extensive Fritzing library to select and design electronic components used in the irrigation system, such as sensors, motors, microcontrollers, and power sources. These components can be dragged and placed onto the canvas to establish their connections, as illustrated in the following figure.

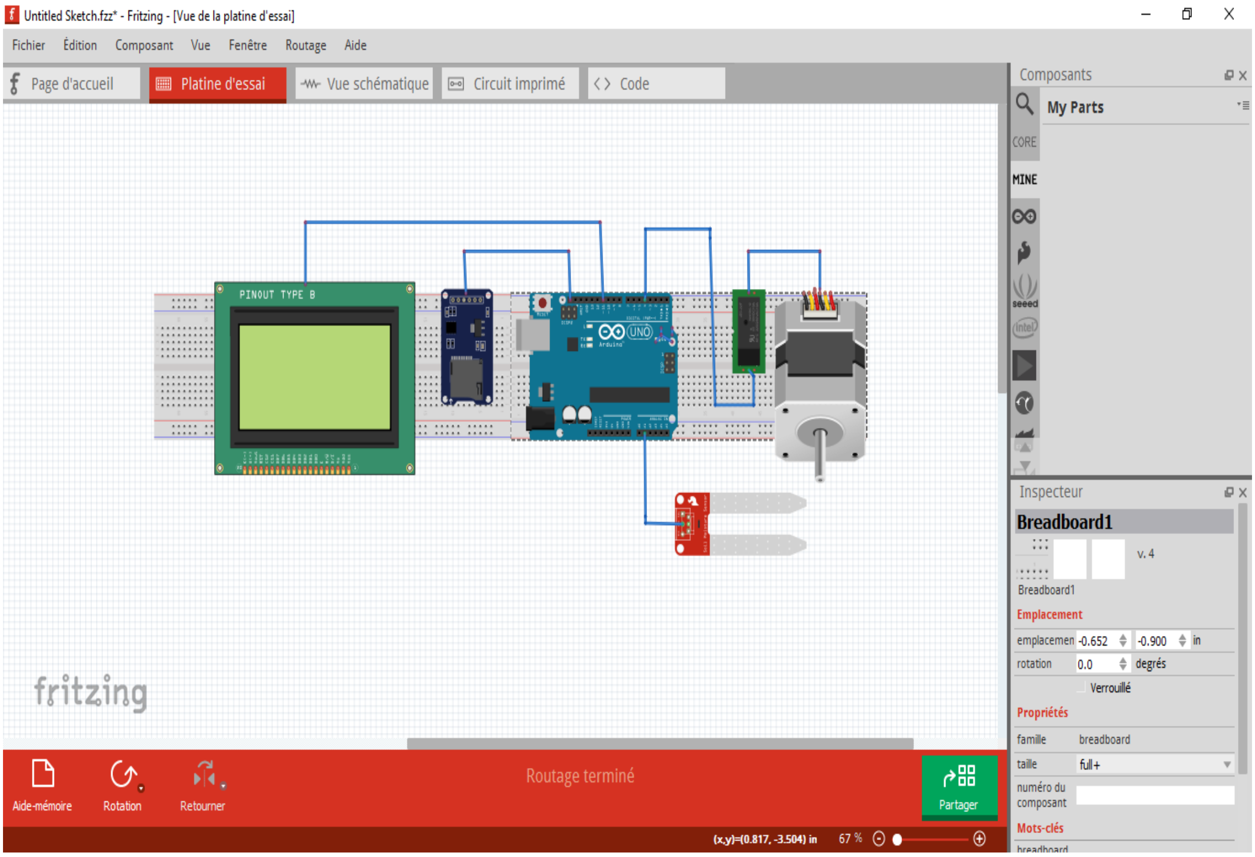

Fig. III. 14. Designing irrigation system on Fritzing.

Fritzing Wiring for Arduino with Moisture Sensor

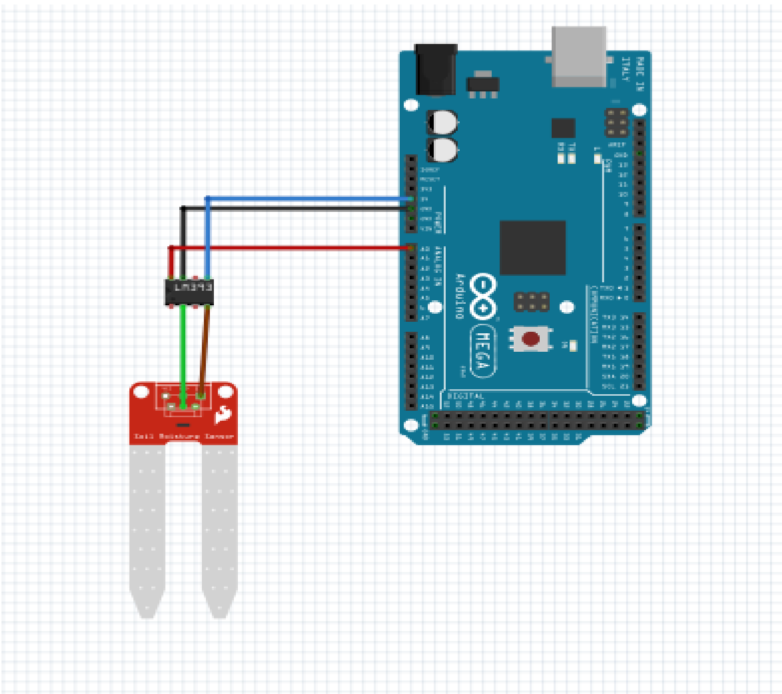

Fig. III. 15. Fritzing Wiring for Arduino and Moisture Sensor.

