AUTOMATION IN PULSE IRRIGATION USING ARDUINO

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PROJECT REPORT

Submitted in partial fulfillment of the requirement for the degree of

Bachelor of Technology

In

Agricultural Engineering

Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

Department of Irrigation and Drainage Engineering

Kelappaji College of Agricultural Engineering & Technology, Tavanur, Malappuram – 679 573. Kerala, India

2016

DECLARATION

We hereby declare that this thesis entitled **"Automation In Pulse Irrigation Using Arduino"** is a bona fide record of project work done by us during the course of project and that the thesis has not previously formed the basis for the award to us of any degree, diploma, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this project report entitled **"AUTOMATION IN PULSE IRRIGATION USING ARDUINO"** is a record of project work done jointly by Ms. Afeefa Mattummal, Ms. Chinju Saju, and Ms. Jayalakshmi R. under my guidance and supervision and that it has not previously formed the basis for any degree, diploma, fellowship or associateship or other similar title of another University or Society.

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ACKNOWLEDGEMENT

It is with immense pleasure that we avail this opportunity to express our deep sense of gratitude to our guide **Er. Vishnu B**., Assistant Professor, Department of IDE, KCAET, Tavanur for his excellent guidance, care, patience and for providing us with an excellent atmosphere for doing our project. We consider it as our greatest fortune to have him as the guide for our project work and our obligation to him lasts forever.

We are thankful to **Dr. Haji Lal**., Dean, Faculty of Agricultural Engineering, KCAET for the support that he offered while carrying out the project work.

We engrave our deep sense of gratitude to **Dr. Sasikala, D**., Associate Professor and Head, Department of Irrigation and Drainage Engineering, KCAET, Tavanur.

We wholeheartedly thank **Er. Sivaji K.P.**, who offered his help to us during the initial stages of our work.

We extend our gratitude to **Dr. Sathian K.K**. and lab assistant **Mr. Unnikrishnan** who helped us with the works in the soil-water laboratory.

We express our heartfelt thanks to **Er. Bijo Lawrence**, who helped us rectify the problems in the electronic aspects of the project.

We are short of words to express our heartfelt gratitude for the selfless help and emotional support that our dear friend **Mr. Ashwin Krishnamoorthy** offered throughout the course of this project.

We heartily express our gratitude to our friend **Ms. Anu Vazhayil** for her aide in solving the last minute crises that we faced.

We sincerely acknowledge the help of our dear friends, particularly **Ms. Aparna, Ms. Mamatha, Ms. Sharmina, Ms. Sruthi**, and **Mr.Vinay** who helped us during the project work.

We are greatly indebted to our **parents and siblings** for their blessings, prayers, and support without which we could not have completed this work.

Last but not the least, we bow our heads before **God Almighty** for the blessings bestowed upon us.

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SYMBOLS AND ABBREVIATIONS

%	Percentage
Δt	Differnce between wet bulb and dry bulb temperature
°C	Degree Celsius
A	Ampere
A	Measuring humidity coefficient
AC	Alternating Current
ADR	Amplitude Domain Reflectometry
ASCII	American Standard Code for Information Interchange
ATMEGA	Atmel megaAVR series
AUR	Arch User Repository
Avg	Average
B_d	Bulk Density
cbar	centibar
CDIL	Continental Device India Limited
Cl	Chlorine
cm	centimetre
DC	Direct Current
DHT11	Digital Humidity and Temperature sensors
e.g.	Example
e_d	Saturation vapour pressure in the dry bulb temperature
ENIG	Electroless Nickel Immersion Gold

ET	Evapotranspiration
et al.	and others
etc.	etcetra
e_w	Saturation vapour pressure in the wet bulb temperature
FDR	Frequency Domain Reflectometry
g	gram
GIS	Geographical Information System
GSM	Granular Metric Sensors
h	Height of the core
i.e	that is
IDE	Integrated Development Environment
in	inch(es)
IWUE	Irrigation Water User Efficiency
KB	Kilobyte(s)
KCAET	Kelappaji College of Agricultural Engineering and Technology
km	kilometre(s)
kPa	kilo Pascal
LCD	Liquid Crystal Display
LED	Light Emitting Diode
m/s	metre per second
mA	milli Amperes
MAD	Management Allowable Depletion
Max	Maximum

mha	million hectares
Mhz	Mega Hertz
MHz	Mega Hertz
Min	Minimum
min	minute(s)
ml	millilitres
Mm	millimetre
Mn	Manganese
M_s	Mass of soil present in the core
MSEL	Master Scenario Events List
M_w	Mass of water present in the soil sample
N	Nitrogen
NMM	Neutron Moisture Meter
No.	number
NPN	Negative-Positive-Negative
NTC	Negative Temperature Coefficient
OTP NVP	One-Time Programmable Non Volatile Memory
P	Phosphorus
PAW	Plant Available Water
PCB	Printed Circuit Board
PSI	Pounds per square inch
P_v	Volume wetness
P_W	Mass wetness

r	Radius of the core
RH	Relative Humidity
RTD	Resistance Temperature Detectors
S	Sensor Value
SSR	Solid State Relay
T_d	Dry bulb temperature
TDR	Time Domain Reflectometry
TDT	Time Domain Transmission
TEG	Thermo Electric Generator
Temp	Temperature
T_w	Wet bulb temperature
USB	Universal Serial Bus
V	Volt
V_t	Total volume of soil sample
W	Watt
Π	pi

CHAPTER 1

INTRODUCTION

Water is the most critical input for enhancing agricultural productivity, and therefore expansion of irrigation has been a key strategy in the development of agriculture in the country. The amount of fresh water on the Earth is only three percent and 97 % of the water on earth is salt water. When the fresh water on the Earth is considered, slightly over two thirds of this is frozen in glaciers and polar ice cap. The remaining unfrozen fresh water is found mainly as groundwater, with only a small fraction present above ground or in the air. Surface water is the water in a river, lake or fresh water wetlands. Surface water is naturally replenished by precipitation and naturally lost through discharge to the oceans, evaporation, evapotranspiration and groundwater recharge.

It is estimated that 70% of worldwide water is used for irrigation, with 15-35% of irrigation withdrawals being unsustainable. It takes around 2,000 - 3,000 litres of water to produce enough food to satisfy one person's daily dietary need. This is a considerable amount, when compared to that required for drinking, which is between two and five litres. To produce food for the now over 7 billion people who inhabit the planet today requires the water that would fill a canal ten metres deep, 100 metres wide and 2100 kilometres long.

Today, the competition for water resources is much more intense. This is because there are now seven billion people on the planet, their consumption of water is rising, and there is increasing competition for water from industry, urbanization, biofuel crops, and water reliant food items. In the future, even more water will be needed to produce food because the Earth's population is forecast to rise to 9 billion by 2050. An additional 2.5 or 3 billion people, choosing to eat fewer cereals and more meat and vegetables could add an additional five million kilometres to the virtual canal.

India has many rivers whose total catchment area is estimated to be 252.8 million ha (mha). Out of about 1869 km^3 of surface water resources, about 690 km^3 of water is available for different uses. The ultimate irrigation potential of the country has been estimated to be 139.5 mha. India has acquired an irrigation potential of about 84.9 mha against the ultimate irrigation potential. About 360 km^3 of groundwater is also available for irrigation. For soil and water conservation on agricultural lands, both agronomic and mechanical measures are deployed, such as contour farming, management of soil fertility, water nutrient interrelationship, balanced IPNS system and micronutrients. Irrigation is implemented through various methods such as border irrigation, basin irrigation, sprinklers and drip irrigation.

The ultimate irrigation potential of India has been estimated to be 139.5 mha, comprising 58.5 mha from major and medium schemes, 15 mha from minor irrigation schemes and 66 mha from groundwater exploitation. India's irrigation potential has increased from 22.6 mha in 1951 to about 90 mha at the end of 1995. It is estimated that even after achieving the full irrigation potential, nearly 50 percent of the total cultivated area will remain rain fed.

If we analyse agricultural growth during the past four decades, we find that high-yielding varieties, irrigated area expansion and fertilizer use have been the major factors contributing to the achievement of green revolution in India. The present level of consumption of total nutrients (NPK) is 14.3 million tonnes/year. On an all-India basis, per-hectare consumption of fertilizer (NPK), which was a meagre 2.0 kg/ha during the early sixties, has risen tremendously during the last 35 years or so, to a level of 76.5 kg/ha.

The share of water use other than for agriculture was only 13 percent in 1985, which is likely to become 27% by 2025. Such a fast growth of water need in the face of emerging supply constraints is likely to result in a wide supply gap for irrigation water in the near future.

Water application method is broadly classified into two groups: surface irrigation methods and pressurized irrigation methods. Surface irrigation, also called gravity irrigation, comprises of the methods of water application in which water is distributed by means of open surface flow. Two basic requirements of prime importance to obtain high efficiency in surface methods of irrigations are properly constructed water distribution system to provide adequate control of water to the field and proper land preparation to obtain uniform distribution of water over the field. Water is applied to the land surface from a field supply channel located at the upper reach of the field and water flows into the field under gravity.

Surface irrigation is the most popular and earliest method. Use of surface irrigation method started since 4000 years ago in Egypt, China, India and countries of Middle East. Irrigation efficiency of surface irrigation is only 20-50%. Besides lesser efficiency, erosion, salinization, water logging, seepage losses, deep percolation and runoff are its other drawbacks. The uniform water distribution in the field and application of accurate amount of water at the correct time by permitting accurate delivery control are the two necessary aspects of irrigation to be considered. These requirements are accomplished only by adopting pressurized irrigation.

In pressurized irrigation systems, water is conveyed through pipes under pressure and applied to the crop by sprinkling it over the land surface or plant canopy or applied on the soil surface as appoint source, usually in the form of drops. Pressurized irrigation system comprise of sprinkler, drip and pulse methods of water application.

Pulse irrigation is a scalable low-flow irrigation technique that allows for close management of water usage and can be employed with either drip or sprinkler irrigation devices and extend conventional low flow irrigation systems with medium-to-low micro-irrigation levels. Pulse irrigation is common in locations such as Israel where water conservation is a priority.

Pulse irrigation systems operate by alternatively switching irrigation on and off or irrigating in “pulses”, wherein irrigation is given during the on cycle and no irrigation is given during the off cycle. The time interval used for the on and off cycles depends on the emitter used, the application rate to be achieved from the emitter, and the water application rate up to which the soil to be irrigated is not effected by soil aeration deficiency. The pulse irrigation on-off system can be employed by electronic, electrical, hydraulic or pneumatic controlling systems. A typical example of a pulsed drip irrigation system works by passively letting water flow into a reservoir at a controlled rate to steadily build pressure within the pressurized reservoir. When the pressure in the reservoir reaches some predetermined pressure level the valve on the reservoir opens and a portion of the fluid contained within the reservoir is forcefully discharged. While the fluid is discharging, the pressure within the reservoir decreases. When the decrease in water pressure reaches a predetermined level the valve closes to resume the charging phase. The charge-discharge cycling will continue as long as the flow rate coming in through the inlet is less than the expel rate passing out through the outlets while the valve is open. A device called a drip flow controller is placed at the inlet for this purpose to regulate the flow into the inlet.

The advantage of low-flow pulse irrigation system is that they can be left operating continuously without overwatering. The constant and frequent irrigation applications have been cited as one way to reduce water demand of the crops and better yields due to the reduction in water stress and improved soil aeration.

Pulse drip irrigation has a number of advantages over conventional drip and sprinkler irrigation techniques. The problem of runoff on heavy soils and also leaching or water loss in sandy soils is kept at bay when pulse irrigation technique is employed. It also facilitates efficient application of irrigation water on shallow soils and in hilly areas. The intermittent operation of sprinklers and foggers in pulse irrigation can provide evaporative cooling for temperature control. Use of pulse irrigation in green house helps in reducing the size of growing containers due to very low discharge rates. Same is the advantage field cultivations also – low flow inputs reduce supply system costs because only smaller conduits and lower capacity pumps would be needed.

Manual irrigation systems do not promote water conservation that result to too much water or too small amount of water in the soil thus poor plant growth. Here is the need for an automated irrigation system. Automated irrigation systems are capable of determining and maintaining the right amount water for the soil. Automation of irrigation is the process of starting, continuing and stopping the frequency and/or intensity of irrigation by using suitable automation techniques like sensors and corresponding software. Commonly used sensors for irrigation automation include those devices that sense soil moisture, soil temperature, soil pH, relative humidity etc. ‘Arduino’ can be used as an integrated automation technique which can be simply called a tiny computer, consisting of a microcontroller board and its software.

Arduino is a tool for making computers that can sense and control more of the physical world than a desktop computer. It's an open-source physical computing platform based on a simple microcontroller board, and a development environment for writing software for the board.

Arduino can be used to develop interactive objects, taking inputs from a variety of switches or sensors, and controlling a variety of lights, motors, and other physical outputs. Arduino projects can be stand-alone, or they can communicate with software running on the computer (e.g. Flash, Processing, and MaxMSP.) The boards can be assembled by hand or purchased preassembled; the open-source IDE (Integrated Development Environment) can be downloaded for free.

The Arduino programming language is an implementation of Wiring, a similar physical computing platform, which is based on the Processing multimedia programming environment.

The present systems of automated irrigation work on the basis of calculating the required amount of irrigation based on the field conditions and crop requirements which have been observed over a few years in the past. Their major disadvantage is that they fail to work according to the varying conditions in the field, say, in the event of an unexpected drought or flood in a particular season. This is where the significance of real time sensing comes in irrigation automation. When there are sensors to detect the real time field conditions, automation can be programmed to be based on the varying parameters existing at the moment which affect irrigation.

Thus in simple words, automation of pulse irrigation can be achieved by using suitable sensors for real time sensing of parameters, providing this as input data for Arduino, writing a program to operate the irrigation ON/OFF valves, assembling the sensors, Arduino board and its software, the valve and pipelines in desired manner and putting these to work.

Specific objectives are:

- To find Arduino compatible sensors for factors affecting irrigation and to use them along with the Arduino board and accessories for the control of pulse irrigation systems.
- To develop programming code in Arduino programming language incorporating the inputs from the sensors, irrigation control parameters and pulse irrigation requirements to operate the pulse irrigation system automatically.
- To test the efficacy of the developed software and hardware assembly to varying pulse irrigation parameters.

CHAPTER 2
REVIEW OF LITERATURE

2.1 Pulse Irrigation

It is a scalable low flow irrigation technique that allows for close management of water usage and can be employed with either drip or sprinkler irrigation devices and extend conventional low flow irrigation systems to ultralow micro irrigation levels.

Water is applied as discrete or continuous drops, tiny streams or miniature spray though emitters or applicators places along a water delivery line near the plant at frequent intervals with resting phases in between. The shape or design of the emitter reduces the operating pressure from the supply line and a small volume of water is discharged at the emission point. Pulsed drip irrigation method is characterized by the following features.

a. Water is supplied at a low rate
b. Water is applied over a long period of time
c. Water is applied at frequent intervals in short pulses
d. Each pulse comprises of operating and resting phases
e. Water is applied by a low pressure delivery system
f. Water is routinely used to transport fertilizers and other agricultural chemicals.

Zur (1976) stated that the pulsed water application principle was developed in order to obtain low application rates from any water emitter. A time averaged hourly water application rate was used to define the pulsed water application regime.

Karneli (1977) examined the basic principles in the design of a pulsating irrigation system. The main factors mentioned were time components of pulse, direction of operation, resting periods of a single pulse and the relationship between these factors and the number of pulses per irrigation.

Levin *et al.* (1977) concluded from his experiments on the effect of discharge rate and intermittent water application by point-source irrigation on soil moisture distribution pattern that the pulse treatment can replace the advantageous low (1 litre/hour) discharge rate while to a large extent avoiding the difficulties of blocking of outlets by maintaining a higher (2 litre/hour) discharge rate.

Chizhikovi *et al.* (1980) established relationships between the application rates and a number of parameters on experiments on intermittent irrigation over nine seasons.

Oron (1981) stated that under pulse irrigation continuous water application is possible and is associated with increased water percolation under the root zone. Intermittent irrigation strategy based on discharge pulses followed by breaks could improve water management in the field and increase irrigation efficiency.

Beeson (1992) stated that pulse-irrigated plants tended to accumulate less daily water stress. With less water stress, plants grew faster and remained healthier than plants that were stressed on a daily basis. Another benefit is that disease prevention is less difficult. Alternatively the major drawback with pulsing is the possible increase of soluble salts. Dole (1993) discovered that to prevent increased amount of soluble salts, low levels of fertilizer in solution is applied so that it keep soluble salts from building up rapidly in the media and reduce the need for leaching.

Pulse irrigation or watering is a recent concept where small frequent irrigation applications are applied to saturate the soil and meet the plant water requirements, while reduced leaching and run-off (Dole, 1994).

Clothier and Green (1994), Coelho and Or (1996) found that pulse irrigation under stressful environments results in larger fruit which has a major impact on farm profitability. On the other hand, Evidence shows that root systems under partial soil wetting are dominated by wetting patterns under the drippers.

High irrigation frequency might provide desirable conditions for water movement in soil and for uptake by roots (Segal *et al.*, 2000). Several experiments have shown some crops' positive responses to high frequent drip irrigation (Freeman *et al.*, 1976; Segal *et. al.*, 2000; Sharmasarkar *et al*,. 2001).

Zin-El-Abedin(2005) conducted a study to determine and evaluate the effects of the traditional and the pulse drip irrigation (5 min on/ 5 min off) on the process of soil water depletion, replenishment, distribution pattern, application efficiency, emission uniformity, distribution efficiency, crop yield characteristics and water use efficiency. The crop measurements were plant height (cm), number of ears/plant, roots distribution area, kernel weight and weight of 100 kernels as an average of two samples taken at random from each plot. The results demonstrated that the Pulse flow resulted in higher values of soil moisture trend for either (0-15cm) or (15-30cm) soil depths. Moisture content showed that there was no significant difference between the two soil depths for pulse flow irrigation technique, while as the L.S.D. test was highly significant for continuous drip between both soil depths.

Assouline *et al.* (2006) studied that pulsed irrigation led to higher plant weight and leaf area at the early stages of plant growth. High frequency drip irrigation was found to supply water and nutrients at a rate that is close to plant uptake. It also led to higher Mn concentrations in leaves and fruits and increased concentration of Cl, N, and P in leaves, confirming earlier conclusions on improved P mobilization and uptake under pulsed irrigation.

Moshtaghimi and Mitchell (2007) conducted a study on pulsed trickling effects on soil moisture distribution. They concluded that compared to continuous irrigation, pulsed applications resulted in significant reduction in water loss below the root zone. Pulsed application rates can replace continuous small discharge rates to reduce irrigation water runoff problems on heavy soils and with restricted infiltration, allow the use of larger emitter orifices to decrease potential clogging of the trickle system.

Simulation results on drip irrigation and water distribution patterns by Skaggs *et al*. (2010) showed that pulsing and lower application rates produced minor increases in horizontal spreading at the end of water application.

Various crops were taken into consideration and extensive research was done by Prof Tarek Kamal Zeinelabedien over the years in experimental farms of Egypt. Details are enumerated in the following paragraphs.

1. Two field experiments were carried out during growing seasons 2010 and 2011, in research farm of national research center in Nubaryia region, Egypt to study the effect of pulse drip irrigation and mulching systems for saving water, increasing and improving yield of soybean. The study factors were, pulse drip irrigation technology (adding of daily water requirements on 4 times, 8 times, 12 times compared with adding of daily water requirements on 1 time) and mulching systems (covering the soil with black plastic mulch “BPM”, rice straw mulch “RSM” and the control treatment was soil surface without mulch “WM”). The parameters in consideration were soil moisture distribution in root zone, growth characters of soybean plant, yield of soybean, efficiency of irrigation in terms of usage of water and economical

parameter. According to the economical view and the results of statistical analysis for effect of pulse drip irrigation and mulching systems on yield, quality traits and IWUE soybean indicated that, applying the irrigation requirements on 8 pulses/day with using BPM is the best conditions because under these conditions was occurred the highest value of yield, quality traits and IWUE soybean and there was significant difference between this case and other treatments.

a. Pulse irrigation technique increased water movement in horizontal direction than in vertical direction hence improve from soil moisture distribution
b. The wetted soil volume in root zone and using BPM decrease from evaporation process rate from soil surface hence decreasing of salts accumulation in addition to decreasing of weed growth in the root zone.

However all the above mentioned traits are found to decrease on 12 pulses/ day, this may be due to irrigation water was very small with every pulse at 12 pulses/day in addition increasing the total time of time-off, meaning insufficient application of irrigation water to remove water stress in the root zone.

2. Two field experiments were carried out during growing seasons 2011 and 2012 in AboGhaleb farm, Cairo- Alex to study the effect of short irrigation cycles (cycle1 = 2 times per day, cycle2= 3 times per day and cycle3= 4 times per day and the time-off between pulses was 30 minute compared with continuous drip irrigation) on soil moisture distribution in root zone and productivity of potato to improve from water management in farms. The results indicated that, maximum productivity of potato occurred under the following conditions: cycle 3 under subsurface drip irrigation. Soil moisture distribution and soil moisture content increased in the root zone after applying short irrigation cycles compared to continuous drip irrigation.Increase in number of pulses increased the water movement in horizontal direction than vertical direction. The study also showed an increase in the volume of available water and nutrients in the root zone.

3. Effects of pulse irrigation on yield and nutritional elements of green beans (*Phaselous vulgaris L.*), irrigated with a subsurface drip irrigation system, were evaluated over two years under field conditions in the Mediterranean region of Egypt in 2012. The irrigation system consisted of four irrigation treatments based on the number of pulses which ranged from T1 where the irrigation water requirement applied at one time to T4 where the irrigation water requirement applied using four pulses. Maximum and minimum yields were obtained from

T4 and T1 treatments respectively. Results showed that the vegetative growth of green bean plants (plant height, number of leaves, plant fresh weight, plant dry weight, total leaf area as well as chlorophyll content) were improved by increasing number of pulses per each irrigation. It was found that the highest concentration of all determined nutrient elements was obtained in the high pulse irrigation T4 while, the lowest concentration in the low pulse irrigation T1.

2.1.1 Advantages of Pulse Irrigation

Pulse drip irrigation has a number of advantages over conventional drip and sprinkler irrigation techniques. The problem of runoff on heavy soils and also leaching or water loss in sandy soils is kept at bay when pulse irrigation technique is employed. It also facilitates efficient application of irrigation water on shallow soils and in hilly areas. The intermittent operation of sprinklers and foggers in pulse irrigation can provide evaporative cooling for temperature control. Use of pulse irrigation in greenhouse helps in reducing the size of growing containers due to very low discharge rates. Same is the advantage field cultivations also – low flow inputs reduce supply system costs because only smaller conduits and lower capacity pumps would be needed.

Levin and Rooyen (1977) found out from numerous workers that higher yield and improved plant growth can be obtained by reducing the time intervals between irrigation and by maintaining low soil moisture stress condition.(Hagan, 1957; Slatyer, 1957; Rauritz, 1967; Rawitz and Hellel, 1969; Assaf *et al.* 1975).Previous works have shown that by maintaining a low infiltration rate a lower value for ‘field capacity’ can be obtained (Rubin, Steinhaldt and Reiniger (1964), Zug (1976). Lower ‘field capacity’ water content naturally implies better aeration in the root zone of the plants.

Levin and Rooyen (1977) found that water movement in the horizontal direction is at a faster rate than in the vertical direction. Such a change in ratio implies changes in the shape of the wetted volume of soil beneath the point source in favour of the lateral direction, when water is applied in a pulsating manner. This effect is particularly large in sandy loam and is expected to increase further towards heavier textured soils. In sand, a decrease in vertical soil water advance is an added benefit, as the excess downward movement of water could cause considerable losses of water and nutrients below the root zones. In medium textured soils, pulse irrigation brought about a significant decrease in soil moisture content in the transmission zone in both vertical and horizontal columns. This phenomenon implies improved soil aeration when intermittent water application technique is done on heavy textured soils.

It was reported by Nir (1982) that pulsated irrigation which provides water only during a certain fraction of time , it, in an intermittent fashion, enables to keep the soil moisture at a high level of availability (or low water stress) and supplies water at the right time.

Rajkumar (1984) inferred that pulsating irrigation given during night time, coupled with mulching, has shown outstanding performance in all aspects – moisture conservation, maintenance of soil quality and enhanced yields – in the case of radish and maize.

2.2 Irrigation Automation

An automation ofirrigation systems has several positive effects. Once installed, the water distribution on fields or small-scale gardens is easier and does not have to be permanently controlled by an operator. There are several solutions to design automated irrigation systems. Modern big-scale systems allow large areas to be managed by just one operator. Sprinkler, drip or subsurface drip irrigation systems require pumps and some high tech-components and if used for large surfaces skilled operators are also required. Extremely high-tech solutions also exist using GIS and satellites to automatically measure the water needs content of each crop parcel and optimise the irrigation system. But automation of irrigation can sometimes also be done with simple, mechanical appliances: with clay pot or porous capsule irrigation networks or bottle irrigation.

2.2.1 High-Tech Principles : Automation of irrigation systems refers to the operation of the system with no or minimum manual interventions.Irrigation automation is justified where a large irrigated area is divided into small segments called irrigation blocks and segments are irrigated in sequence to match the discharge available from the water source. There are six high-tech automation systems, which are described below.

2.2.2 Time Based System : Irrigation time clock controllers, or timers, are an integral part of an automated irrigation system. A timer is an essential tool to apply water in the necessary quantity at the right time. Timers can lead to an under- or over-irrigation if they are not correctly programmed or the water quantity is calculated incorrectly. A timer starts and stops the irrigation process.

2.2.3 Volume Based System : The pre-set amount of water can be applied in the field segments by using automatic volume controlled metering valves (Rajakumar *et al*., 2008).

2.2.4 Open Loop Systems :In an open loop system, the operator makes the decision on the amount of water to be applied and the timing of the irrigation event. The controller is programmed correspondingly and the water is applied according to the desired schedule. Open loop control systems use either the irrigation duration or a specified applied volume for control purposes. Open loop controllers normally come with a clock that is used to start irrigation. Termination of the irrigation can be based on a pre-set time or may be based on a specified volume of water passing through a flow meter.

2.2.5 Closed Loop Systems: In closed loop systems, the operator develops a general control strategy. Once the general strategy is defined, the control system takes over and makes detailed decisions on when to apply water and how much water to apply. This type of system requires feedback from one or more sensors.Irrigation decisions are made and actions are carried out based on data from sensors. In this type of system, the feedback and control of the system are done continuously. Closed loop controllers require data acquisition of environmental parameters (such as soil moisture, temperature, radiation, wind-speed, etc.) as well as system parameters (pressure, flow, etc.).

2.2.6 Real Time Feedback System: With this application irrigation is based on actual dynamic demands of the plant itself; the plant root zone is effectively reflecting all environmental factors acting on the plant. Operating within controlled parameters, the plant itself determines the degree of irrigation required. Various sensors, tensiometers, relative humidity sensors, rain sensors, temperature sensors etc. control the irrigation scheduling. These sensors provide feedback to the controller to control its operation.

2.2.7 Computer Based Irrigation Control Systems: Control board showing timers, soil moisture sensor-controllers, solenoid valves, wiring, and flowmeters-datalogger. A computer-based control system consists of a combination of hardware and software that acts as a supervisor with the purpose of managing irrigation and other related practices such as fertigation and maintenance. Generally, the computer-based control systems used to manage irrigation systems (e.g. drip irrigation systems) can be divided into two categories: interactive systems and fully automatic systems.

2.3 Advantages of Irrigation Automation

a. Automation eliminates the manual operation of opening or closing valves

b. Possibility to change frequency of irrigation and fertigation processes and to optimise these processes

c. Adoption of advanced crop systems and new technologies, especially new crop systems that are complex and difficult to operate manually

d. Use of water from different sources and increased efficiency in water and fertiliser use

e. System can be operated at night, water loss from evaporation is thus minimised

f. Irrigation process starts and stops exactly when required, thus optimising energy requirements

Through proper irrigation, average vegetable yields can be maintained (or increased) while minimizing environmental impacts caused by excess applied water and subsequent agrichemical leaching. Recent technological advances have made soil water sensors available for efficient and automatic operation of irrigation systems. Automatic soil water sensor-based irrigation seeks to maintain a desired soil water range in the root zone that is optimal for plant growth. The target soil water status is usually set in terms of soil tension or metric potential (expressed in kPa or cbar, 1 kPa=1 cbar), or volumetric moisture (expressed in percentage of water volume in a volume of undisturbed soil). Another benefit of automatic irrigation techniques is convenience. In a previous experience working with a soil-moisture-based automatic irrigation system, Dukes *et al.* (2003) found that once such a system is set up and verified, only weekly observation was required. This type of system adapts the amount of water applied according to plant needs and actual weather conditions throughout the season. This translates not only into convenience for the manager but into substantial water savings compared to irrigation management based on average historical weather conditions.

2.4 Soil Moisture Sensors

Various instruments for measuring soil moisture are available commercially. These instruments may not give such accurate results as the soil sampling & drying procedures, i.e.; gravimetric methods, but are sufficiently accurate for practical purposes. The types of instruments commonly in use for soil moisture content are

A) Tensiometers: Tensiometers work on the principle that a partial vacuum is created in a closed chamber when water moves out through a porous ceramic cup to the surrounding soil.

Tension is measured by a manometer or a vacuum gauge which may be graduated in either hundredths of an atmosphere or in centimetres of water. A porous clay cup and a manometer are interconnected by a tube filled with water. Michael & Ojha (2012) stated that tensiometers do not satisfactorily measure the entire range of available moisture in all soil types. They are satisfactory for sandy and sandy loam soils where tensions are low, but they are not so well adapted to clay soils when tensions normally are high, or where the soil cracks badly.

B) Electrical resistance measuring devices: Electrical instruments indicate the soil moisture indirectly by measuring the electrical resistance of a porous block buried in the soil within the root zone. Michael (2007) wrote that resistance blocks aren't useful for saline soils, since the resistance reading is affected by salt concentration. However, gypsum blocks work better even in saline conditions because of buffering action.

C) Neutron moisture meter: Neutron scattering method is a rapid means of making in situ measurement of soil moisture. It is based on the measurement of the number of hydrogen nuclei that are present in a unit volume of soil , their number being a direct function of the number of water molecules contained in that same volume. This measurement is made by inserting a source of fast neutrons and by counting the slow neutrons produced.

Anonymous (1982) claimed that a moisture sensor including in one embodiment a probe formed with a first cylindrical tube extending outward from a base and having a plurality of axially extending slots around the periphery thereof, and a second slotted cylindrical tube extending outward from the base separated and insulated from the first tube, and extending coaxially with the first tube. The tubes form an effective coaxial capacitor and are insertable into material to be sensed appear as a ground plane. In a second and third embodiment a member defining flat surfaces extends from a base forming in cross-section a volume with a square centre and legs extending from each side thereof to an open peripheral end. An RC bridge circuit, preferably a Wien bridge or a capacitor divider circuit is connected to the tubes to measure the impedance of the material.

2.4.1 Soil Moisture Sensors for Manual Irrigation Control

Although soil water status can be determined by direct (soil sampling) and indirect (soil moisture sensing) methods, direct methods of monitoring soil moisture are not commonly used for irrigation scheduling because they are intrusive and labour intensive and cannot provide immediate feedback. Soil moisture probes can be permanently installed at representative points in an agricultural field to provide repeated moisture readings over time that can be used for irrigation management. Special care is needed when using soil moisture devices in coarse soils since most devices require close contact with the soil matrix that is sometimes difficult to achieve in these soils.

Many indirect methods are available for monitoring soil water content. These methods estimate soil moisture by a calibrated relationship with some other measurable variable. The suitability of each method depends on several issues such as cost, accuracy, response time, installation, management and durability. Depending on the quantity measured (i.e., volumetric water content or soil tension), indirect techniques are first classified into volumetric and tensiometric. Both quantities are related through the soil water characteristic curve that is specific to a given soil. Therefore, it is important to remember that they cannot be related to each other the same way for all soil types. In addition, this relationship might not be unique and may differ along drying and wetting cycles, especially in finer soils. To calculate irrigation requirements (the amount of water that needs to be applied with each irrigation based on crop needs), suction values from tensiometric methods need to be converted to soil moisture through the soil characteristic curve. Among the available tensiometric techniques, tensiometers and granular matrix sensors (GMS) are the most used for automatic irrigation.

Most of the currently available volumetric sensors suitable for irrigation are dielectric. This group of sensors estimate soil water content by measuring the soil bulk permittivity (or dielectric constant) that determines the velocity of an electromagnetic wave or pulse through the soil. In a composite material like the soil (i.e., made up of different components like minerals, air and water), the value of the permittivity is made up by the relative contribution of each of the components. Since the dielectric constant of liquid water is much larger than that of the other soil constituents, the total permitivity of the soil or bulk permitivity is mainly governed by the presence of liquid water. The dielectric methods use empirical (calibrated) relationships between volumetric water content and the sensor output signal (time, frequency, impedance, wave phase). These techniques are becoming widely adopted because they have good response time (almost instantaneous measurements), do not require maintenance, and can provide continuous readings through automation. Although these sensors are based on the dielectric principle the various types available (frequency domain reflectometry-FDR, capacitance, time domain transmission-TDT, amplitude domain reflectometry-ADR, time domain reflectometry-TDR, and phase transmission) present important differences in terms of calibration requirements, accuracy, installation and maintenance requirements and cost.

A probe that can measure electrical resistance as well as soil moisture was developed by Shinn *et. al*. (1997). It consists of a penetration rod, along which there are four concentric rings with insulators in between. By using a modified clap high frequency transistor oscillator, which operates at 100 MHz, the two outer rings will calculate soil resistance.

For the management of natural resources various soil moisture sensors have been used. The management practices mainly include precision farming and irrigation scheduling. Environment monitoring, watershed management, research on crop yield etc. are other uses of this. Inorder to optimize water use and to produce a good quality crop, soil moisture sensors can be used which will help to take timely decision of when to start and when to stop water application (Hanson *et al.,* 2000). Scheduling of irrigation by reducing chemical percolation and nutrient loss in the soil is important for environment quality management and would help the irrigators in achieving crop specific water requirement (Leib *et al.,* 2002)

To measure the soil moisture, many instruments and various methods have been utilized in innovative agricultural practices. Commonly used are tensiometers, gravimetric methods resistance blocks etc. and for scheduling of irrigation, these all will continue to be utilized (Leib *et al.,* 2002). For the qualitative and quantitative evaluation of soil water devices, many studies have been done in the past. Variety of sensors, which are now in use, is a result of coupling of sensor industry with computer technology. A real time based continuous moisture sensing can be done using these sensors.

For efficient on farm management, timing and amount of irrigation are important. To calculate when and how to irrigate the crop, scientific irrigation scheduling uses crop evaporation and transpiration data as well as soil moisture content. If commercial farm practices are incorporated with this technology, it will result in timely and efficient water management (Leib *et al.*, 2002).

Physical property of unsaturated subsurface and electrical resistance has been related and the relationship was described by Yoon *et al*. (2002). The experiment revealed that the electrical resistance of soil decreased exponentially as the moisture density increased. Electrical resistance was decreased by the addition of leachate with various ions.

For a soil moisture sensor controlled irrigation system, evaluation of water application rates, leaching and quality of couch grass were done by Pathan *et al*. (2003). The system with soil moisture sensor was compared with conventional irrigation system. It was observed that cumulative volume of water applied during summer with sensor controlled system was 25% less than that applied in conventional system.

For the cultivation of crops with large and timely water requirement, time domain reflectometers have been proven to be helpful (Jeffrey, 2004).

Soil moisture sensing was used for automatic furrow irrigation by Mathew and Senthilvel (2004). Prevailing soil moisture was monitored by an electronic tensiometer and this data is given to a solenoid valve, accordingly irrigation cycle may ON or OFF. When the soil moisture tension reaches zero, irrigation stops. In this system about 20% saving of irrigation water was saved as compared to the conventional method.

A different solution for measurement of volumetric soil moisture is to use neutron probe or neutron moisture meter. For the soil water measurements, it is considered to be one of the accurate methods (Charlesworth, 2005). The collision of hydrogen ions and fast moving neutrons from a small radioactive substance will reduce their speed and will be slowed down. This is the principle behind neutron moisture meter. Extent of collisions will be higher with high water content (George, 1999). However its use has been reduced due to its radiation threats.

A theta probe is used for the moisture measurement by Charlesworth (2005). It is a capacitance based instrument. The steel pin on the probe work by monitoring soil moisture changes and act as a transmission line.It transmits radio frequency energy to the soil and the properties of the reflected energy waves have been utilized for moisture measurement. The sensor and internal circuitry can be used for continuous or point measurements. By using a linear calibration equation the output of the probe in volts can be converted to soil moisture.

An Echo probe, which is made up of copper electrodes and sealed in epoxy impregnated fibre glass operates on the principle of capacitance (Fares and Polyakov, 2006). By measuring change time of a capacitor placed in soil, Echo probe will measure the soil moisture content (Czarnomski *et al*., 2005).These are permanently installed throughout the growing season.