Fritzing Wiring for Arduino with flow meter

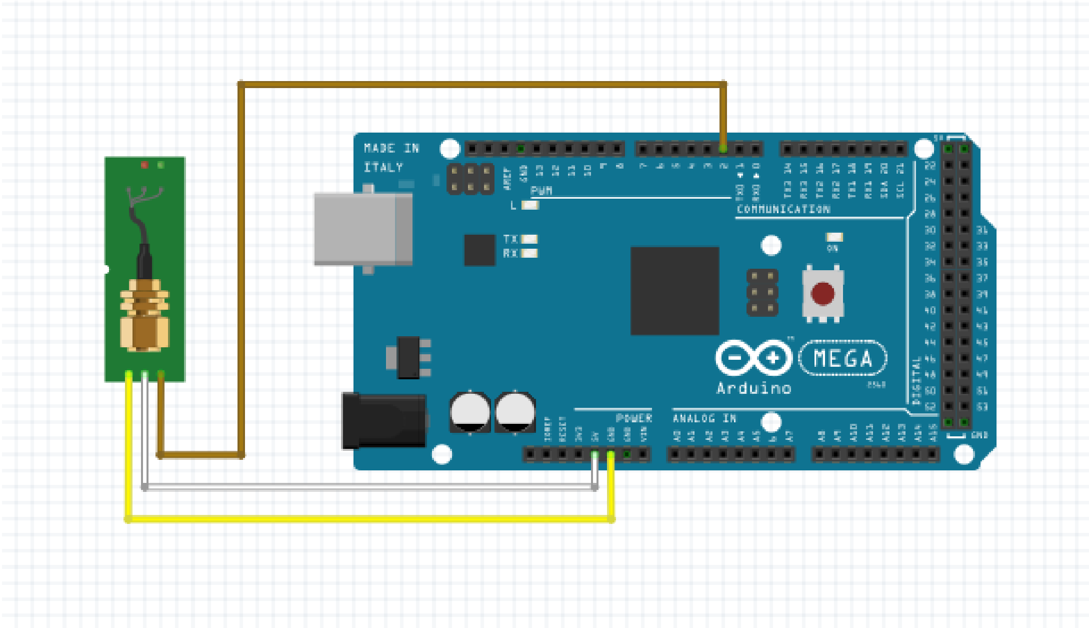

Fig. III. 16. Fritzing Wiring for Arduino with flow meter.

Fritzing Wiring for Arduino with relay and pump

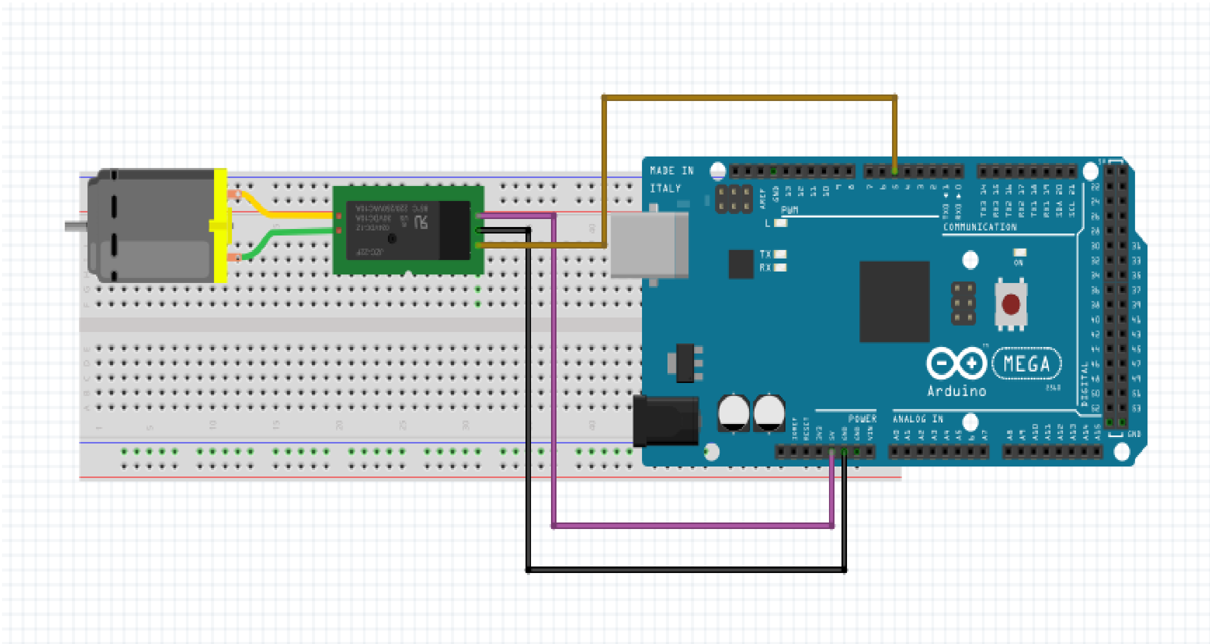

Fig. III. 17. Fritzing Wiring for Arduino with relay and pump.

Fritzing Wiring for Arduino with lcd display

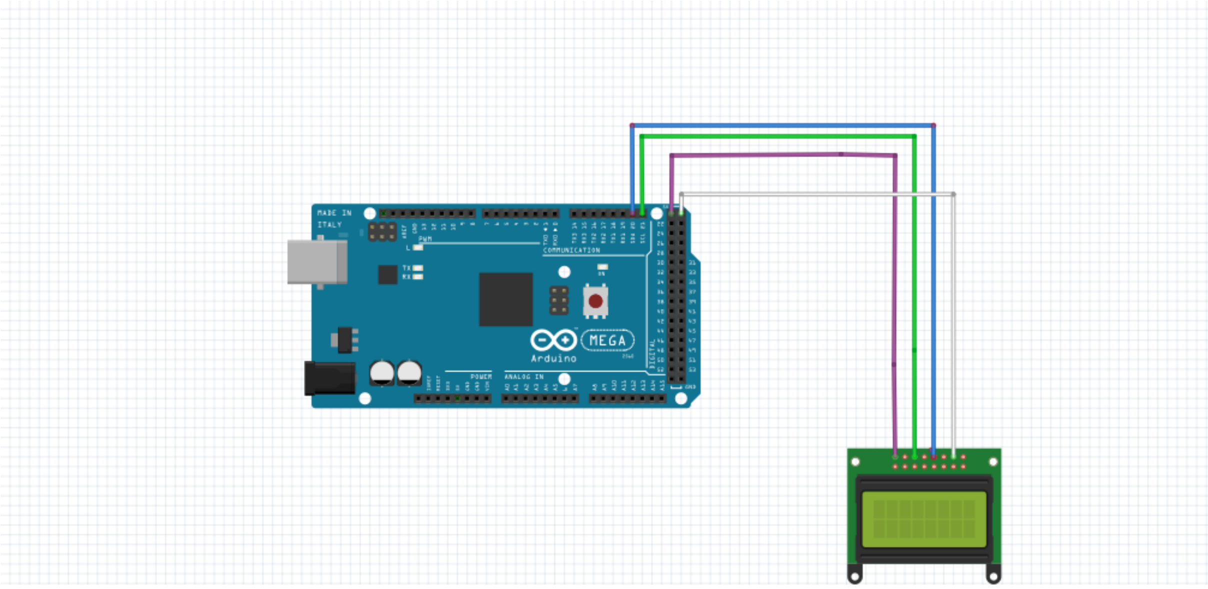

Fig. III. 18. Fritzing Wiring for Arduino with lcd display.