Measurement of soil moisture content can be done by using resistance blocks also. There is a direct relationship between electrical resistance of a porous block and its water content. Resistance blocks make use of this principle. Nowadays we make use of certain blocks which will measure the rate of heat dissipation in the soil. These are called thermal dissipation blocks mainly available ones are ceramic type. Kolev (2005) has done an experiment to measure soil moisture content using the method of electrical resistance and soil moisture meter with gypsum blocks.

An experiment by Thompson *et al*. (2007) was conducted in Mediterranean type greenhouses on the south-eastern coast of Spain in which bell pepper, melon and spring and winter tomato were grown. The experiment was done with an intention of determining the thresholds of available soil water content and soil matric potential. This data will be useful for preventing water limitations for the above crops. The results show the uncertainty of using fixed threshold values.

For the *in situ* determination of volumetric soil moisture content, TDR 300 (Time Domain Reflectometer) is found to be effective. This sensor is portable. By using the propagation time of electromagnetic waves, TDR300 will calculate permittivity. The bulk permittivity of soil is directly related to soil moisture content (Spectrum Technologies Inc; 2007).

Sensors that work on the basis of the relationship between resistance and soil moisture are also in use. These are called electrical resistance sensors. Hignett and Evett (2008) have done a study on these sensors. For all the trials carried out almost constant nature could be observed in the relationship between resistance and soil moisture content for the sensor with brass plate electrode and washed sand porous medium. A predetermined moisture level could be maintained in the root zone when this automated system was used. There was no need for frequency supervision. Results obtained were specific for each soil type and soil salinity levels.

Another method to calculate and measure soil moisture content is the technology of neutron probe. It has got a probe and a scaler for the counting of electrons. By using a radioactive substance, high energy neutrons will be released into the soil. These neutrons, when come in contact with hydrogen atoms in the soil moisture, will get slowed down (Chanasyk and Naeth, 1996). Commonly depth probes and surface probes are in use. Depth probes can be used to measure soil moisture at a depth while the latter can be used for soil moisture measurements in the upper most soil layer (Schmugge *et al.* 1980). The data obtained from the neutron probe can be correlated with the soil moisture content directly (Chanasyk and Naeth, 1996). This equipment is dangerous to health due to its radioactive nature and for the same reason it demands a trained operator (Tarantino *et al.,* 2008). Calibration of the instrument is difficult as it has to be done specifically for each soil. This accounts for its limited use along with its high cost.

2.4.2 Automatic Soil-Water Based Irrigation Control

A soil water-based irrigation control system uses feedback on the soil water status to bypass a time-based pre- programmed schedule or to maintain soil water content with a specified range. These two approaches are bypass and on-demand, respectively. Bypass configurations skip an entire timed irrigation event based on the soil water status at the beginning of that event or by checking the soil water status at intervals within a time-based event.

Tensiometers and GMS were the first types of sensors adapted to automatic irrigation control. Phene and Howell (1984) first used a custom made soil matric potential sensor to control subsurface drip-irrigated processing tomatoes. Their results indicated that yields of the automated system were similar to those from tomatoes irrigated based on pan evaporation with the potential to use less irrigation water.

Switching tensiometers are devices that operate in bypass mode typically with a timer such that irrigation will be allowed within a timed irrigation window if the soil matric potential exceeds a threshold setting. Smajstrla and Locascio (1996) reported that using switching tensiometers placed at 15 cm depths and set at 10 and 15 kPa tensions in a fine sandy soil in Florida reduced irrigation requirements of tomatoes by 40-50% without reducing yields.

Meron *et al*. (2001) discussed the use of tensiometers to automatically irrigate apple trees. They noted that spatial variability was problematic when the tensiometers were installed 30 cm from the drip irrigation emitters. Smajstrla and Koo (1986) discussed the problems associated with using tensiometers to initiate irrigation events in Florida. Problems included entrapped air in the tensiometers, organic growth on the ceramic cups, and the need for re-calibration.

Shock *et al*. (2002) described a system to irrigate onion with frequent bypass control using GMS. The overall water used was slightly lower than calculated crop evapotranspiration with acceptable yields.

Nogueira *et al*. (2003) described an automatic subsurface drip irrigation control system used in a sweet corn/peanut crop rotation. This system used TDR sensors to control a subsurface drip irrigation system on-demand. During subsequent testing of this system, 11% irrigation savings with the on-demand subsurface drip irrigation system (23 cm deep) compared to sprinkler irrigation was reported with similar yields between the systems.

Dukes *et al.* (2003) used a commercially available dielectric sensor for lawns and gardens to control irrigation on green bell pepper (*Capsicum annuum L.*). They found 50% reduction in water use with soil-water-based automatically irrigated bell pepper when compared to once daily manually irrigated treatments that had similar yields; however, maximum yields and water use were on the farmer treatment that was irrigated 1-2 times each day.

Carpena *et al*. (2004) developed an irrigation controller that uses a voltage signal from a dielectric probe that is related to soil water. This system performed similarly to switching tensiometers (both in bypass mode) by reducing irrigation water by 70% on drip irrigated tomato in South Florida.

Carpena *et al*. (2005) found that both tensiometer and GMS controlled drip irrigation systems on tomato saved water when compared to typical farmer practice.

Bathan *et al*. (2013) designed and fabricated a Thermo-electric generator (TEG) and implemented an automated irrigation system using TEG as a soil moisture detector. The TEG inserted in two heat exchangers is capable of finding the thermal difference between the air and the soil that establishes a relationship with the soil's moisture condition. Being able to obtain the soil moisture level from the TEG's output, a microcontroller is used to automate the irrigation system. The irrigation system adapts to the soil area's condition it irrigates based from the moisture it detects via the TEG. The water consumption of the soil is controlled by the automated irrigation system based on the soil's condition and therefore, promotes water conservation compared to that of the water consumption of manual irrigation system. It also optimizes plant growth in that it waters it to the correct moisture level at the right time.

Verma *et al*. (2014) developed an automatic Irrigation System using DTMF (Dual Tone Multiple Frequency) technology for Indian farmers with a facility to operate a motor at a distant and controlled using microcontroller 8051. Temperature sensor and humidity sensor are connected to internal ports of micro controller via comparator, Whenever there is a change in temperature and humidity of the surroundings these sensors senses the change in temperature and humidity and gives an interrupt signal to the micro-controller and thus the motor is activated and if the power supply is off we can start the motor with the help of DTMF. This study represents the prototype design of microcontroller based automatic irrigation system which will allow irrigation to take place in zones where water is required, while by passing zones where adequate soil moisture is indicated.

2.5 Temperature and Humidity Sensors

In many systems, temperature control is fundamental. There are a number of passive and active temperature sensors that can be used to measure system temperature, including: thermocouple, resistive temperature detector, thermistor and silicon temperature sensors. These sensors provide temperature feedback to the system controller to make decisions such as, over-temperature shutdown, turn-on/off cooling fan, temperature compensation or general purpose temperature monitor. Microchip offers a broad portfolio of thermal management products, including Logic Output, Voltage Output and Serial Output Temperature Sensors. These products allow the system designer to implement the device that best meets their application requirements. Key features include high accuracy, low power, extended temperature range and small packages. In addition, Microchip's linear products can be used to support Thermocouple, RTD and Thermistor applications.

Air temperature and relative humidity probes typically consist of two separate sensors packaged in the same housing. Often relative humidity is measured with a capacitive RH .The humidity sensor just senses the humidity or the moisture of the soil. The change in humidity is proportional to the amount of current flowing through the soil. The humidity sensors available in market are too costly to be used for such small household applications. So for domestic purpose, we have designed a simple humidity sensor which works on the principle of conductivity of the soil.

2.5.1 Temperature and Humidity Sensor Based Irrigation

Gutiérrez *et al.* (2012) developed an automatic irrigation system using both soil moisture sensor and temperature sensor. In this system plant water status was monitored and irrigation is scheduledbased on canopytemperature distribution of the plant, whichwas acquiredwith thermal imaging.Other authors have reported the use of remote canopy temperature to automate cotton crop irrigation using infrared thermometers. Through a timed temperature threshold, automatic irrigation was triggered, once canopy temperatures exceeded the threshold for certain time accumulated per day. Automatic irrigation scheduling consistently has shown to be valuable in optimizing cotton yields and water use efficiency with respect to manual irrigation based on direct soil water measurements.

Kumar *et al.* (2012) water-saving irrigation system based on automatic control by using GSM technology.This system provides uniform and required level of water for the agricultural farm and it avoids water wastage by real time sensing and control irrigation system. When the condition of water in the agricultural farm is abnormal then the system automatically switches ON the motor. When the water level reaches normal level the motor automatically switch OFF. In this work they interface microcontroller through temperature sensor, humidity sensor and GSM.

Gunturi (2013), designed a micro controller based automatic plant irrigation system which consists of temperature and humidity sensors connected to internal ports of micro controller via comparator. Whenever there is a change in temperature and humidity of the surroundings, these sensors sense the change and give an interrupt signal to the micro controller and thus the sprinkler is activated. The system supplies water only when the humidity in the soil goes below the reference. Due to the direct transfer of water to the roots water conservation takes place and also helps to maintain the moisture to soil ratio at the root zone constant to some extent. Thus the system is efficient and compatible to changing environment.

Srinath (2014), implemented GSM based automatic irrigation control system which uses high sensitivity sensors. This system avoids over irrigation, under irrigation, top soil erosion and reduce the wastage of water. The main advantage is that the system's action can be changed according to the situation (crops, weather conditions, soil etc.).

Wireless technology using various sensors for precision agriculture has become a popular research with the greenhouse effect. People are utilizing the merits of embedded system into monitoring and control system for agriculture parameter. Monitoring parameters of temperature and humidity is an important means for obtaining high-quality environment. Remote monitoring is an effective method in order to avoid interference environment and improve efficiency. Recent advances in wireless sensor networking technology have led to the development of low cost, low power, multifunctional sensor nodes. Sensor nodes enable environment sensing together with data processing. Instrumented with a variety of sensors, such as temperature, humidity and volatile compound detection, allow monitoring of different environments. They are able to network with other sensor systems and exchange data with external users (Chavan and Karande, 2014)

Abdurrahman *et al*. (2015) automated sensor based irrigation management system in which humidity and temperature levels are transmitted at regular time interval to the LCD through a serial port for data display and analysis. The aim is to use the readily available material to construct low cost sensors. Relays are controlled by the microcontroller through the high current driver IC and provided for controlling solenoid valves, which controls the flow of water to different parts of the field. Other relay is used to shut-off the main motor which is used to pump the water to the field.

2.6 Arduino

Arduino is like a small computer which can be used for supplementing a number of operations for physical computing, of which here, irrigation automation is considered. There are many other microcontrollers and microcontroller platforms available for physical computing. Parallax Basic Stamp, Netmedia's BX-24, Phidgets, MIT's Handyboard, and many others offer similar functionality. All of these tools take the messy details of microcontroller programming and wrap it up in an easy-to-use package. Arduino also simplifies the process of working with microcontrollers.

Arduino boards are relatively inexpensive compared to other microcontroller platforms commonly available. The least expensive version of the Arduino module can be assembled by hand, and even the pre-assembled Arduino modules cost less than INR 3000.

The Arduino software runs on Windows, Macintosh OSX, and Linux operating systems whereas most microcontroller systems are limited to use in Windows. Arduino programming environment is easy-to-use for beginners, yet flexible enough for advanced users to take advantage of as well. For teachers, it's conveniently based on the Processing programming environment, so students learning to program in that environment will be familiar with the look and feel of Arduino.

The Arduino software is published as open source tools, available for extension by experienced programmers. The language can be expanded through C++ libraries, and people wanting to understand the technical details can make the leap from Arduino to the AVR C programming language on which it's based. Similarly, AVR-C code can be added directly into Arduino programs if required.

The Arduino is based on Atmel's ATMEGA8 and ATMEGA168 microcontrollers. The plans for the modules are published under a Creative Commons license, so experienced circuit designers can make their own version of the module, extending it and improving it. Even relatively inexperienced users can build the breadboard version of the module in order to understand how it works and save money.

2.5.1 Automation in Irrigation Using Arduino

Nagarajapandian *et al.* (2012) designed an automated irrigation mechanism which turns the pumping motor ON and OFF on detecting the dampness content of the earth. In the domain of farming, utilization of appropriate means of irrigation is significant. The benefit of employing these techniques is to decrease human interference and still make certain appropriate irrigation. This automated irrigation project brings into play an Arduino board ATmega328 micro-controller ,is programmed to collect the input signal of changeable dampness circumstances of the earth via dampness detecting system. Combined with the principle of rain water harvesting, it could lead to huge water savings if applied in the right manner. In agricultural lands with severe shortage of rainfall, this model can be successfully applied to achieve great results with most types of soil.

Devika *et al*. (2014) developed a prototype of automatic irrigation mechanism using Arduino board, which consists of ATmega328 Microcontroller. It is programmed in such a way that it will sense the moisture level of the plants and supply the water if required. This type of system is often used for general plant care, as part of caring for small and large gardens. Normally, the plants need to be watered twice daily, morning and evening. So, the microcontroller has to be coded to water the plants in the greenhouse about two times per day. The proto type reports status of its current conditions and also reminds the user to refill the water tank. The system automation is designed to be assistive to the user.

Njoroge (2014) developed a system to monitor moisture levels in the soil. The system was used to switch on/off the watering system/pump according to set soil moisture levels. The control unit the prototype was implemented using a microcontroller on arduino platform while the sensing bit was implemented using a SMS YL-69. Aim of the study was to use control engineering principles and concepts to provide a microcontroller based irrigation system. The system will help in saving money and water and at the same time increasing crops production. The system is programmed via the microcontroller to give interrupt signal to the irrigation system (drip, sprinkler, ditch etc.) depending on the soil moisture levels. The soil moisture/humidity levels are checked using soil moisture sensor. Whenever there is a change in moisture/humidity in the soil this sensor senses the change and gives an interrupt signal to the micro-controller and thus the watering system is activated or deactivated.

Table 2.1 A Summary of the Main Classes of Irrigation Scheduling Approaches, Indicating their Main Advantages and Disadvantages

	Advantages	**Disadvantages**
I. Soil water measurement		
(a) Soil water potential (tensiometers, psychrometers, etc.)	Easy to apply in practice; can be quite precise; at least water content measures indicate 'how much' water to apply; many commercial systems available; some sensors (especially capacitance and time domain	Soil heterogeneity requires many sensors (often expensive) or extensive monitoring programme (e.g. neutron probe); selecting position that is representative of the root-zone is difficult; sensors do not generally measure water status at

	sensors) readily automated	root surface (which depends on evaporative demand)
(b) Soil water content (gravimetric; capacitance/TDR; neutron probe)		
II. Soil water balance calculations		
(Require estimate of evaporation and rainfall)	Easy to apply in principle; indicate 'how much' water to apply	Not as accurate as direct measurement; need accurate local estimates of precipitation/runoff; evapotranspiration estimates require good estimates of crop coefficients (which depend on crop development, rooting depth, etc.); errors are cumulative, so regular recalibration needed
III. Plant 'stress' sensing		
(Includes both water status measurement and plant response measurement)	Measures the plant stress response directly; integrates environmental effects; potentially very sensitive	In general, does not indicate 'how much' water to apply; calibration required to determine 'control thresholds'; still largely at research/development stage and little used yet for routine agronomy (except for thermal sensing in some situations)
(a) Tissue water status	It has often been argued that leaf water status is the most appropriate measure for many	All measures are subject to homeostatic regulation (especially leaf water status), therefore not

	physiological processes (e.g. photosynthesis), but this argument is generally erroneous (as it ignores root–shoot signalling)	sensitive (isohydric plants); sensitive to environmental conditions which can lead to short-term fluctuations greater than treatment differences
(i) Visible wilting	Easy to detect	Not precise; yield reduction often occurs before visible symptoms; hard to automate
(ii) Pressure chamber (ψ)	Widely accepted reference technique; most useful if estimating stem water potential (SWP), using either bagged leaves or suckers	Slow and labour intensive (therefore expensive, especially for predawn measurements); unsuitable for automation
(iii) Psychrometer (ψ)	Valuable, thermodynamically based measure of water status; can be automated	Requires sophisticated equipment and high level of technical skill, yet still unreliable in the long term
(iv) Tissue water content (RWC, leaf thickness [γ- or β-ray thickness sensors], fruit or stem diameter)	Changes in tissue water content are easier to measure and automate than water potential measurements; RWC more directly related to physiological function than is total water potential in many cases; commercial micromorphometric sensors available	Instrumentation generally complex or expensive, so difficult to get adequate replication; water content measures (and diameter changes) subject to same problems as other water status measures; leaf thickness sensitivity limited by lateral shrinkage
(v) Pressure probe	Can measure the pressure component of water potential which is the driving force for xylem flow and much cell function (e.g. growth)	Only suitable for experimental or laboratory systems
(vi) Xylem cavitation	Can be sensitive to increasing	Cavitation frequency depends on

	water stress	stress prehistory; cavitation–water status curve shows hysteresis, with most cavitations occurring during drying, so cannot indicate successful rehydration
(b)Physiological responses	Potentially more sensitive than measures of tissue (especially leaf) water status	Often require sophisticated or complex equipment; require calibration to determine 'control thresholds'
(i)Stomatal conductance	Generally a very sensitive response, except in some anisohydric species	Large leaf-to-leaf variation requires much replication for reliable data
– Porometer	Accurate: the benchmark for research studies	Labour intensive so not suitable for commercial application; not readily automated (though some attempts have been made)
– Thermal sensing	Can be used remotely; capable of scaling up to large areas of crop (especially with imaging); imaging effectively averages many leaves; simple thermometers cheap and portable; well suited for monitoring purposes	Canopy temperature is affected by environmental conditions as well as by stomatal aperture, so needs calibration (e.g. using wet and dry reference surfaces)
– Sap-flow sensors	Sensitive	Only indirectly estimates changes in conductance, as flow is also very dependent on atmospheric conditions; requires complex instrumentation and technical expertise; needs calibration for each tree and for definition of irrigation control thresholds

(ii) Growth rate	Probably the most sensitive indicator of water deficit stress	Instrumentation delicate and generally expensive

CHAPTER 3

MATERIALS AND METHODS

3.1 GENERAL

3.1.1 LOCATION

The study was conducted at KCAET,Tavanur, in Malappuram district of Kerala. KCAET campus has geographical co-ordinates 10°51′5″North latitude and75°59′14″East longitude and is spread over an area of 40.99 ha.

3.1.2 CLIMATE

Agro climatically, Tavanur falls within the borderline of Northern zone and Central zone of Kerala. Major part of the rainfall in this region is obtained from South - West monsoon. The area has a relative humidity average of about 62%. The mean maximum temperature of the area is about 42.1°C and mean minimum temperature of the area is about 22°C.

3.1.3 SOIL

The subsurface strata in KCAET consist mainly of metamorphic origin. The principle formation of KCAET includes lateritic rock, lateritic soil and sandy soil. The thickness of various layers varies spatially in the campus. The top layer, i.e., the lateritic rock is present in the high elevation part of the campus only, whereas sandy soil is the top layer in the low-lying paddy fields in the North. The hydraulic conductivity of the soil used for the study (lateritic rock and lateritic soil) varies between $3.76*10^{-5}$ to $6*10^{-4}$ m/s.

3.2 ARDUINO

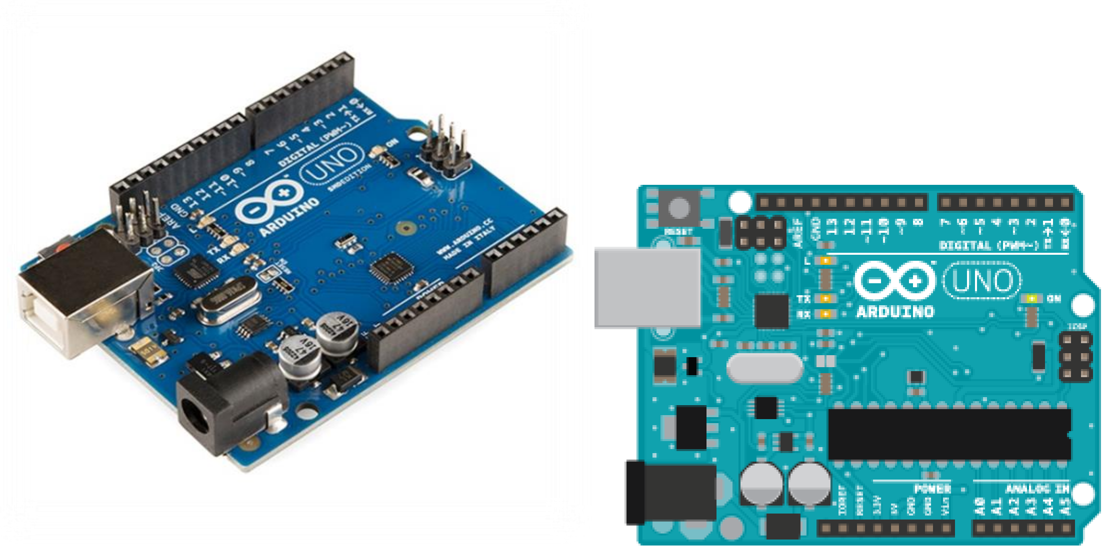

Fig. 3.1 Arduino Uno hardware

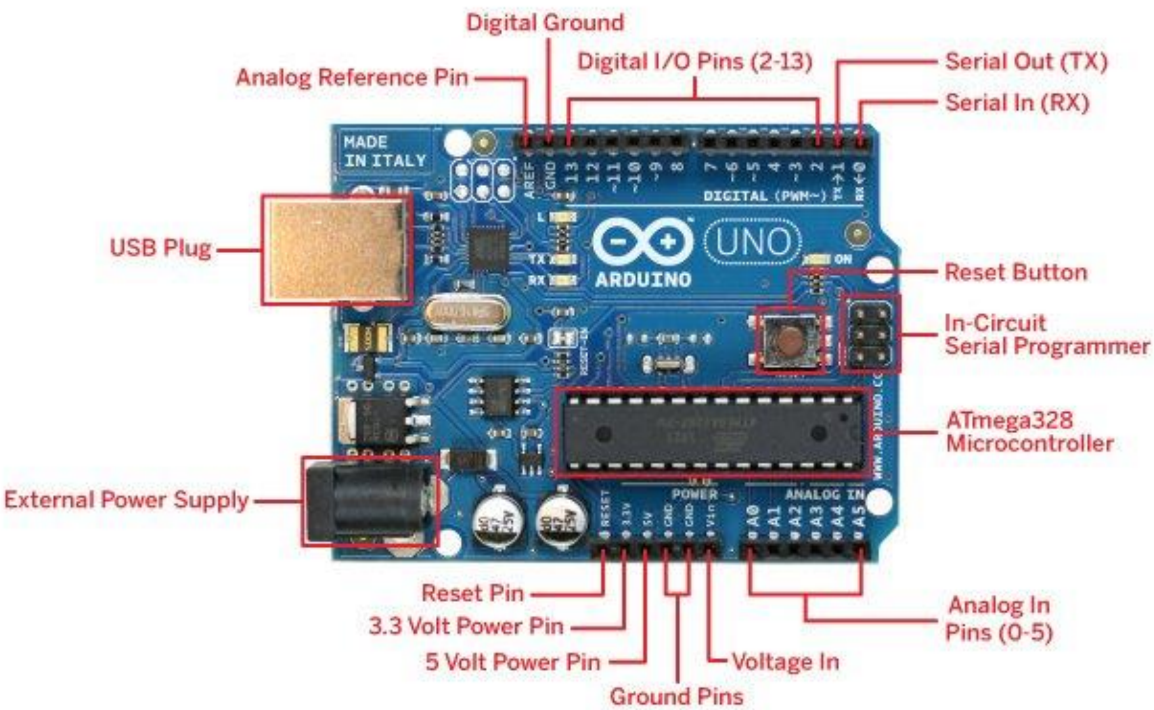

Fig. 3.2 Arduino Uno pin configuration

Arduino is an open-source electronics platform based on easy-to-use hardware and software intended for anyone making interactive products. The prototyping Arduinoboards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. One can tell the board what to do by sending a set of instructions to the microcontroller on the board. To do so the Arduinoprogramminglanguagebased on ‘Wiring’, (another development platform) is used, along with the Arduino Software (IDE), based on ‘Processing’ (a similar programming language).

The specifications of the Arduino Uno board used for the study are as follows.

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analogue Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by boot loader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
Length	68.6 mm
Width	53.4 mm
Weight	25 g

For the purpose of the study, the board was powered from the computer itself using which the coding was done. For field installations, the Uno board can be powered via the USB connection or with an external power supply.External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm centre-positive plug into the board's power jack. Leads from a battery can be inserted in the “GND” and “Vin” pin headers of the POWER connector.

The board can operate on an external supply from 6 to 20 volts. If supplied with less than 7 V, however, the 5V pin may supply less than five volts and the board may become unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

3.3 BREADBOARD

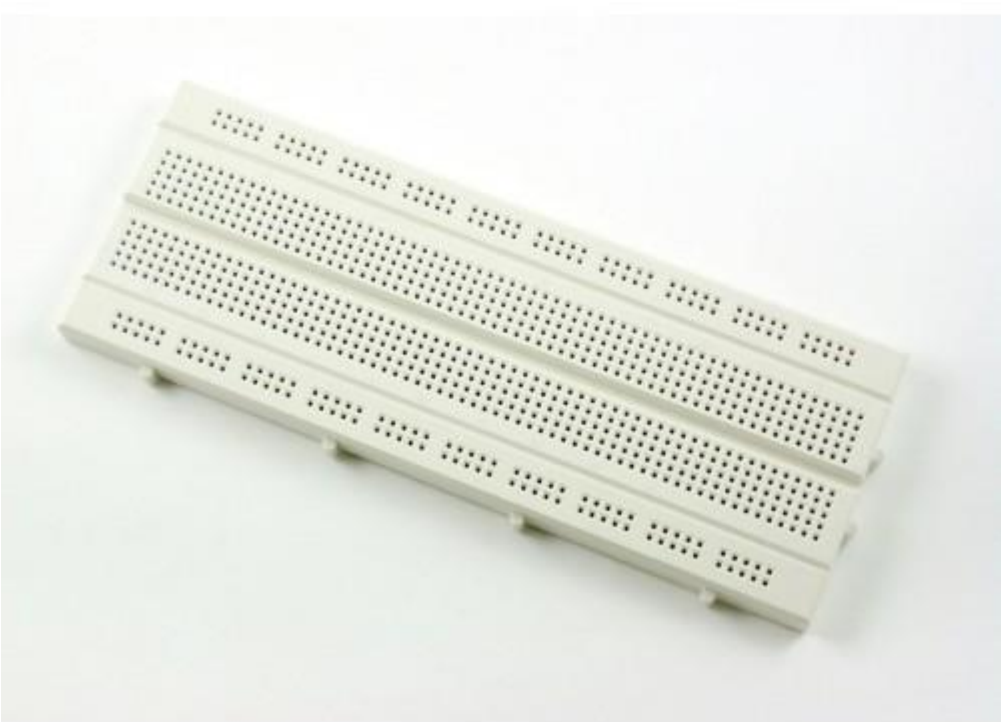

Fig 3.3 Breadboard

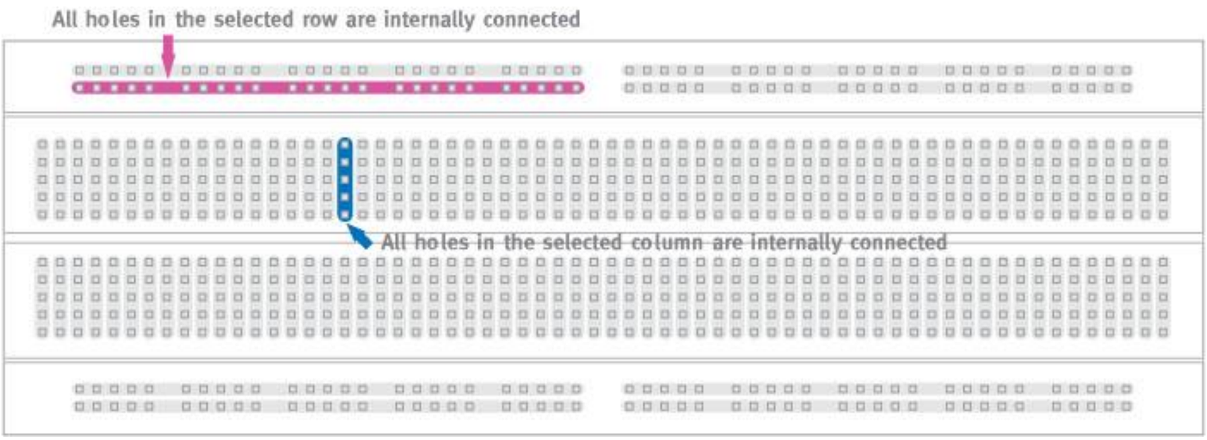

Fig 3.4 Breadboard connections

A breadboard is a construction base for prototyping of electronics without having to solder them. It is used to build and test circuits quickly before finalizing any circuit design. The breadboard has many holes into which circuit components like ICs and resistors can be inserted. The bread board has strips of metal which run underneath the board and connect the holes on the top of the board. The metal strips are laid out as shown above. The top and bottom rows of holes are connected horizontally while the remaining holes are connected vertically. A modern solder less breadboard consists of a perforated block of plastic with numerous tin platedphosphor bronze or nickel silver alloy spring clips under the perforations. The clips are often called tie points or contact points. The number of tie points is often given in the specification of the breadboard.

The spacing between the clips (lead pitch) is typically 0.1 in (2.54 mm). To use the bread board, the legs of components are placed in the holes. Each set of holes connected by a metal strip underneath forms a node. A node is a point in a circuit where two components are connected. Connections between different components are formed by putting their legs in a common node. The long top and bottom row of holes are usually used for power supply connections. The rest of the circuit is built by placing components and connecting them together withjumper wiresor solid conductor wires, for ease of use. Typically the spring clips are rated for 1 ampere at 5 volts and 0.333 amperes at 15 volts (5 watts).

Terminal strips are the main areas, to hold most of the electronic components. In the middle of a terminal strip of a breadboard, one typically finds a notch running in parallel to the long side. The notch is to mark the centreline of the terminal strip. The clips on the right and left of the notch are each connected in a radial way; typically five clips (i.e., beneath five holes) in a row on each side of the notch are electrically connected. The five clip columns on the left of the notch are often marked as A, B, C, D, and E, while the ones on the right are marked F, G, H, I and J.

Bus strips are to provide power to the electronic components. A bus strip usually contains two columns: one for ground and one for a supply voltage. However, some breadboards only provide a single-column power distributions bus strip on each long side. Typically the column intended for a supply voltage is marked in red, while the column for ground is marked in blue or black. Some manufacturers connect all terminals in a column. Others just connect groups of, for example, 25 consecutive terminals in a column. The breadboard used for the study is of this type. This design provides a circuit designer with some more control and flexibility in designing the circuit. Bus strips typically run down one or both sides of a terminal strip or between terminal strips. On large breadboards additional bus strips can often be found on the top and bottom of terminal strips.

3.4 JUMPER WIRES

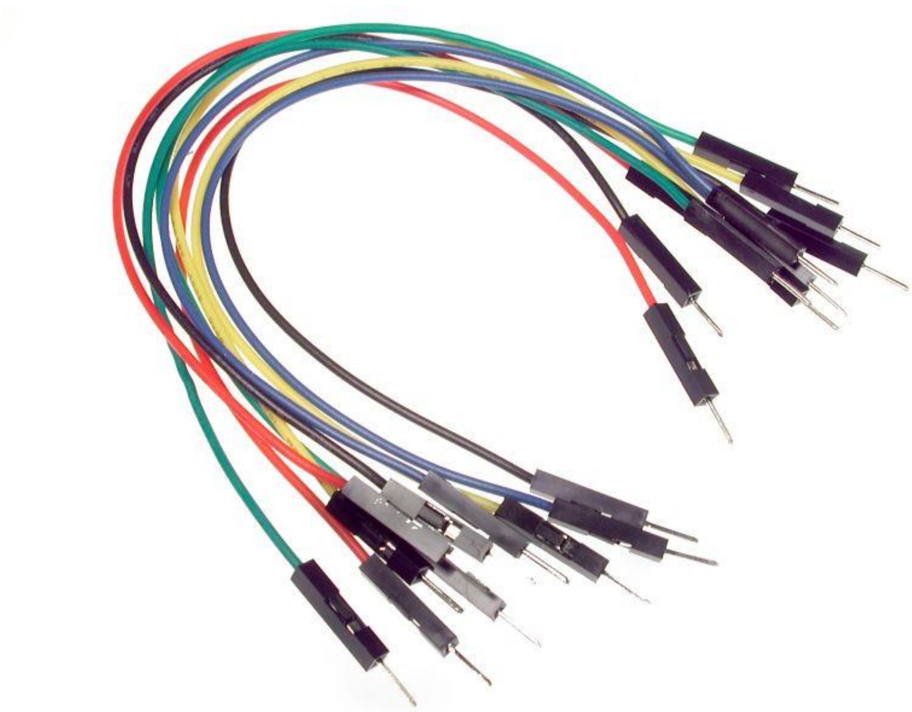

Fig. 3.5 Jumper wires (male - to - male)

A jumper wire (or simply jump wire) is a short electrical wire with a solid tip at each end (or sometimes without them, simply tinned), which is normally used to interconnect the components in a breadboard. They are used to transfer electrical signals from anywhere on the breadboard to the input/output pins of a microcontroller.Jump wires are fitted by inserting their end connectors into the slots provided in the breadboard that beneath its surface has a few sets of parallel plates that connect the slots in groups of rows or columns depending on the area. The end connectors are inserted into the breadboard, without soldering, in the particular slots that need to be connected in the specific prototype.For the purpose of the study, jumper wires with insulated terminals were used. When using those with insulated solid tips the arrangement of the elements and ease of insertion of the insulated jump wire connectors on the breadboards allows increasing the mounting density of both -components and jump wires- without fear of short-circuits. The jumper wires vary in size and colour to distinguish the different working signals. Variation of jump wires with insulated terminals as per male-female combinations:

a) Male to Male (solid tips at both ends)

b) Male to Female (solid tip at one end and slot at the other end)

c) Female to Female (slots at both ends)

3.5 SOIL MOISTURE SENSOR

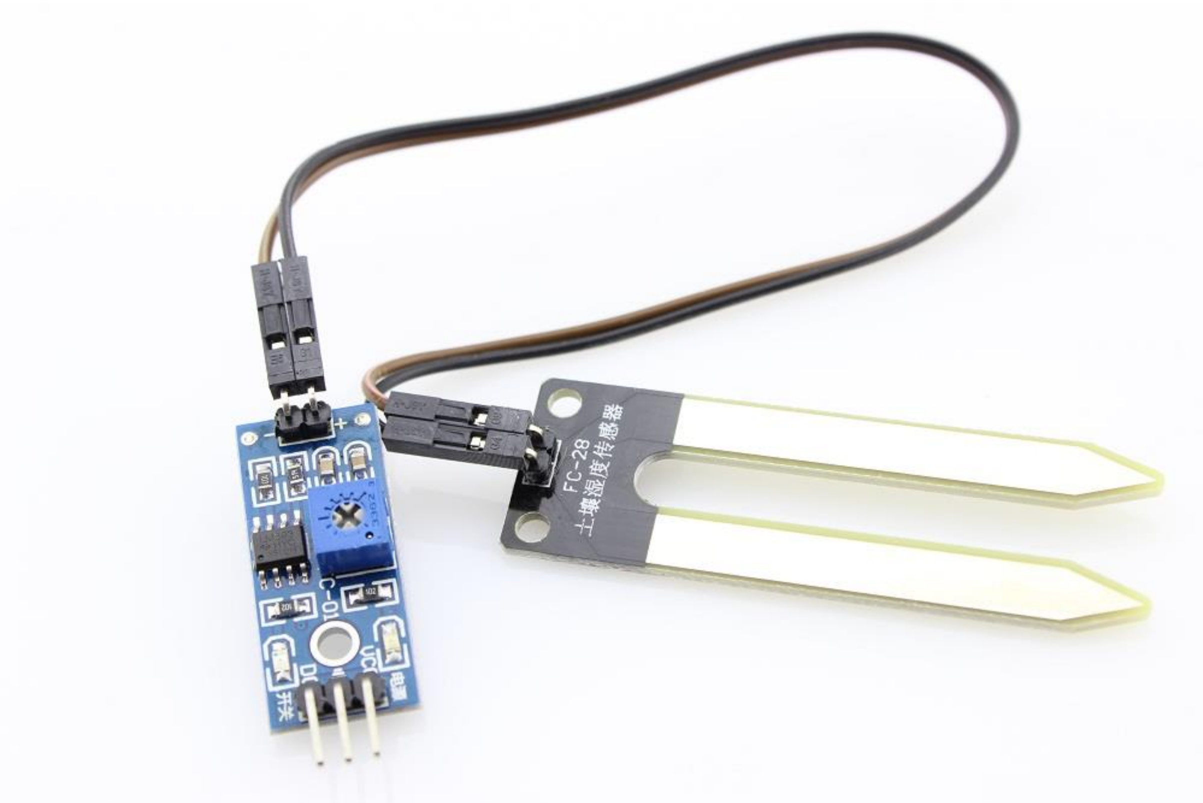

Fig. 3.6 Soil moistures Sensor

The soil moisture sensor was used to measure the water content(moisture) of soil. It shows the deficit of soil moisture, i.e., in open air, the sensor shows a reading of 99% to 100% whereas when dipped in soil, the value lowers according to the amount of water in the soil being sensed. The soil moisture sensor uses capacitance to measure dielectric permittivity of the surrounding medium. In soil, dielectric permittivity is a function of the water content. The sensor creates a voltage proportional to the dielectric permittivity, and therefore the water content of the soil. The sensor averages the water content over the entire length of the sensor. There is a 2 cm zone of influence with respect to the flat surface of the sensor, but it has little or no sensitivity at the extreme edges. The sensor is commonly used to measure the loss of moisture over time due to evaporation and plant uptake, evaluate optimum soil moisture contents for various species of plants, monitor soil moisture content to control irrigation in greenhouses and enhance bottle biology experiments.