Fritzing Wiring for Arduino with sd card

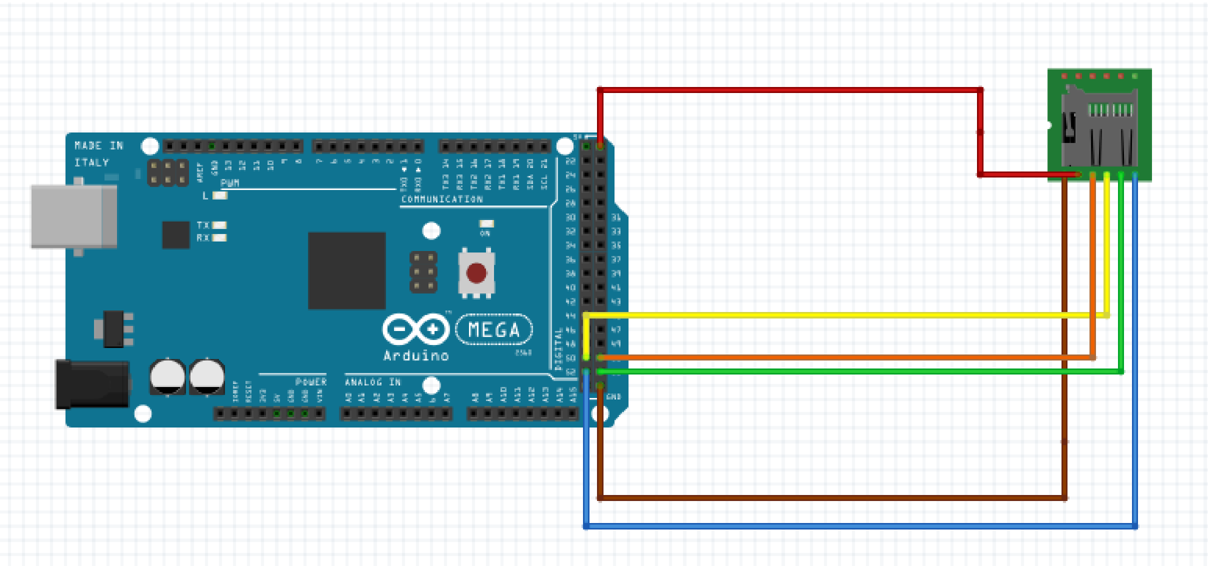

Fig. III. 19. Fritzing Wiring for Arduino with sd card.

III.6. OPERATING SYSTEM

Different components were used to create a program using Arduino automation. The program was then loaded onto an Arduino Mega via the communication port (COM). A soil moisture sensor and an Arduino Mega were connected using connecting wires and a breadboard. To connect an LCD screen to the Arduino, jumper wires were used. Then, with the help of crossover wires, a relay was connected between the pump and the Arduino Mega. The pump was powered by a photovoltaic power source. The moisture sensor detected soil moisture. Through programming, the controller responded to the data. In the programming section, the minimum threshold for soil moisture was set at 50% and the maximum threshold at 80%. When the sensor detects a decrease in soil moisture below 50%, the pump is immediately activated. And when the moisture value reaches 80%, the pump is then stopped. The flow meter measures the flow rate in liters per minute to display the moisture and flow values on the LCD screen. All data is collected and recorded on an SD card throughout the irrigation period. This entire process is automated, as shown in the following flowchart.

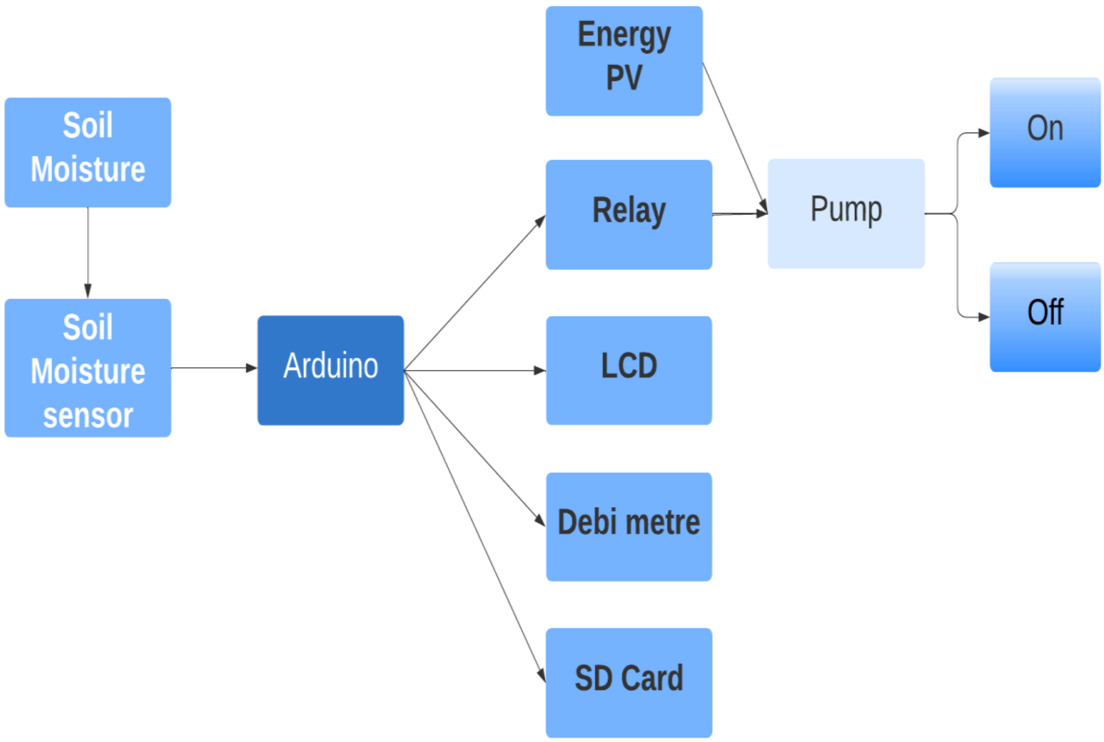

Fig. III. 20. Comprehensive Workflow Diagram of Our Smart Irrigation System.

III.7. The designed prototype

We have completed a mini project for an automated irrigation system that we are working on. We obtained a piece of polycarbonate and used it to create a small greenhouse, which we attached to the polycarbonate. We also gathered a significant amount of sand for the experiment. After that, we set up a small water basin as a water source for the irrigation process in the project. We installed components such as an Arduino board, an LCD display card, an SD card, a pump, a flow meter, and a relay on the polycarbonate. We also used a small solar panel as a power source to operate the pump and the Arduino board.

To activate the system, we placed a soil moisture sensor on the sand inside the greenhouse. Initially, when we wet the sand, we observed that the pump did not turn on because the soil moisture was around 90. After a certain period of time, we noticed that the system started running, and the soil moisture level dropped to around 30. All of this was programmed into the system, where the pump operates when the soil moisture drops to 50 and stops when it reaches 80, as at this moisture level, the soil is saturated and does not require irrigation.

Through this project, we learned about the variations in soil moisture and how the pump responds to different moisture levels, as well as the different flow rates based on pump operation. All the data collected was stored on the SD card for analysis in the next phase. All of this is illustrated in the graph in front of us.

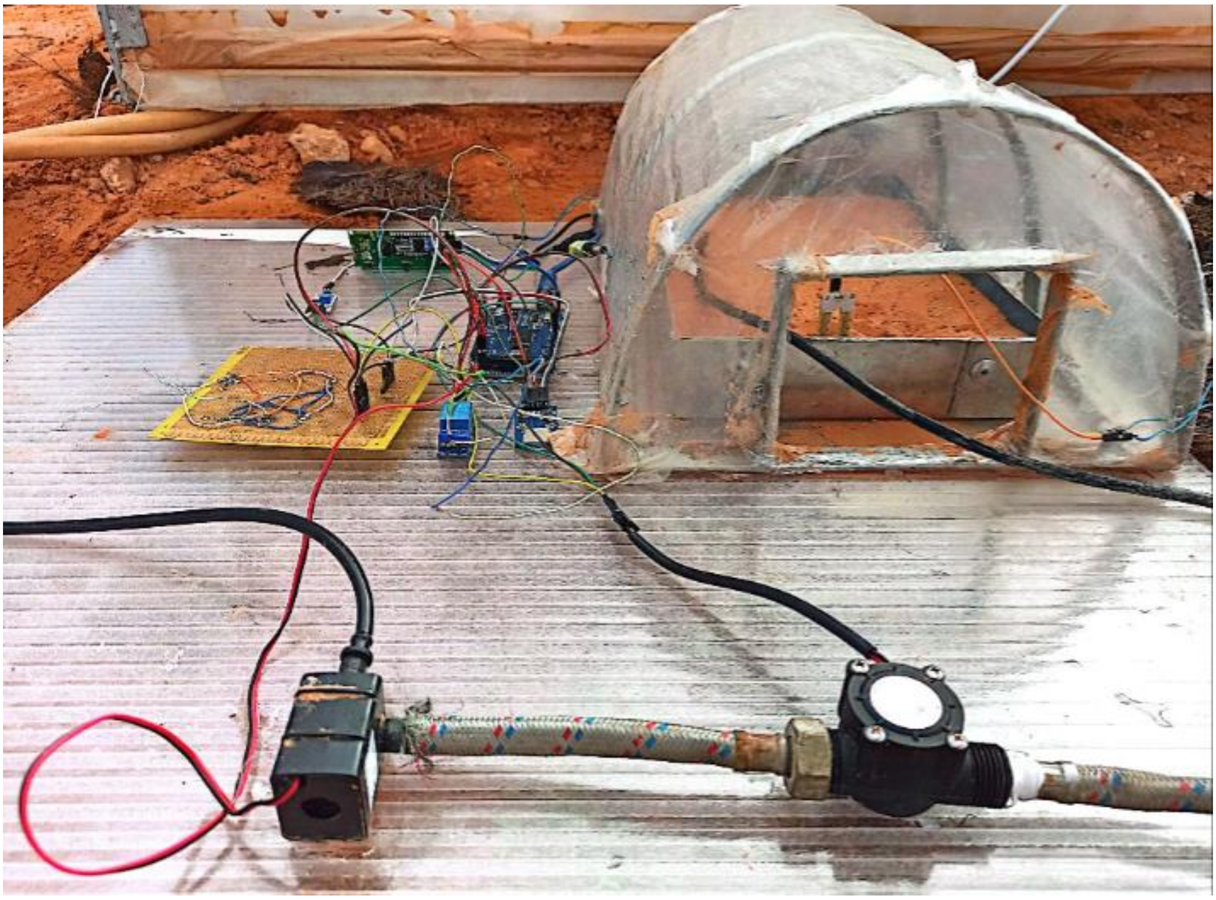

Fig. III. 21. A picture of the designed prototype.

III.8. Practical test

In this practical test, we installed all the equipment we previously discussed in our project (Arduino Mega, moisture sensor, pump, SD card, and an LCD screen). We waited for the soil moisture values to be recorded on the SD card, which is displayed in front of us in Figure 21.