One commonly known issue with soil moisture sensors is their short lifespan when exposed to a moist environment. To combat this, sensors with the probe coated in gold finishing (ENIG or Electroless Nickel Immersion Gold) were used. The soil moisture sensor uses an LM393 chipset with a working voltage of 3.3V-5V and having a fixed screw hole for easy installation. The sensor weighs 21 g and has dimensions 43 mm x 14 mm x 0.8 mm.

3.6 HUMIDITYAND TEMPERATURE SENSOR

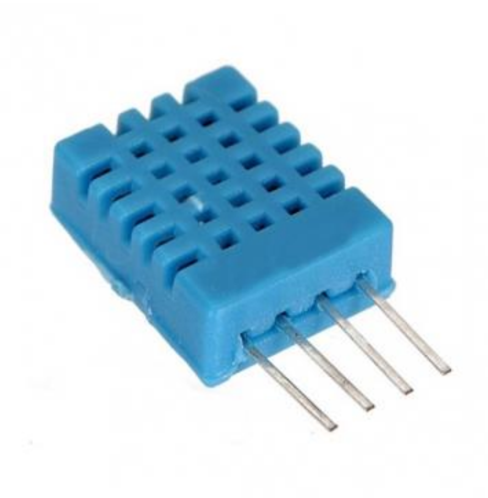

Fig. 3.7 Humidity and temperature sensor

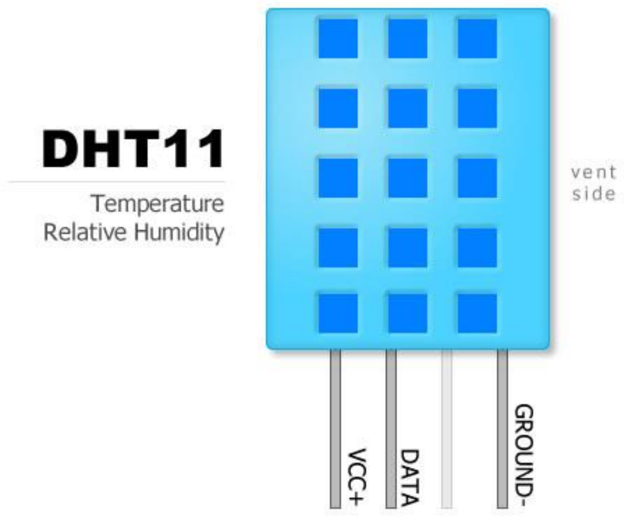

Fig. 3.8 Humidity and temperature sensor pin configuration

This DFRobot DHT11 Humidity and Temperature Sensor feature a temperature & humidity sensor complex with a calibrated digital signal output. By using the exclusive digital-signal-acquisition technique and temperature & humidity sensing technology, it ensures high reliability and excellent long-term stability. This sensor includes a resistive-type humidity measurement component and an NTC temperature measurement component, and connects to a high performance 8-bit microcontroller, offering excellent quality, fast response, anti-interference ability and cost-effectiveness.

Each DHT11 element is strictly calibrated in the laboratory by the manufacturer and the calibration coefficients are stored as programmes in the OTP memory, which are used by the sensor's internal signal detecting process. The single-wire serial interface makes system integration quick and easy. Its small size, low power consumption and up-to-20 meter signal transmission making it the best choice for various applications, including those most demanding ones. The component is 4-pin single row pin package. It is convenient to connect and easy to use even for novices in electronics.

The specifications of the Humidity and Temperature Sensor are as follows:

Table 3.1 Specifications of humidity and temperature sensor

Item	Measurement Range	Humidity Accuracy	Temperature Accuracy	Resolution	Package
DHT11	20-90%RH 0-50 ℃	±5%RH	±2℃	1	4 Pin Single Row

Parameters	**Conditions**	**Minimum**	**Typical**	**Maximum**
Humidity				
Resolution		1%RH	1%RH	1%RH
			8 Bit	
Repeatability			±1%RH	
Accuracy	25℃		±4%RH	
	0-50℃			±5%RH
Interchangeability	Fully Interchangeable			
Measurement Range	0℃	30%RH		90%RH
	25℃	20%RH		90%RH
	50℃	20%RH		80%RH
Response Time (Seconds)	1/e(63%)25℃, 1m/s Air	6 S	10 S	15 S
Hysteresis			±1%RH	
Long-Term Stability	Typical		±1%RH/year	
Temperature				

Resolution		1℃	1℃	1℃
		8 Bit	8 Bit	8 Bit
Repeatability			±1℃	
Accuracy		±1℃		±2℃
Measurement Range		0℃		50℃
Response Time (Seconds)	1/e(63%)	6 S		30 S

3.7 LCD

Fig 3.9 LCD front side

Fig 3.10 LCD back side

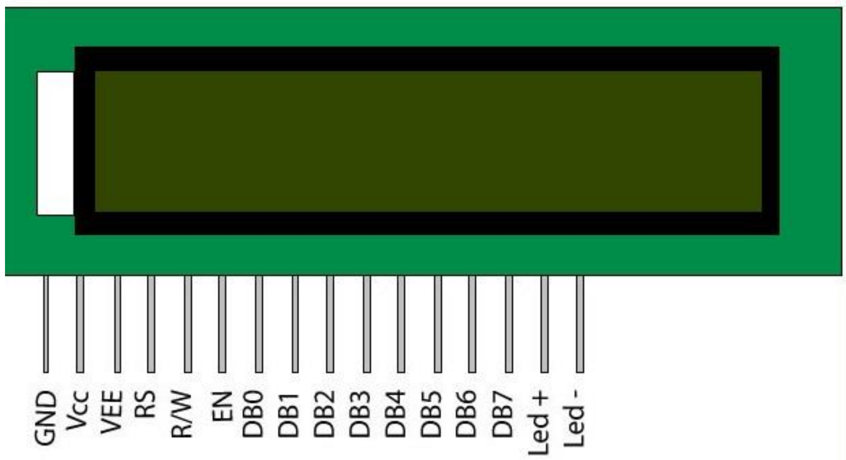

Fig 3.11 LCD pin configuration

The 2x16 Liquid Crystal Display screen is an electronic display module and find a wide range of applications. A 2x16 LCD is very basic module and is very commonly used in various devices and circuits. These modules are preferred over seven segments and other multi segment LEDs. The reasons being: LCDs are economical; easily programmable; have no limitation of displaying special & even custom characters (unlike in seven segments), animations and so on.

A 2x16LCD means it can display 16 characters per line and there are 2 such lines. In this LCD each character is displayed in 5x7 pixel matrix. This LCD has two registers, namely, Command and Data. The command register stores the command instructions given to the LCD. A command is an instruction given to LCD to do a predefined task like initializing it, clearing its screen, setting the cursor position, controlling display etc. The data register stores the data to be displayed on the LCD. The data is the ASCII value of the character to be displayed on the LCD.

In this study, the LCD was used to display the number of hours left to start the next irrigation, according to the existing conditions of soil moisture, relative humidity and temperature as sensed by the corresponding sensors.

3.8 SOLENOID VALVE

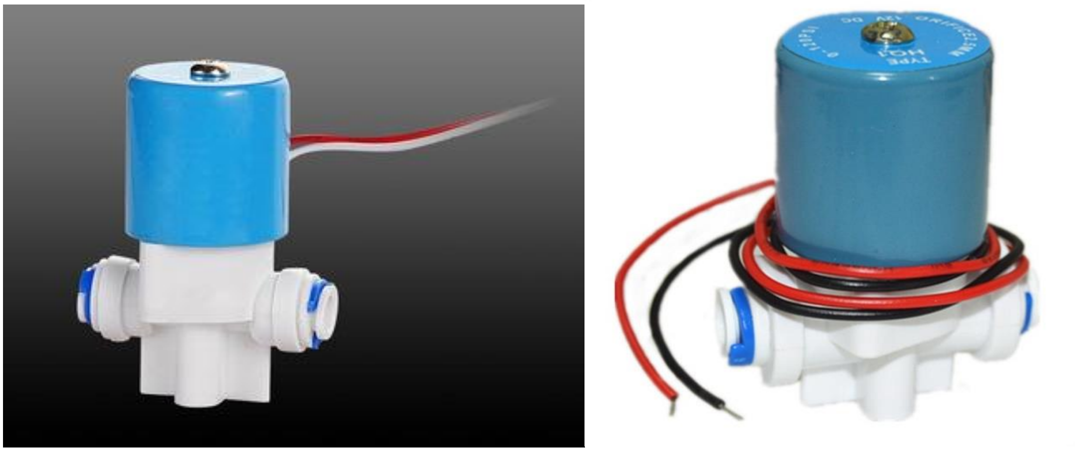

Fig 3.12 Solenoid valve

A solenoidvalve is an electromechanically operated valve. The valve is controlled by an electric current through a solenoid: in the case of a two-port valve the flow is switched on or off; in the case of a three-port valve, the outflow is switched between the two outlet ports. Multiple solenoid valves can be placed together on a manifold.

Solenoid valves are the most frequently used control elements in fluidics. Their tasks are to shut off, release, dose, distribute or mix fluids. They are found in many application areas.

Solenoids offer fast and safe switching, high reliability, long service life, good medium compatibility of the materials used, low control power and compact design.

Besides the plunger-type actuator which is used most frequently, pivoted-armature actuators and rocker actuators are also used.

While there are multiple variants of solenoid valve, the following is the breakdown of the working principle of the solenoid valve used for the study.

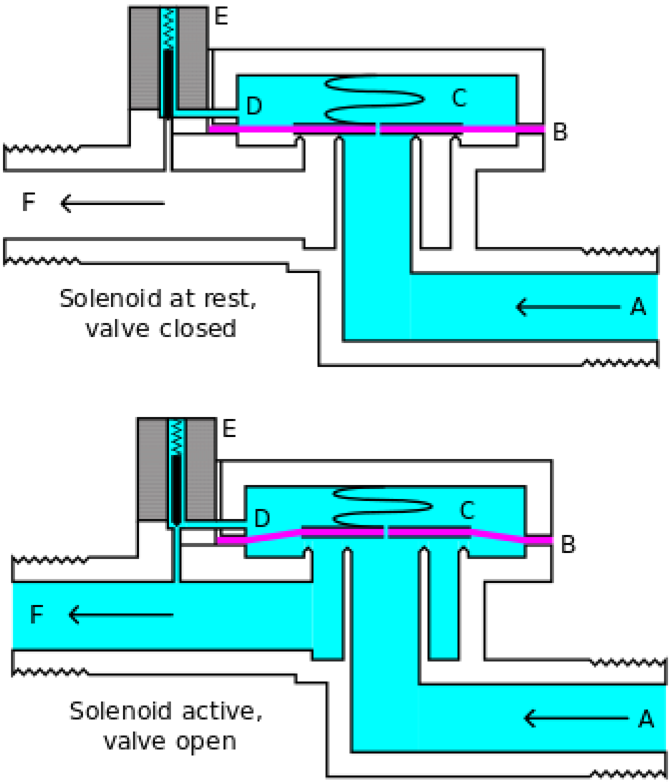

Fig.3.13 working principle of solenoid valve

A - Input side

B - Diaphragm

C – Pressure Chamber

D – Pressure Relief Passage

E – Solenoid

F- Output Side

A solenoid valve has two main parts: the solenoid and the valve. The solenoid converts electrical energy into mechanical energy which, in turn, opens or closes the valve mechanically. A direct acting valve has only a small flow circuit, shown within section E of this diagram (this section is mentioned below as a pilot valve). In this example, a diaphragm piloted valve multiplies this small pilot flow, by using it to control the flow through a much larger orifice.

Solenoid valves may use metal seals or rubber seals, and may also have electrical interfaces to allow for easy control. A spring may be used to hold the valve opened (normally open) or closed (normally closed) while the valve is not activated.

The diagram to the right shows the design of a basic valve, controlling the flow of water in this example. At the top figure is the valve in its closed state. The water under pressure enters at A. B is an elastic diaphragm and above it is a weak spring pushing it down. The diaphragm has a pinhole through its centre which allows a very small amount of water to flow through it. This water fills the cavity C on the other side of the diaphragm so that pressure is equal on both sides of the diaphragm; however the compressed spring supplies a net downward force. The spring is weak and is only able to close the inlet because water pressure is equalized on both sides of the diaphragm.

Once the diaphragm closes the valve, the pressure on the outlet side of its bottom is reduced, and the greater pressure above holds it even more firmly closed. Thus, the spring is irrelevant to holding the valve closed.

The above all works because the small drain passage D was blocked by a pin which is the armature of the solenoid E and which is pushed down by a spring. If current is passed through the solenoid, the pin is withdrawn via magnetic force, and the water in chamber C drains out the passage D faster than the pinhole can refill it. The pressure in chamber C drops and the incoming pressure lift the diaphragm, thus opening the main valve. Water now flows directly fromA to F.

When the solenoid is again deactivated and the passage D is closed again, the spring needs very little force to push the diaphragm down again and the main valve closes. In practice there is often no separate spring; the elastomer diaphragm is moulded so that it functions as its own spring, preferring to be in the closed shape.

It can be seen that this type of valve relies on a differential of pressure between input and output as the pressure at the input must always be greater than the pressure at the output for it to work. Should the pressure at the output, for any reason, rise above that of the input, then the valve would open regardless of the state of the solenoid and pilot valve.

The specifications of the solenoid valve used for the study are as follows.

Model No.:SLC 2 in SLC Series

Type:2-way normally closed, direct acting

Size:1/4 in

Orifice size:2.5mm

Response time:6-20MSEL

Fluid media: Water

Power consumption:AC 6.8VA(Holding), DC 5W

Voltage:AC 24V 110V 220V 50/60HZ, DC 24V

Operating Pressure: 120 PSI (AC and DC)

The red wire shows the positive terminal and the white wire shows the negative terminal of the solenoid valve.

3.9 NPN TRANSISTOR

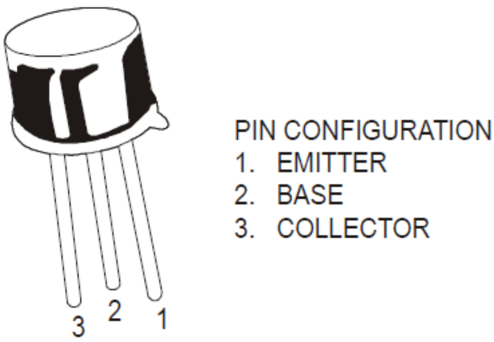

Fig 3.14 NPN transistor and its pin configuration

NPN is one of the two types of bipolar transistors, consisting of a layer of P-doped semiconductor (the "base") between two N-doped layers. A small current entering the base is amplified to produce a large collector and emitter current. That is, when there is a positive potential difference measured from the emitter of an NPN transistor to its base (i.e., when the base is high relative to the emitter) as well as positive potential difference measured from the base to the collector, the transistor becomes active. In this "on" state, current flows between the collector and emitter of the transistor. Most of the current is carried by electrons moving from emitter to collector as minority carriers in the P-type base region. To allow for greater current and faster operation, most bipolar transistors used today are NPN because electron mobility is higher than holemobility. The purpose of the NPN transistor in the circuit for the study is to check the supply of current to the solenoid valve as and when required. A CDIL CK100 transistor of 20V rating and ability to pass current greater than 0.8A.

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3.10 RELAY

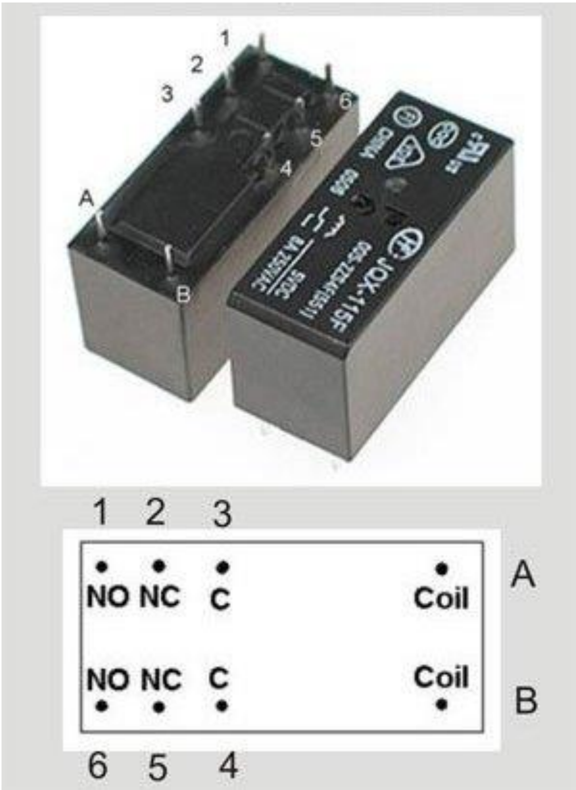


Fig. 3.15 5V double pole relay

A relay is an electrically operated switch. Many relays use an electromagnet to mechanically operate a switch, but other operating principles are also used, such as solid-state relays. Relays are used where it is necessary to control a circuit by a low-power signal (with complete electrical isolation between control and controlled circuits), or where several circuits must be controlled by one signal.

A simple electromagnetic relay consists of a coil of wire wrapped around a soft iron core, an iron yoke which provides a low reluctance path for magnetic flux, a movable iron armature, and one or more sets of contacts (there are two in the relay pictured). The armature is hinged to the yoke and mechanically linked to one or more sets of moving contacts. It is held in place by a spring so that when the relay is de-energized there is an air gap in the magnetic circuit. In this condition, one of the two sets of contacts in the relay pictured is closed, and the other set is open. Other relays may have more or fewer sets of contacts depending on their function. The relay in the picture also has a wire connecting the armature to the yoke. This ensures continuity of the circuit between the moving contacts on the armature, and the circuit track on the printed circuit board (PCB) via the yoke, which is soldered to the PCB.