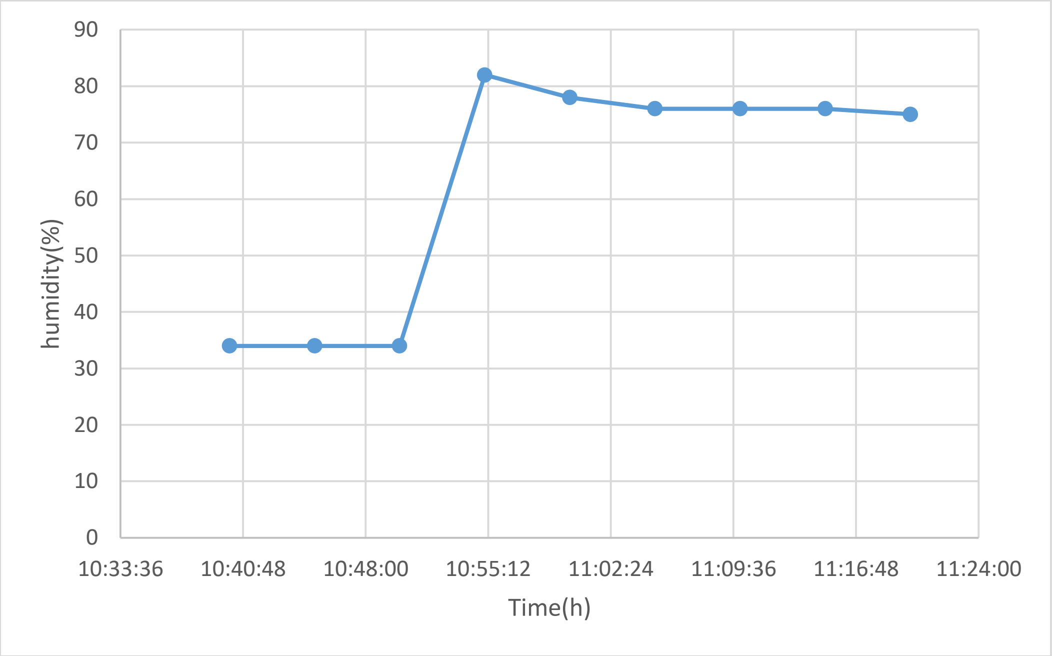

Fig. III. 22. The results of the practical test.

In the first ten minutes, where the water pump was not connected to the photovoltaic energy system, we can observe that the humidity ratio was maintained at 34% which is unfavorable for our soil moisture needs (34% < 50%). This is due to the absence of the irrigation.

Afterward, we connected the pump with photovoltaic energy (12V) and immediately noticed an increase in the moisture percentage. It reached 82% after five minutes, indicating that the Arduino successfully sent a signal to activate the pump for watering the soil and meeting its needs. Once the soil became saturated with water, exceeding 80%, the threshold value at which the Arduino sends signal to stop the pump, we observed a decrease in the recorded moisture ratio. After 25 minutes, it reached 75%, indicating that the soil still maintained the necessary moisture level, and the plant was in a good condition as it was saturated and did not require additional water.

The aim of this experiment was to determine the impact of this system on the soil moisture percentage, which would provide complete comfort for the plant needs by supplying the required amount of water at the appropriate time.

III.9. Results of soil moisture measurements

By measuring soil moisture results during the irrigation process in our smart system with varying flow rates, on different days, 5th, 6th, and 7th of July, where temperatures ranged from 33 to 45 degrees, we obtained the curves 23, 24, 25, and 26 presented before us.

1) On July 5th, from 12:00 PM to 7:00 PM, the following results were observed:

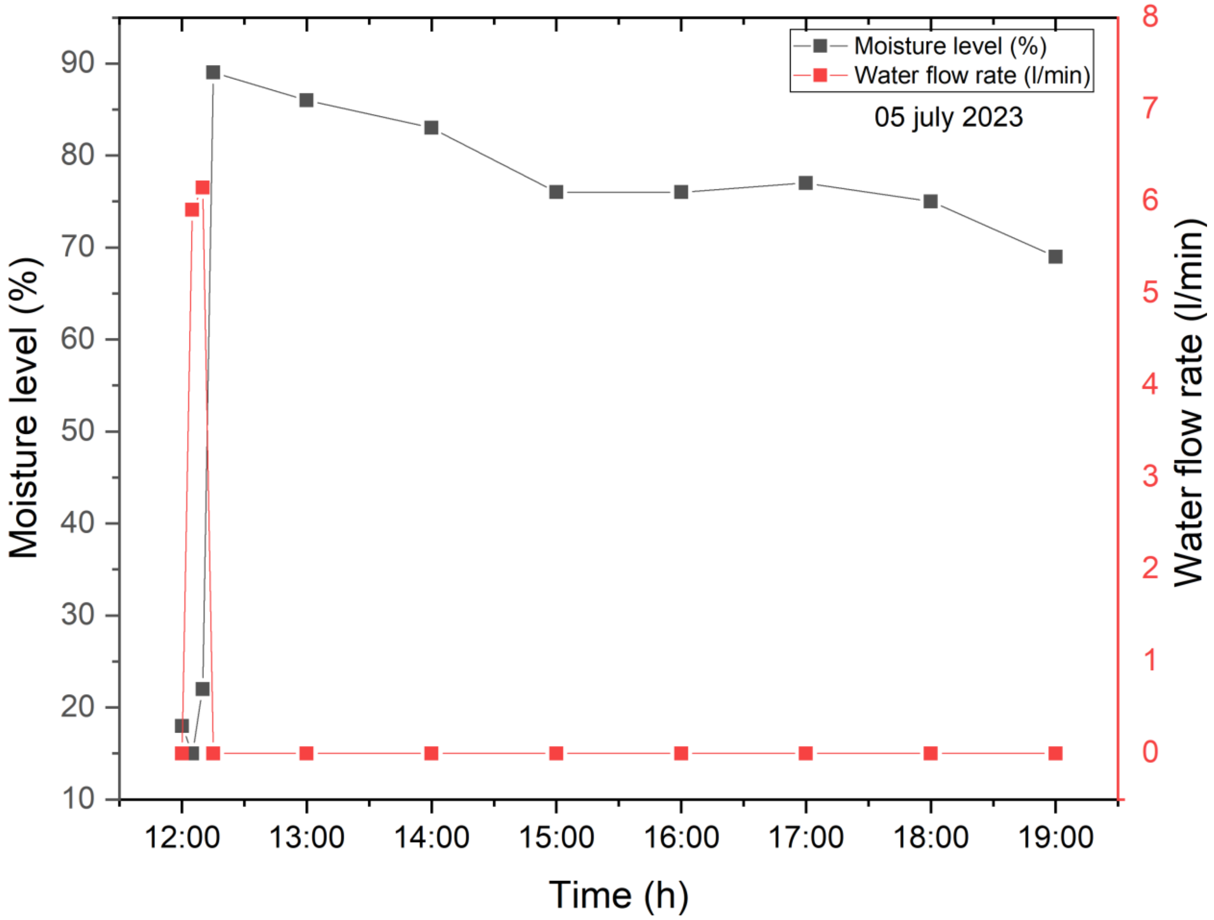

Fig. III. 23. Results of soil moisture and flow rate on July 5th.

Curve 23 represents the relationship between soil moisture percentage and water flow rate in liters per minute over time in a smart irrigation project. It is observed that there are fluctuations in the moisture values and water flow rate over time.