When an electric current is passed through the coil it generates a magnetic field that activates the armature and the consequent movement of the movable contact either makes or breaks (depending upon construction) a connection with a fixed contact. If the set of contacts was closed when the relay was de-energized, then the movement opens the contacts and breaks the connection, and vice versa if the contacts were open. When the current to the coil is switched off, the armature is returned by a force, approximately half as strong as the magnetic force, to its relaxed position. Usually this force is provided by a spring, but gravity is also used commonly in industrial motor starters. Most relays are manufactured to operate quickly. In a low-voltage application this reduces noise; in a high voltage or current application it reduces arcing.

When the coil is energized with DC, a diode is often placed across the coil to dissipate the energy from the collapsing magnetic field at deactivation, which would otherwise generate a voltage spike dangerous to semiconductor circuit components. Such diodes were not widely used before the application of transistors as relay drivers, but soon became ubiquitous as early germanium transistors were easily destroyed by this surge. Some automotive relays include a diode inside the relay case.

If the coil is designed to be energized with AC, some method is used to split the flux into two out-of-phase components which add together, increasing the minimum pull on the armature during the AC cycle. Typically this is done with a small copper "shading ring" crimped around a portion of the core that creates the delayed, out-of-phase component, which holds the contacts during the zero crossings of the control voltage.

A solidstaterelay or SSR is a solid state electronic component that provides a function similar to an electromechanical relay but does not have any moving components, increasing long-term reliability. A solid-state relay uses a solid-state switching device, activated by the control signal, to switch the controlled load, instead of a solenoid.

As every solid-state device has a small voltage drop across it, this voltage drop limits the amount of current a given SSR can handle. The minimum voltage drop for such a relay is a function of the material used to make the device.

The relay used in the study is a 5V, double pole relay and is used for the purpose of switching the solenoid valve on and off, according to the output voltage supplies by the transistor.

3.11 FLYBACK DIODE

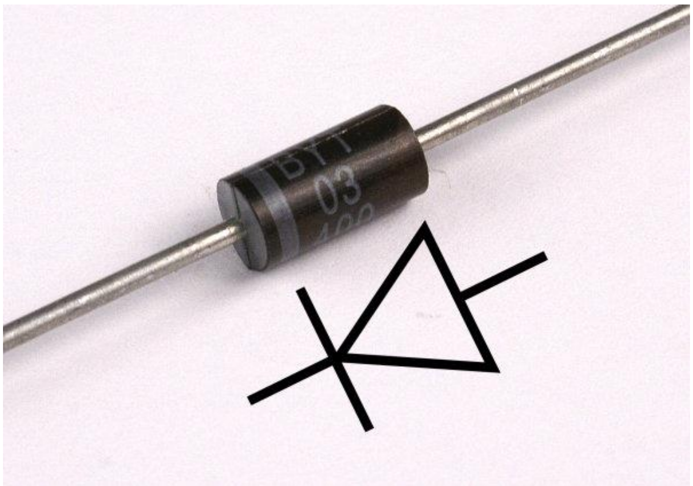


Fig 3.16 Flyback diode

A "freewheeling diode", also called a flyback diode, snubber diode, suppressor diode, clamp diode or catch diode) is a diode used to eliminate flyback, which is the sudden voltage spike seen across an inductive load when its supply voltage is suddenly reduced or removed. It is put into a circuit to protect the switching device from being damaged by the reverse current of an inductive load. It is normally placed in a circuit so that it does not conduct when the current is being supplied to the inductive load. When the current flow to an inductor is suddenly interrupted, the inductor tries to maintain the current by reversing polarity and increasing the voltage. Without the freewheeling diode the voltage can go high enough to damage the switching device, which is the 5V relay mentioned earlier. With it, the reverse current is allowed to flow through the diode and dissipates, so that any damage likely to be caused to the circuit components due to the reverse current, is prevented.

3.12 RESISTORS

Fig 3.17 1000 Ohm resistor

Fig 3.18 220 Ohm resistor

A resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element. Resistors act to reduce current flow, and, at the same time, act to lower voltage levels within circuits. In the circuit for the study, one 220 ohm and one 1000 ohm resistor was used for the purpose of controlling the voltage in the circuit according to the voltage rating of the other components to facilitate their smooth functioning.

3.13 CORE CUTTER

Fig 3.19 Core cutter, dolly and rammer

The core cutter was used for calibrating the soil moisture sensor for the soil used for the study. The core cutter has a cylindrical core consisting of a seamless steel tube of 100 mm internal diameter, 3mm of wall thickness and 120 mm of length. One end of steel tube is bevelled as shown in the figure. The cutter was greased on the inside prior to the experiment. Thee steel dolly consists of steel tube of having 100 mm internal diameter, 7.5 mm of wall thickness and 25 mmin length. Empty weight of the core cutter was measured.

3.14 SOIL CHARACTERISTICS DETERMINATION

Plate 3.1 Soil sampling using core cutter

To find out soil characteristics, core cutter method was employed.The area from where soil was to be taken into the core cutter was carefully cleaned and levelled. Then the core was driven into the soil using a rammer weighing about 9kg with a staff length of 900 mm. The core was excavated with extreme care so as to not disturb the soil inside it. The top and bottom surfaces of the core cutter were trimmed and it was weighed again. Three such samples were taken and weighed and then saturated with water. They were kept in the lab without any disturbance for 24 hours to attain field capacity. Field capacity weight of the three samples were taken and then they were kept in a drying oven at 105°C for 24 hours for complete drying to find out the permanent wilting point. The quantity of available water was found out from this experiment as follows:

Water Content = Field capacity – Amount of water in complete dry condition

3.15 CALCULATIONOF MASS WETNESS AND VOLUME WETNESS

Let W_1 be the weight of the core, W_2 be the weight of the moist soil along with core, and W3 be the weight of dry soil with core.

Bulk density, $B_d = M_s/V_t$

where,M_s is the mass of soil and Vt is the total volume

Mass wetness, $Pw = M_w/M_s$

$= (W_2 – W_3)/(W_3-W_1)$

where, Mw is the mass of water present.

Volume wetness, $P_V = P_W * B_d$

$= (W_1 – W_2)/(\pi r^2 h * d_W)$

Where,d_W is the density of water which is equal to 1g/cc and r and h are the height and radius of the core cutter respectively.

The average volume wetness of three samples should be found out in order to calculate MAD

Management Allowable Depletion: MAD is the maximum amount of Plant Available Water (PAW) allowed to be removed from the soil before irrigation refill occurs. Increased surface evaporation of water and usually higher rates of transpiration are associated with high frequency irrigation. It is best suited to irrigate only when the root zone has reached MAD. For most landscape purposes, 50% MAD represents a reasonable overall value; for sensitive, shallow rooted plants, or heavy compacted soils, a smaller depletion should be considered (30-50% MAD). For stress-tolerant plants, deep root zones or lighter soils, a large depletion can be used (50-70% MAD).

Here, the value of 50% of average volume wetness is taken as MAD. This value is substituted in the equation obtained by averaging the equations of calibration curves (soil moisture deficit v/s volume wetness) of three soil samples. So we get the sensor value at which the irrigation has to be started.

3.16 CALCULATION OF EVAPOTRANSPIRATION RATE

Evapotranspiration or consumptive use is the sum of two terms: (1) transpiration, which is the water entering the plant roots and used to build plant tissue or being passed through the leaves of the plant into atmosphere; and (2) evaporation, which is the water evaporating from adjacent soil, water surfaces, or plant foliage.

Evaporation pan method

A close relation exists between the rates of evaporation from a well located evaporation pan. This correlation indicates that measurements of pan evaporation are useful for scheduling irrigation. Evaporation pan data are approximations of consumptive use and are not measurements of soil moisture. The amount of soil moisture used in a given period must be calculated. This can be done by applying the factor for the crop to be irrigated to the amount of water, or depth of water evaporated from the pan during that period. In other words,

Evapotranspiration = pan evaporation * crop coefficient

Crop coefficient: It is the ratio coefficient between maximum evapotranspiration and actual evapotranspiration. For common cultivated crops the value of crop factor usually ranges from 0.9 to 1.2.

3.17 CALCULATION OF AVERAGE TEMPERATURE

Here, average temperature is calculated by taking the maximum and minimum temperature values taken from the data collected from meteorological observatory given in Appendix I.

3.18 CALCULATION OF RELATIVE HUMIDITY

If the wet bulb and dry bulb temperature are known, RH can be determined. Huang Y. *et al.* (2013) deduced a theoretical formula for the calculation of relative humidity from dry bulb and wet bulb temperature. The principle of psychrometric hygrometry is that the humidity is calculated by the dry and wet bulb equation according to the wet bulb and dry bulb temperatures. The dry and wet bulb equation is:

$$\mathrm{Hr} = ((\mathrm{e_w} - \mathrm{A} * \mathrm{P} * \Delta \mathrm{t})/\mathrm{e_d}) * 100) \qquad (3.1)$$

where, Hr = the relative humidity

e_w = The saturation vapor pressure in the wet-bulb temperature

e_d = The saturation vapor pressure in the dry-bulb temperature

A = the measuring humidity coefficient

P = the mean atmospheric pressure

Δt = the difference between the dry-bulb temperature (Td) and the wet-bulb

temperature (Tw), (assumed to be Td - Tw)

In this study, we use the Buck formula (Buck, 1981) to calculate $e_w$ande_d. The Buck formula is as follows:

$$E = 6.112 * e^{\frac{(17.502 * t)}{240.97+t}} \qquad (3.2)$$

According to formula (3.2), we can gete_w ande_d. They are:

$$e_w = 6.112 * e^{\frac{(17.502 * T_W)}{(240.97 + T_W)}} \qquad (3.3)$$

$$e_d = 6.112 * e^{\frac{(17.502 * T_D)}{(240.97 + T_D)}} \qquad (3.4)$$

A is the conversion factor which can be calculated by empirical formula (Butler and García-Suárez, 2012):

$$A = 0.00066 * (1 + 0.00115 * T_W)(3.5)$$

When P is the mean atmospheric pressure (assumed to be 1013.25024 mb), substituting formulas (3), (4) and (5) into formula (1), we have:

$$H_r = \frac{6.112 * e^{\frac{17.502 * T_W}{240.97 + T_W}} - 0.00066 * (1\ 0.00115 * T_W) * P * (T_D - T_W)}{6.112 * e^{\frac{17.502 * T_D}{240.97 + T_D}}} * 100 \qquad (3.6)$$

Equation (3.6) is taken for the calculation of RH.

3.19 ASSEMBLING OF ARDUINO CIRCUIT

A suitable circuit diagram was designed as per the requirements, components and their ratings.

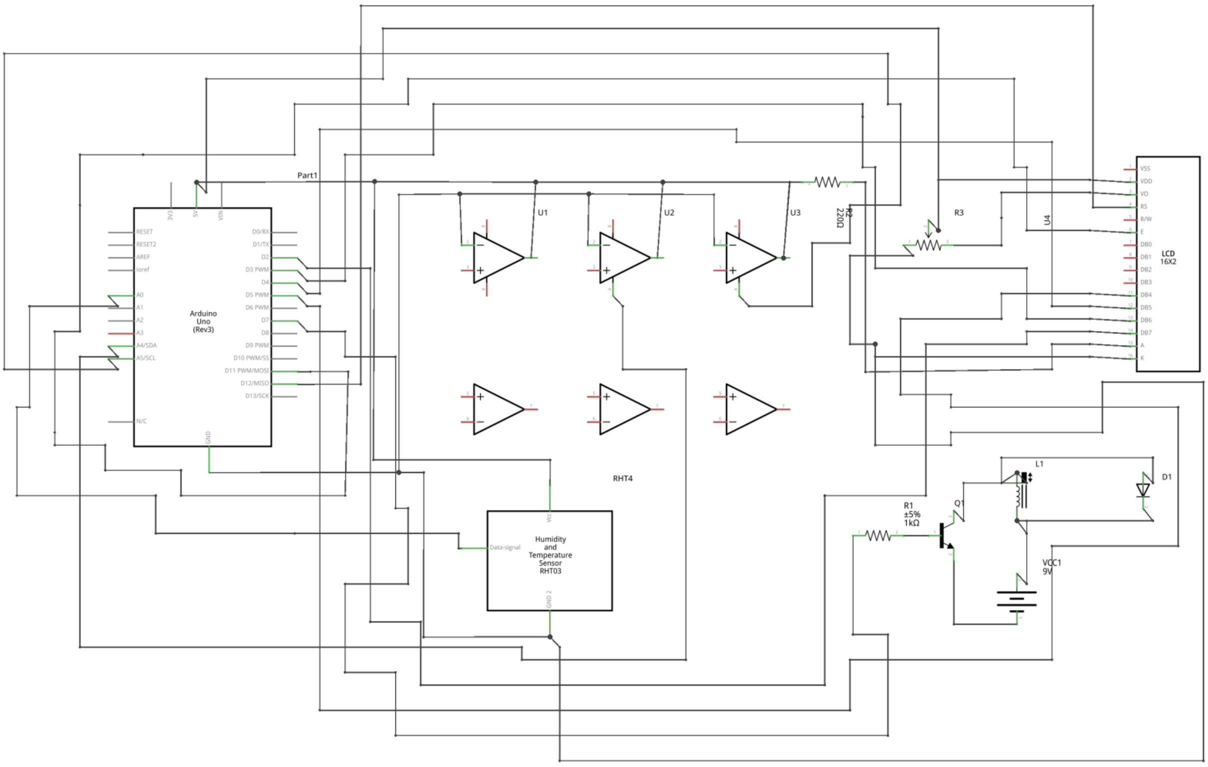


Fig 3.20 Circuit diagram to operate all components of the irrigation system

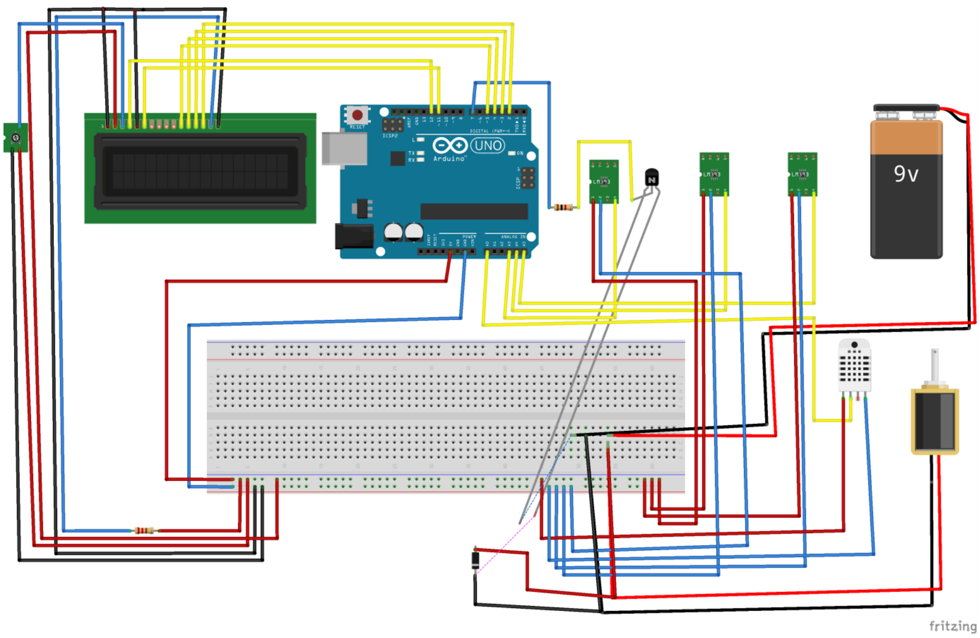


Fig. 3.21 Diagrammatic representation of the circuit

Initially for the purpose of testing, the circuit was assembled with only the Arduino and the soil moisture sensor and the humidity sensor. A suitable code was written in the Arduino language which is based on C/C++ and the sensors were tested.

3.20 CALIBRATION OF SOIL MOISTURE SENSORS

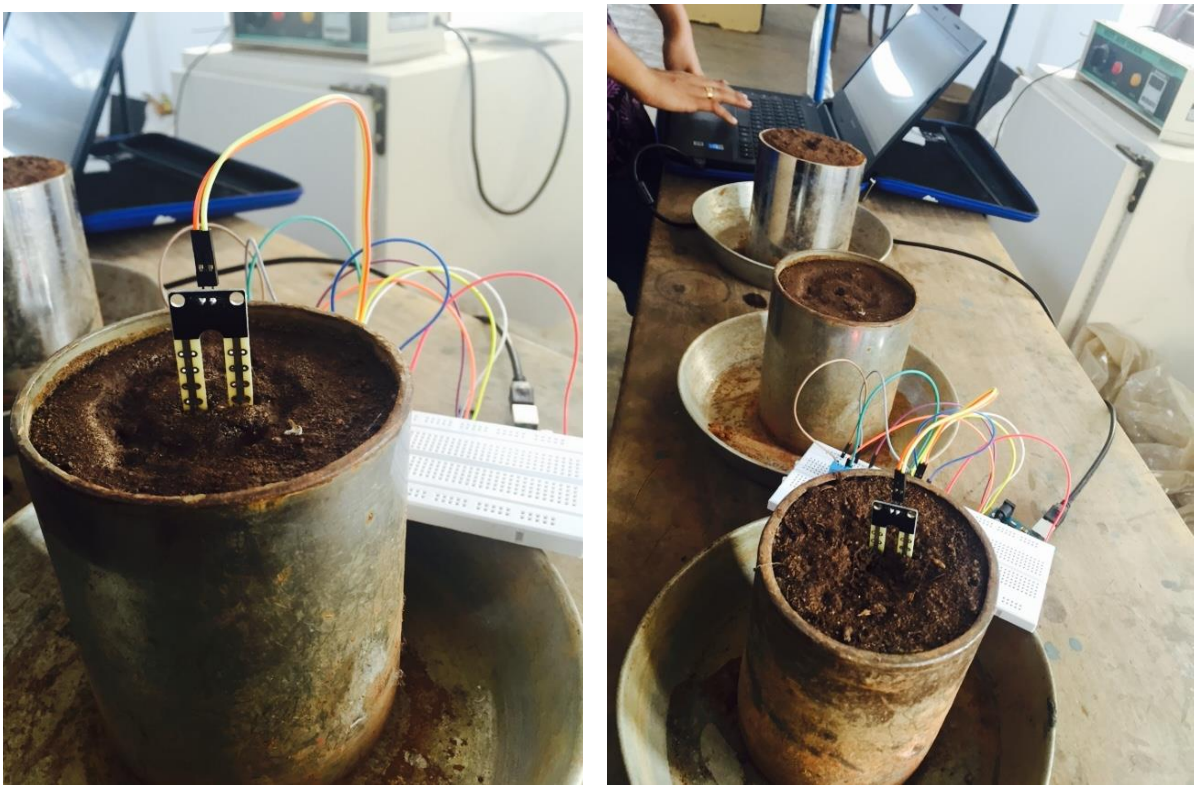


Plate 3.2 Calibration of soil moisture sensors in the lab in undisturbed soil sample

The next step is the calibration of the soil moisture sensor. The sensor for detecting soil moisture was connected to the Arduino using a breadboard and was inserted in the soil samples in the core cutters. The amount of available water was poured to the respective core cutters after splitting it into 8 parts. Each time, the soil moisture sensor was allowed to show a stable reading. This reading was noted down for all the three sensors. Then, calibration curves were drawn with volume wetness on the x axis and soil moisture deficit on the y axis with the help of Microsoft Excel. From these curves, the points where irrigation has to be started and stopped was found out. Starting and stopping of irrigation was done using the help of solenoid valve.