Initially, the project starts at 12:00, where the moisture level is 18% and the water flow rate is zero, indicating that irrigation has not started yet. At 12:05, there is a slight change in the moisture percentage, and the water flow begins, ranging between 5.91 liters per minute and 6.15 liters per minute. This indicates that the smart system responds to changes in moisture levels and increases the amount of water irrigated when the moisture is low.

From then until 19:00, the water flow rate remains at zero, indicating that irrigation has completely stopped. The moisture level during this period ranges between 69% and 86%, suggesting that the soil moisture level is high and does not require additional water at these times.

It can be inferred that this curve reflects the adaptation of the smart irrigation system to soil moisture conditions. The system increases water flow when the moisture level is low and stops irrigation when the moisture level is sufficiently high. This contributes to water conservation and improves irrigation efficiency by utilizing water only when needed and avoiding waste.

2) On July 6th, the following results were observed:

   1. From 9:00 AM to 14:00 PM:

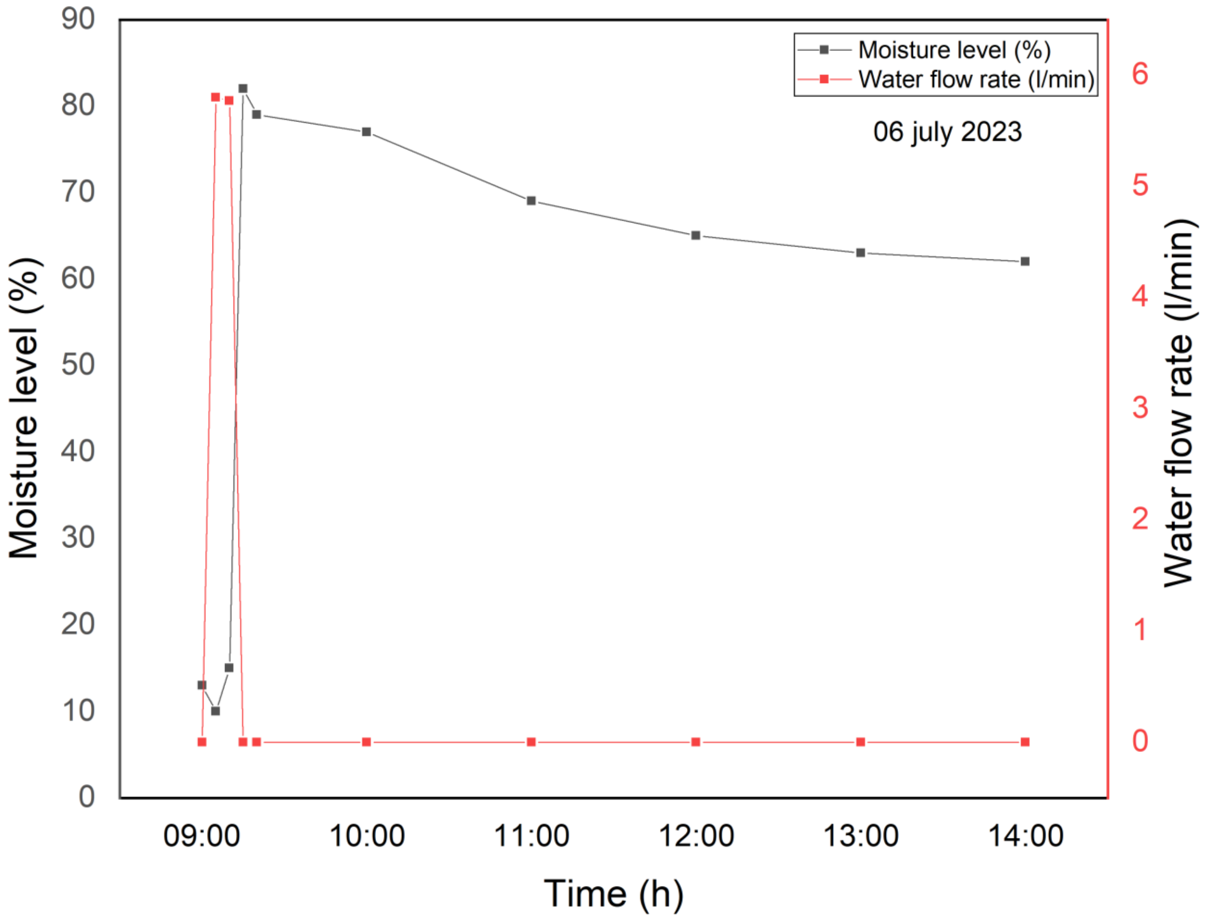

Fig. III. 24. Results of soil moisture and flow rate on the morning of July 6th.

The values presented in Curve 24 show variations in soil moisture percentage and water flow rate over time in our project.

At 09:00, the moisture level is 13%, and the water flow rate is zero, indicating that irrigation has not started yet, and the soil moisture level is low.

From then until 09:10, the moisture level decreases to 10% and 15% respectively, with an increase in the water flow rate to 5.8 and 5.77 liters per minute. It is observed that water is being sprayed onto the soil to compensate for the moisture deficit.

Starting from 09:15 until 14:00, the moisture level rises to 82% and 79% respectively, and then gradually starts to decrease, while the water flow rate completely stops. This indicates that the current moisture level in the soil is sufficiently high and does not require further irrigation.

Overall, it appears that the smart irrigation system adapts well to the needs of plants and soil moisture conditions. The system increases water flow when the moisture level is low and stops irrigation when the moisture level is sufficiently high. This contributes to efficient irrigation and reduces water waste.