3.21 DISPLAYS IN THE LCD SCREEN

The next step was to find out a method to display in the LCD, the time left until the next irrigation cycle starts, according to the existing conditions of soil moisture, temperature and humidity.

The average value of available water from three core cutters was found.

Time left until next irrigation starts is obtained by multiplying the average value of available water with percentage of moisture in the soil and dividing it by the area in which the irrigation is to be done, and dividing this throughout with the evapotranspiration occurring in the field. Hence,

$$\text{Time left until next irrigation(in hours)} = \frac{(100 - \text{Sensor reading}) * 24 * \text{Avg. Available Water} * 10^{-3}}{1 * \text{ET equation}}$$

Available water was taken in ml, sensor reading in percentage, area to be irrigated was taken as unit area in m^2, ET in mm per day.

3.21 PULSE IRRIGATION CYCLES

Generally, the application rate of a drip system should not exceed the basic intake rate of thesoil. (The basic intake rate of the soil is the rate at which the soil absorbs water after the initial application of water in a dry condition.) Basic intake rate estimates can be obtained from the USDA Web Soil Survey, or as shown in the table below. If the intake rate is exceeded by the irrigation system, water can be “pulsed” through the soil by scheduling several cycles of irrigation.

Table 3.2 Infiltration rates for different soils

Soil Type	Maximum application rate (in/h) on slopes		
	0 – 5%	5 – 8%	8 – 12%
Sand, coarse	1.5 – 2.0	1.0 – 1.5	0.75 – 1.0
Sand, fine	0.75 – 1.0	0.5 – 0.8	0.4 – 0.6
Loam, silt loam	0.3 – 0.5	0.25 – 0.4	0.15 – 0.3
Clay, clay loam	0.15	0.10	0.08

The discharge of emitter was calculated by Roberson and Crowe (1993) as follows:

$$Q = 0.61 * A_0 * (2gh)^{0.5}$$

Where: Q = Discharge through orifice (in' sec"1),

A_0 = Area of cross-section of the orifice (m^2),

g = Acceleration due to gravity, 9.81 (m sec^{-2}},

h = Depth of water over the centre of the orifice (on the upstream side) in case of free flow orifice, or the difference in elevation between the water surface at the upstream and downstream faces of the orifice plate in case of submerged orifices (m).

The principles of pulsing were first set out by Karmelli and Pen (1974). They described a pulse as consisting of an operating phase (t_0), during which water is applied to the soil at a discharge (Qp) and a resting phase (t_r) when the flow is zero. The average pulsed discharge (Q_a) over the irrigation period ($t_0 + t_r$) would be:

$$Q_a = \frac{Q_P . t_0}{t_0 + t_r}$$

The average pulsed discharge (Qa) is equivalent to a continuous discharge (Qc). Thus the same amount of water would be applied with a continuous discharge (Qc) as in the pulsed regime provided the irrigation period was (t_0+ t_r).

Pulse application regimes were selected within the range of most commercially available trickle equipment for comparison with a continuous flow of 8 L mm^{-1} h^{-1}.

The flow rates are:

applied continuously: 8 L mm^{-1} h^{-1} (1.33 cm^3 min^{-1} cm^{-1})

applied as 30 min on, 30 min off pulse: 16 L mm^{-1} h^{-1} (2.66 cm^3 min^{-1} cm^{-1})

applied as 20 min on, 40 min off pulse: 24 L mm^{-1} h^{-1} (4 cm^3 min^{-1} cm^{-1})

3.22 ARDUINO CODING

The code uploaded in Arduino for the working of the full circuit is as follows:

```
//Automation of Pulse Irrigation Using Arduino
#include <dht.h>
#include <LiquidCrystal.h>

#define dht_dpin A0 //no ; here. Set equal to channel sensor is on
#define mpin1 A3
#define mpin2 A4
#define mpin3 A5
#define outputPin 7

LiquidCrystallcd(12, 11, 5, 4, 3, 2);
int counter = 0;

dht DHT;
double eqn449(double x, double y);

/*-------------------------------------------------------------*/
doubleevalcpoly(int order, intlogx, int logy, double x, double y, double *p,
double s0, double s1, double s2, double s3,
double s4, double s5, double s6, double s7)
/*-------------------------------------------------------------*/
{
inttcnt,j,m,iv;
doubletx[12],ty[12],v[70],ans;
if(!logx) x=(x-s0)/s1;
else x=(log(x)-s2)/s3;
if(!logy) y=(y-s4)/s5;
```

```
else y=(log(y)-s6)/s7;
switch(order){
case 5:  tcnt=3; break;
case 9:  tcnt=4; break;
case 14: tcnt=5; break;
case 20: tcnt=6; break;
case 27: tcnt=7; break;
case 35: tcnt=8; break;
case 44: tcnt=9; break;
case 54: tcnt=10; break;
case 65: tcnt=11; break;
default: return 0.0;
   }
if(tcnt>6){
if(x<-1.0) x=-1.0;
if(x>1.0)  x= 1.0;
if(y<-1.0) y=-1.0;
if(y>1.0)  y= 1.0;
   }
tx[0]=ty[0]=1.0;
tx[1]=x; ty[1]=y;
for(j=2;j<tcnt;j++){
tx[j]=2*x*tx[j-1]-tx[j-2];
ty[j]=2*y*ty[j-1]-ty[j-2];
   }
iv=0;
for(j=0;j<tcnt;j++){
for(m=j; m>=0; m--)
v[iv++]=tx[m]*ty[j-m];
```

```
}
ans=0.0;
for(j=0;j<=order;j++)
ans += p[j]*v[j];
returnans;
}

double eqn449(double x, double y)
{
double z;
static double c[]= {
    -3071344.789947274,
    7094124.630038226,
    5447010.261049199,
    -5055499.016034635,
    -13069434.31537653,
    -3871717.428354957,
    3007878.093601090,
    8944477.867679691,
    10255938.67191115,
    2195573.462861618,
    -2454386.643263244,
    -5464488.339982810,
    -6294965.141180927,
    -6852813.400275560,
    -1055712.786532505,
    477287.4037133983,
    4294233.166312142,
    4117183.078283315,
```

3510107.556859676,

3884762.797049085,

421889.0471969264,

-510001.7347560691,

-815362.4596677455,

-2898502.702265839,

-2570155.514452620,

-1639754.291711669,

-1831137.134230341,

-157955.9604145777,

25870.19749179138,

860134.8155963539,

504507.4272799410,

1485091.564072061,

1321344.504166708,

631686.0584589423,

688670.6060810888,

40895.11152451481,

-437.0714810167012,

-42018.01756071385,

-510573.2232612408,

-219459.9988549262,

-590349.4030683374,

-536185.3052543339,

-222864.3793307698,

-204245.0203501401,

-13586.33869887798,

156.1027807538212,

454.6841642129811,

```
    19820.23515783538,
    195749.0138443317,
    63915.46032439279,
    171964.5618329141,
    153718.1182332336,
    50017.05886768922,
    42962.94154491633,
    1590.366155921240,
    -12.30143324870012,
    -367.3709726885598,
    -237.4825907872690,
    -4874.718954346409,
    -40111.84224610813,
    -10745.85728788772,
    -38868.21039697626,
    -26242.01553466402,
    -13298.40511404092,
    -7343.338380550691,
    -501.7948838994531,
    };
  z=evalcpoly(65,0,1,x,y,c,
   82.88358361672725,29.17858788536969,
   4.351279923773369,0.3677738962065096,
   23.87500000000000,8.625000000000000,
   3.102909796194556,0.3783302931411356);
return z;
}
void setup() {
```

```
Serial.begin(9600);
delay(300);//Let system settle
Serial.println("Soil Moisture Deficit, Humidity and Temperature\n\n");
delay(700);//Wait rest of 1000ms recommended delay before
pinMode(outputPin, OUTPUT);
lcd.begin(16, 2);
lcd.print("hello, world!");
  //accessing sensor
}//end "setup()"

void loop() {
  //This is the "heart" of the program.
if(counter%60 == 0)
  {

        DHT.read11(dht_dpin);
        double SoilMoisture1 = (1+analogRead(mpin1))/1024.0;
          SoilMoisture1*=100;
        double SoilMoisture2 = (1+analogRead(mpin2))/1024.0;
          SoilMoisture2*=100;
        double SoilMoisture3 = (1+analogRead(mpin3))/1024.0;
          SoilMoisture3*=100;
        Serial.print("Current humidity = ");
        Serial.print(DHT.humidity);
        Serial.print("%  ");
        Serial.print("temperature = ");
        Serial.print(DHT.temperature);
        Serial.println("C  ");
        Serial.print("Soil Moisture 1: ");
```

```
Serial.print(SoilMoisture1);
Serial.println("% ");
Serial.print("Soil Moisture 2: ");
Serial.print(SoilMoisture2);
Serial.println("% ");
Serial.print("Soil Moisture 3: ");
Serial.print(SoilMoisture3);
Serial.println("% ");

doubleSoilMoisture = (SoilMoisture1 + SoilMoisture2 + SoilMoisture3)/3.0;
if(SoilMoisture> 76.33)
  {
digitalWrite(outputPin,HIGH);
  }

if(SoilMoisture< 35)
  {
digitalWrite(outputPin,LOW);
  }

double z=eqn449(DHT.humidity,DHT.temperature);
doubleval = (100 - SoilMoisture)*232.83 * 1e-3;
val/=z;
val*=24;
char buffer[40];
lcd.clear();
lcd.setCursor(0,0);
sprintf(buffer,"Soil MC: %d%%",(int)(100- SoilMoisture) );
lcd.print(buffer);
```

```
		lcd.setCursor(0, 1);
		sprintf (buffer, "%d hours left.",(int)val);
		lcd.print(buffer);
  }
else if(counter %60 == 1)
  {
		digitalWrite(outputPin,LOW);
  }
counter++;
delay(1000*10);
}
```

CHAPTER 4

RESULTS AND DISCUSSION

The work entitled 'Automation of Pulse Irrigation Using Arduino' was undertaken to automate pulse irrigation system with on field real time sensing based on parameters such as soil moisture, temperature and relative humidity. The result of this work is explained in this chapter.

4.1 ASSEMBLING THE ARDUINO SYSTEM AND CODING

The Arduino Uno board and the components were assembled according to the circuit diagram. The Arduino home screen looks like:

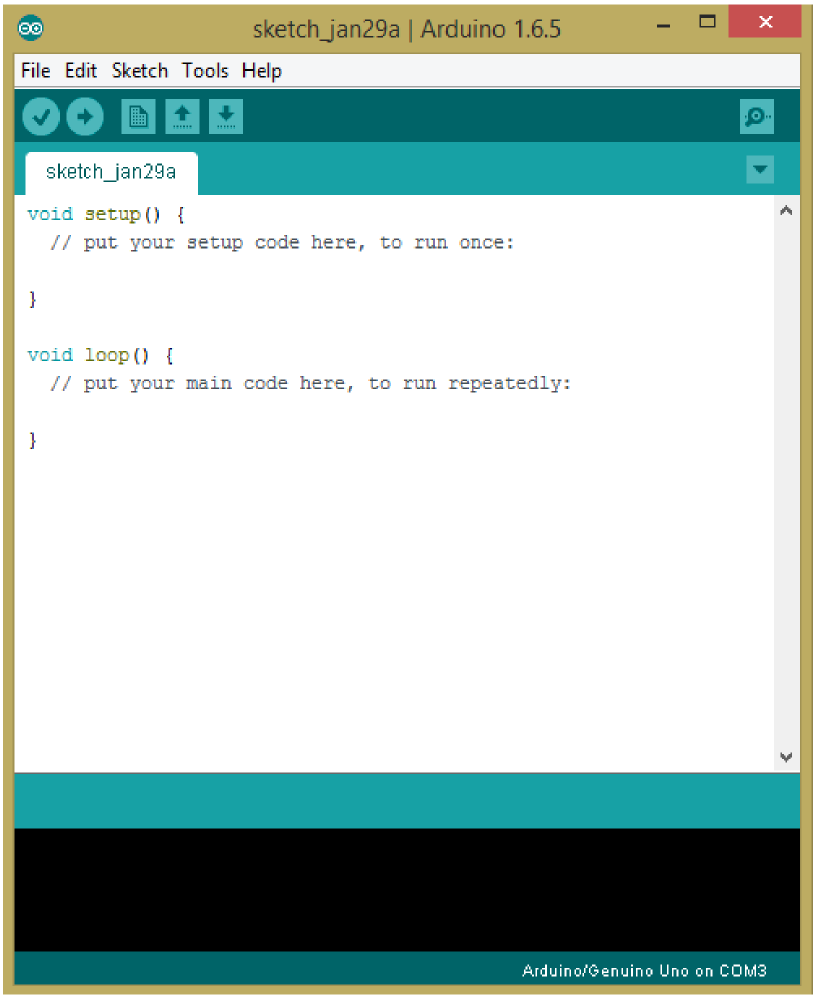


Fig. 4.1 Arduino home screen

To verify and compile the written code, i.e., to check for errors in the code the "Verify / Compile" command was used.

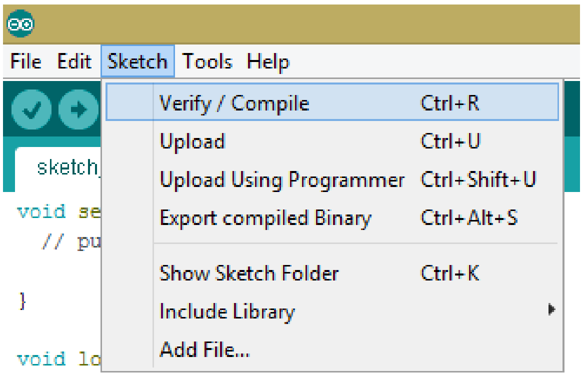


Fig 4.2 Compiling a code in Arduino

Then the program was uploaded to the Arduino board using the "Upload" command.

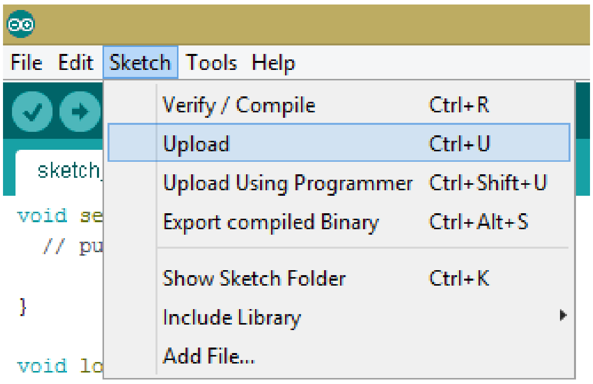


Fig. 4.3 Uploading the code to the Arduino board

To see the running status of the system, the "Serial Monitor Command" was used.

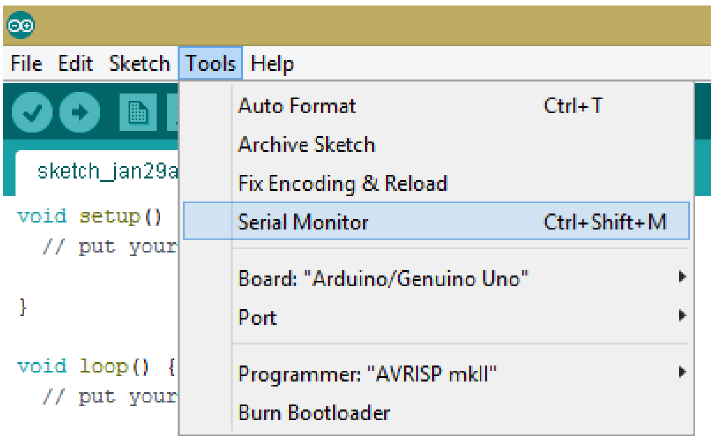
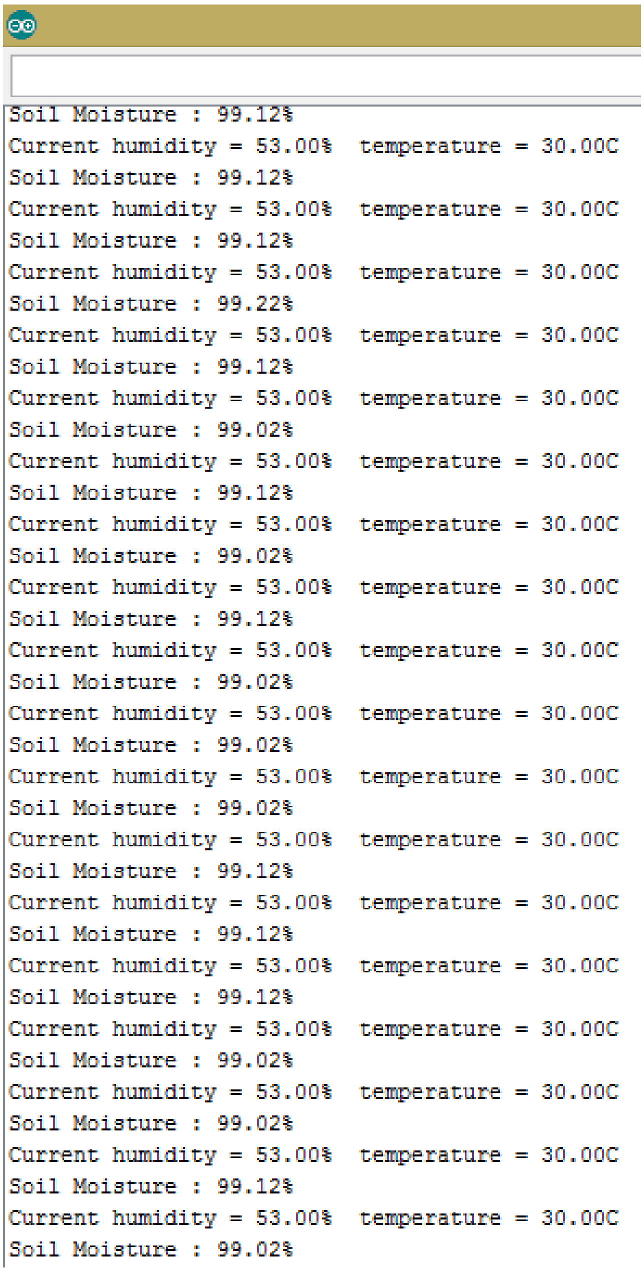


Fig. 4.4 Serial Monitor command

The serial monitor shows the readings from soil moisture sensors and the humidity and temperature sensor. A sample of what the serial monitor showed during the testing of the sensors is shown next.



```
Soil Moisture : 99.12%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.12%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.12%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.22%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.12%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.02%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.12%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.02%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.12%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.02%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.02%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.02%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.12%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.12%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.12%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.02%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.02%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.12%
Current humidity = 53.00%  temperature = 30.00C
Soil Moisture : 99.02%
```

Fig 4.5 Serial Monitor window during sensor testing

4.2 CALIBRATION OF SOIL MOISTURE SENSORS

4.2.1 Evaluation of soil moisture characteristics

The soil moisture constants such as field capacity and permanent wilting point of the undisturbed soil sample collected by core cutter method was determined. The details of the observations are as shown in the table below:

Table 4.2.1 Details of observations collected during soil sampling

	Sample 1	Sample 2	Sample 3
Radius of core cutter (cm)	5	5	5
Height of core cutter (cm)	12.5	12	12
Weight of core cutter (g)	982	942	942
Volume of core cutter (cm3)	924.5	946	983
Field capacity weight (g)	1913	2124	1858
PWP weight (g)	1617	1940	1640
Dry weight of sample (g)	692	993.5	657
Available water (ml)	296.5	184.5	218

4.2.2 Testing of soil moisture sensors

Volume of available water was found out by subtracting weight of samples during Permanent Wilting Point (PWP) from the Field Capacity (FC) weight of the soil samples. Calibration was done by adding water in eight stages. So available water obtained from each sample is first divided by eight and this much amount of water is added in each sample respectively. The data obtained from the sensor is collected. Data is selected only when the value is consecutively repeated thrice. Amount of water obtained for each sample and volume of water to be added in each sample during the intervals are shown in the table below:

Table 4.2.2 Observations of amount of water available and water added during calibration.