2. From 20:00 PM to 06:00 AM:

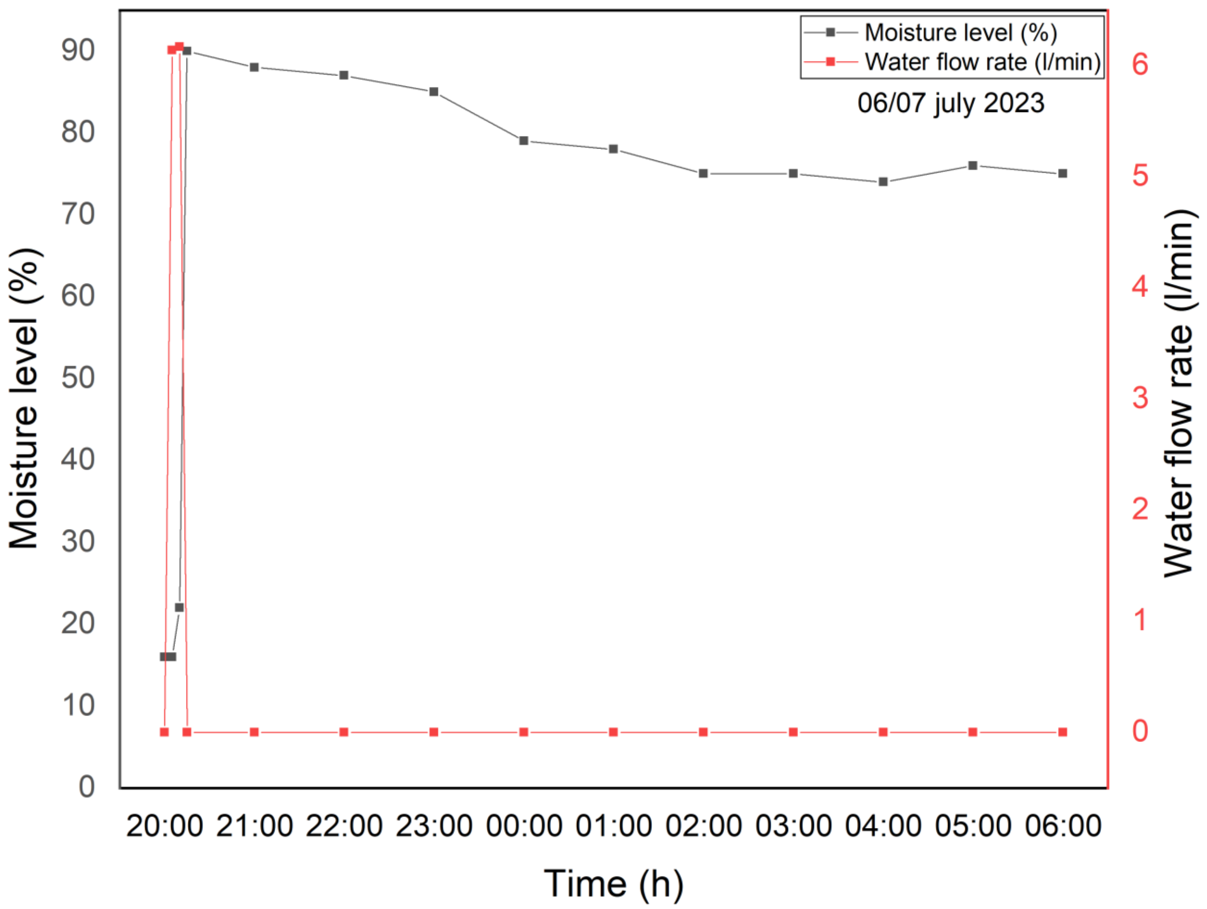

Fig. III. 25. Results of soil moisture and flow rate on the evening of July 6th.

The curve 25 illustrates the relationship between soil moisture percentage and water flow rate in liters per minute over time in a smart irrigation project. It is observed that there are fluctuations in the moisture values and water flow rate over time.

At 20:00, the moisture level is 16%, and the water flow rate is zero, indicating that irrigation has not started yet. From 20:05 to 20:10, there are slight changes in the moisture level, and the water flow rate increases to 6.14 and 6.17 liters per minute. It is noted that the water is used to irrigate the soil to compensate for moisture deficiency.

From 20:15 to 06:00, the moisture level increases to 90% and then gradually decreases over time due to high temperatures, reaching a percentage of 74%. The water flow rate stops completely. This indicates that the soil moisture level is very high and the soil is fully saturated with water, thus not requiring additional irrigation.

From this analysis, it is evident that the smart irrigation system adapts well to soil moisture conditions. The system responds by increasing the water flow rate when the moisture level is low and stops irrigation when the moisture level is sufficiently high. This contributes to achieving better efficiency in meeting the plant's needs.

3) On July 7th, from 08:00 AM to 20:00 PM, the following results were observed:

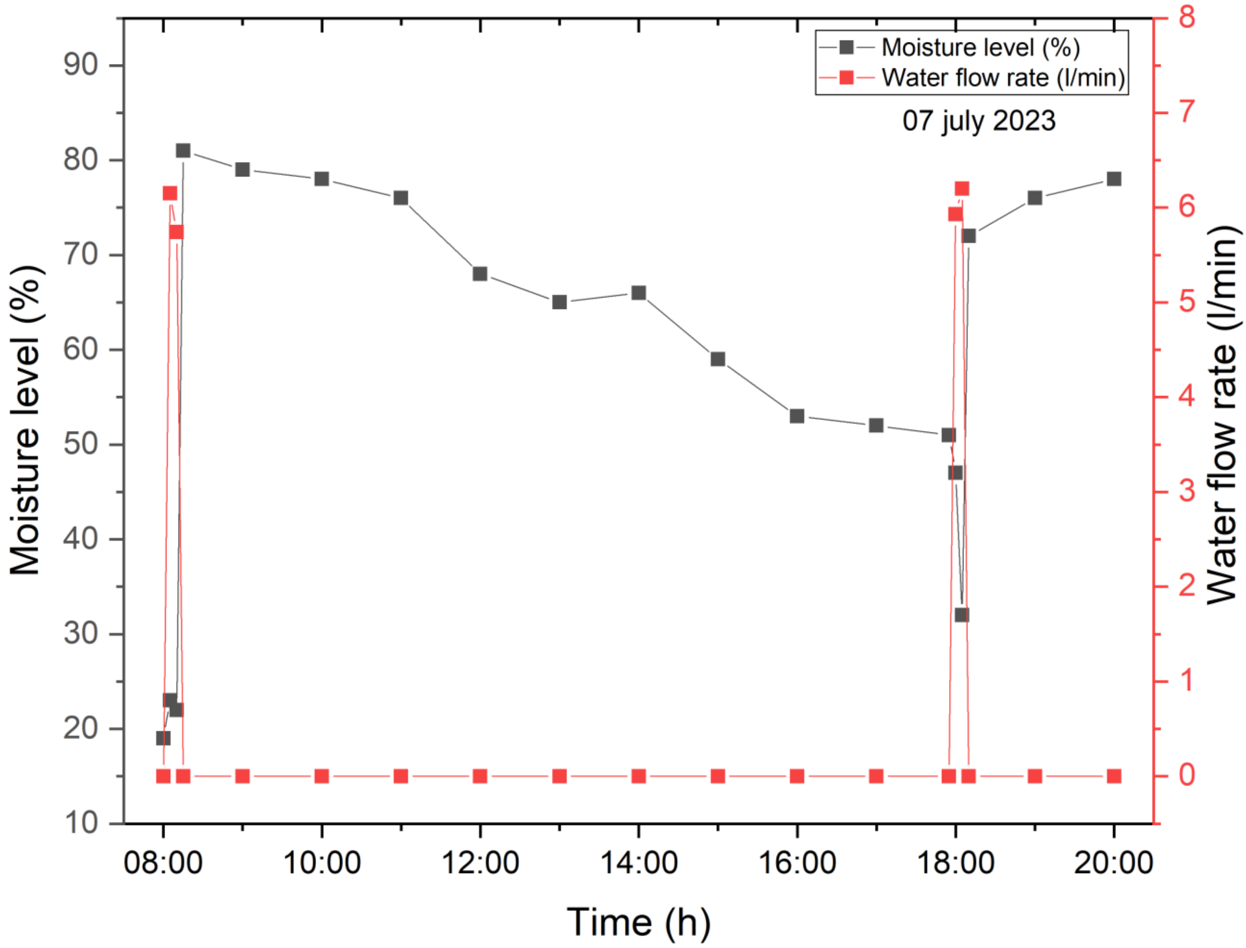

Fig. III. 26 Results of soil moisture and flow rate on July 7th.

The values presented in the given curve, which is in front of us, illustrate the variations in soil moisture levels and water flow rate over time in hours during a specific period in a smart irrigation project. Here are some comments on the values:

At 08:00, the moisture level is 19%, and the water flow rate is zero, indicating that irrigation has not started yet.

At 08:05 and 08:10, the moisture level changes to 23% and 22% respectively, with the irrigated water quantity changing to 6.15 and 5.74 liters per minute. This is in response to our smart system, which triggers the irrigation process as long as the moisture level is below the required amount for the plant (less than 50%).

At 08:15, the moisture level rises to 81%, and the water flow rate completely stops. This means that the soil moisture level is very high and does not require additional water.

From 09:00 to 17:00, the water flow rate remains at zero, with a gradual decrease in the moisture level. This indicates that the current moisture level in the soil is sufficient and does not require additional irrigation.

At 18:00 and 18:05, the moisture level reaches 47% and 32% respectively, and the water flow rate increases due to the moisture level dropping below the minimum required by the plant, ranging from 5.93 to 6.2 liters per minute.

From 18:10 to 20:00, the moisture level is 76% and 78% respectively, and the water flow rate completely stops.

From this analysis, it appears that the smart irrigation system adapts well to the plant's needs and soil moisture conditions. The water flow increases when the moisture level is below the minimum value of 50% and stops when the moisture level is above 80%. This contributes to water conservation and improves irrigation efficiency.

These are some pictures of an LCD screen displaying various values of moisture and flow rate.

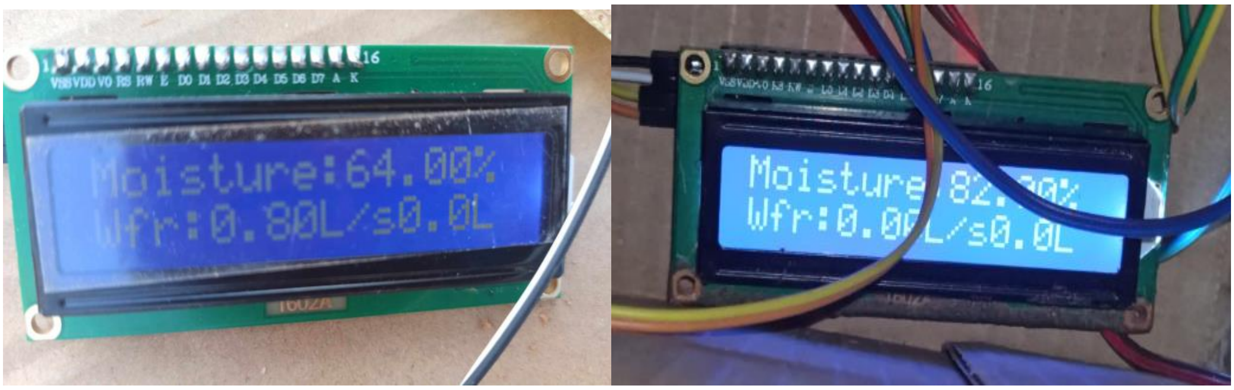

Fig. III. 27. LCD screens for displaying moisture and flow values.

- When the moisture was sufficient and below the maximum threshold of 80%, the flow rate was weak as shown in image a) 27 that is in front of us.
- When the moisture was high and exceeded the maximum threshold of 80%, the flow was zero as the plants were in a fully saturated state and did not require water, as shown in image 27 in front of us.

III. Conclusion

In this chapter, we provided a detailed explanation of humidity and its measurement methods. We also explained the concept of the proposed system for measuring soil moisture, as we recognized the success of the smart and remote irrigation system. We tested and utilized several sensors required by farmers, including soil moisture sensor, LCD display for results, flow meter sensor, stage, pump, and an SD card for data collection and analysis. Using Arduino, allowed us to access an economical system that prevents water wastage and provides the necessary amount of water to plants at the appropriate time when as desired, while eliminating the physical effort in watering. Our project is a smart greenhouse that is automatically watered.

General conclusion

In conclusion, our study presents an automated irrigation system utilizing soil moisture measurement and an arduino Mega board to activate a water pump as desired. Through our research, we gained insights into different types of greenhouses, irrigation systems, and the challenges they face. We identified the necessary components and proposed the use of an LCD screen and solar panels for data display and power supply, respectively.

This system offers numerous benefits, including water efficiency, improved agricultural practices, and the provision of essential climate data for farmers. By activating the water pump based on actual soil moisture needs, it ensures effective and targeted irrigation.

Given the global water crisis and environmental concerns, it is crucial to implement smart irrigation systems like ours in real-life applications. We believe this technology has the potential to make a significant impact on sustainable agriculture practices. Moving forward, we are committed to further developing and refining this system to contribute to a smarter and more sustainable environment.

Overall, our study provides a foundation for the practical implementation of automated and intelligent irrigation systems, promoting water conservation and more efficient agricultural practices.

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