	Available water (ml)	Amount of water added in each stages (ml)
Sample I	296.5	37
Sample II	184.5	23
Sample III	218	27

Details of the amount of water added in each stage and sensor values selected are given in the following table.

Table 4.2.3 Observations of amount of water added in each stage and soil moisture deficit values obtained from the sensor.

Sample I		Sample II		Sample III	
Amount of water added (ml)	Sensor value (%)	Amount of water added (ml)	Sensor value (%)	Amount of water added (ml)	Sensor value (%)
37	97.75	23	98.83	27	94.14
74	98.73	46	85.16	54	83.2
111	97.85	69	77.73	81	77.34
148	95.51	92	65.14	108	69.14
185	81.45	115	61.82	135	58.4
222	74.51	138	61.5	162	51.37
259	63.38	161	66.89	189	47.07
296	54.1	184	60.74	216	44.34

The values of Mass Wetness and Volume Wetness are calculated and Soil Moisture Deficit value is collected from the system and tabulated as shown below:

Table 4..2.4 Values of volume wetness, mass wetness and soil moisture deficit of three samples

Sample I			Sample II			Sample III		
Pw	Pv	S	Pw	Pv	S	Pw	Pv	S
0.053468	0.037688	97.75	0.02315	0.024404	98.83	0.041096	0.028648	94.14
0.106936	0.075376	98.73	0.046301	0.048808	85.16	0.082192	0.057296	83.2
0.160405	0.113064	97.85	0.069451	0.073211	77.73	0.123288	0.085944	77.34
0.213873	0.150752	95.51	0.092602	0.097615	65.14	0.164384	0.114592	69.14
0.267341	0.188439	81.45	0.115752	0.122019	61.82	0.205479	0.143239	58.4
0.320809	0.226127	74.51	0.138903	0.146423	61.5	0.246575	0.171887	51.37
0.374277	0.263815	63.38	0.162053	0.170826	66.89	0.287671	0.200535	47.07
0.427746	0.301503	54.1	0.185204	0.19523	60.74	0.328767	0.229183	44.34

In the table, Pw indicates Mass Wetness, Pv indicates Volume wetness and S indicates Soil Moisture Deficit (%)

The calibration curves obtained for the three samples, Sample I, Sample II, Sample III and the equation fitted for each sample are shown in the figures below:

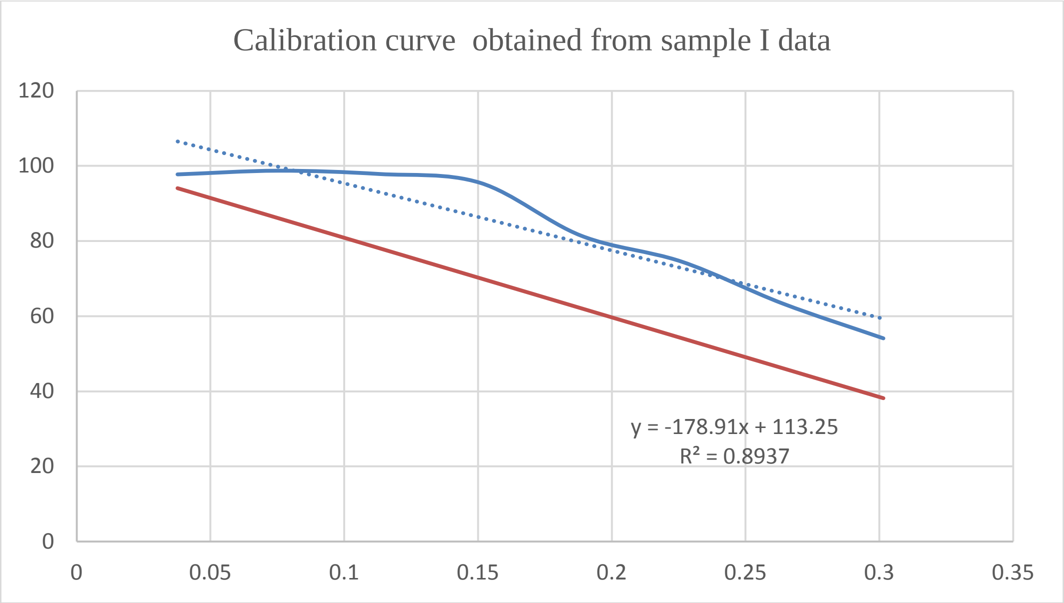


Fig.4.6 Soil moisture deficit v/s volume wetness curve of soil sample I

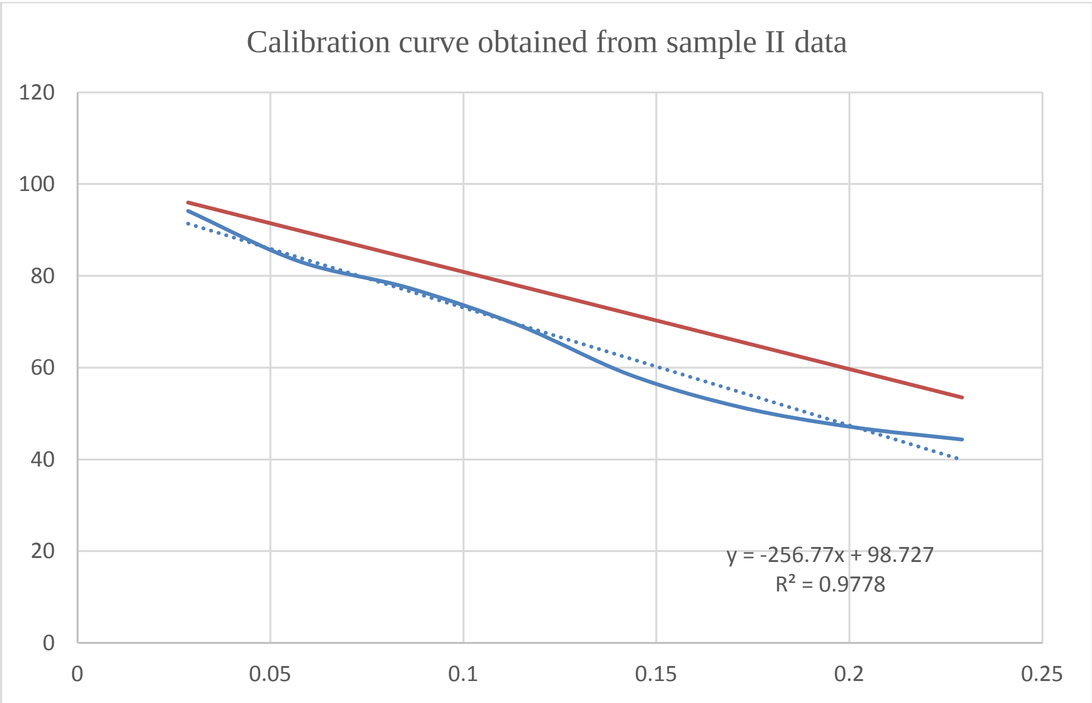


Fig.4.7 Soil moisture deficit v/s volume wetness curve of soil sample II

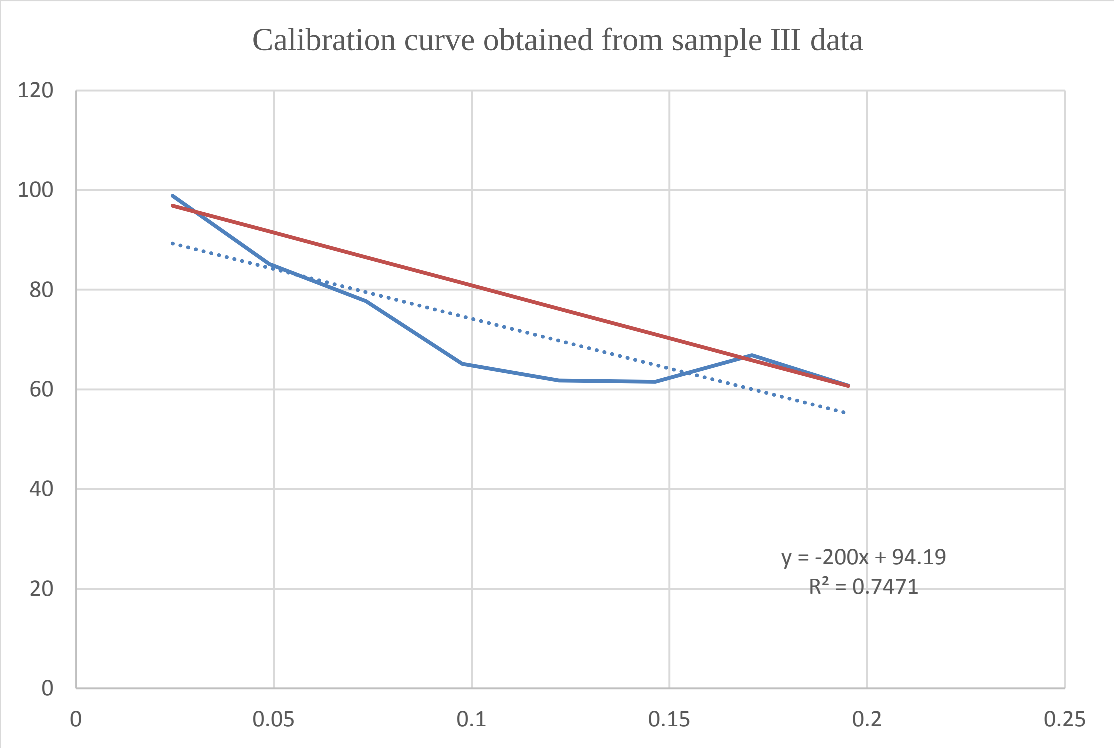


Fig.4.8 Soil moisture deficit v/s volume wetness curve of soil sample III

Calibration was done and the equation having the highest R^2 value near to 1 has been selected. The equations corresponding to each sample are listed in the table below:

Table 4.2.5 Samples and corresponding equations obtained

Samples	Equation
Sample I	y = -178.9x + 113.2
Sample II	y = -256.77x + 98.72
Sample III	y = -200x + 94.19

The equation obtained by taking the average of above equations is

$$y = -211.893\,x + 102.0557 \ldots\ldots (a)$$

Therefore, $x = (y - 102.0557)/ -211.893$

Average volume wetness found from three sample conditions are shown in the table below:

Table 4.2.6 Volume wetness of three samples

Sample No.	Volume Wetness
I	0.302012
II	0.195761
III	0.230775

Average value of volume wetness = (0.302012+0.195761+0.230775)/3

= 0.2428

Management Allowable Depletion (MAD) value obtained = (0.2428)/2 = 0.1244

y = -211.893 * 0.1244 + 102.557

= 76.33

Hence when the soil moisture sensor value becomes 76.33%, irrigation is started and is stopped when the sensor shows 35%.

4.3 CALCULATION OF FREQUENCY OF IRRIGATION

4.3.1 Collection of Meteorological Data

The meteorological data (2007) collected from meteorological observatory of KCAET campus having minimum and maximum temperature value, wet bulb and dry bulb temperature values, and pan evaporation data were collected. The collected data is given in the appendix I.

4.3.2 Calculation of Evapotranspiration, RH and Average temperature

Evapotranspiration can be calculated by the following equation:

Evapotranspiration (ET) = Pan evaporation * Crop coefficient

Pan evaporation data is collected from the meteorological data given in appendix I. Crop coefficient of a crop, say amaranths which is 0.95, is taken.

The temperature value is calculated by taking the average of maximum and minimum temperature value collected from the meteorological data given in appendix I.

RH can be calculated by using the values of wet bulb temperature and dry bulb temperature taken from the meteorological data given in appendix I. It can be calculated using the equation (3.6) mentioned in materials and methods.

Table 4.3 Calculation of ET, RH and temperature from the meteorological data

Dry bulb temp	wet bulb temp	Max temp	Min temp	Pan evaporation	Avg temp	ET	ew	ed	A	RH
(°C)	(°C)	(°C)	(°C)	(mm)	(°C)	(mm)	(mb)	(mb)		(%)
24.0	20.0	33.0	18.5	2.0	25.75	24.4625	23.37244	29.8	0.000675	69.17807
25.0	24.5	33.0	19.0	2.0	26	24.7	30.73797	31.7	0.000679	95.97203
24.5	21.0	35.0	20.0	2.0	27.5	26.125	24.85967	30.7	0.000676	73.07748
26.0	25.0	33.5	21.0	2.2	27.25	25.8875	31.66983	33.6	0.000679	92.18632
28.0	23.0	33.0	22.0	4.0	27.5	26.125	28.08464	37.8	0.000677	65.22355
26.0	22.5	34.0	23.0	4.0	28.5	27.075	27.24588	33.6	0.000677	73.92528
25.5	22.0	34.0	22.0	6.4	28	26.6	26.42913	32.6	0.000677	73.65015
26.0	25.0	34.5	22.5	2.0	28.5	27.075	31.66983	33.6	0.000679	92.18632
25.0	21.5	33.5	22.5	3.4	28	26.6	25.63388	31.7	0.000676	73.36764
24.5	20.5	34.5	20.5	2.6	27.5	26.125	24.10601	30.7	0.000676	69.51652
25.0	22.0	35.0	22.0	4.0	28.5	27.075	26.42913	31.7	0.000677	76.95695
25.0	22.5	34.0	21.0	2.3	27.5	26.125	27.24588	31.7	0.000677	80.61541
25.0	21.5	34.0	20.5	2.0	27.25	25.8875	25.63388	31.7	0.000676	73.36764
24.0	21.0	34.0	19.5	2.2	26.75	25.4125	24.85967	29.8	0.000676	76.44939
24.0	24.0	34.0	20.0	4.0	27	25.65	29.83017	29.8	0.000678	100
24.0	20.5	34.0	19.0	1.8	26.5	25.175	24.10601	29.8	0.000676	72.77941
21.0	19.0	34.0	18.5	2.0	26.25	24.9375	21.96376	24.9	0.000674	82.85327
24.0	21.0	35.0	19.5	4.0	27.25	25.8875	24.85967	29.8	0.000676	76.44939
23.0	19.5	35.0	19.0	4.2	27	25.65	22.65851	28.1	0.000675	72.15835
25.5	19.0	35.0	19.0	4.2	27	25.65	21.96376	32.6	0.000674	53.705
26.0	21.5	36.0	21.0	4.0	28.5	27.075	25.63388	33.6	0.000676	67.09775
25.0	21.5	33.5	21.0	4.0	27.25	25.8875	25.63388	31.7	0.000676	73.36764
27.0	23.0	33.5	22.0	4.0	27.75	26.3625	28.08464	35.6	0.000677	71.07947
26.0	23.50	34.0	23.0	4.0	28.5	27.075	28.9459	33.6	0.000678	81.01929
27.0	22.5	33.5	24.0	4.0	28.75	27.3125	27.24588	35.6	0.000677	67.76871
27.5	23.00	34.4	23.0	3.6	28.7	27.265	28.08464	36.7	0.000677	68.09129
27.0	22.5	34.5	22.0	4.2	28.25	26.8375	27.24588	35.6	0.000677	67.76871
26.0	21.5	34.5	20.0	6.0	27.25	25.8875	25.63388	33.6	0.000676	67.09775
25.5	24.0	35.0	19.5	4.4	27.25	25.8875	29.83017	32.6	0.000678	88.27046
26.0	22.0	35.0	19.5	4.0	27.25	25.8875	26.42913	33.6	0.000677	70.47894
25.0	22.5	33.0	22.0	6.0	27.5	26.125	27.24588	31.7	0.000677	80.61541
26.5	22.5	34.0	22.0	4.0	28	26.6	27.24588	34.6	0.000677	70.78312
26.0	21.0	33.0	22.0	4.0	27.5	26.125	24.85967	33.6	0.000676	63.78028

25.0	23.0	34.0	21.0	3.4	27.5	26.125	28.08464	31.7	0.000677	84.34455
26.5	23.0	34.5	21.0	4.0	27.75	26.3625	28.08464	34.6	0.000677	74.1933
24.0	19.5	35.5	19.5	3.8	27.5	26.125	22.65851	29.8	0.000675	65.64385
27.0	23.0	35.0	21.0	4.0	28	26.6	28.08464	35.6	0.000677	71.07947
27.0	22.5	34.5	22.0	6.0	28.25	26.8375	27.24588	35.6	0.000677	67.76871
27.5	23.0	34.0	22.0	42.0	28	26.6	28.08464	36.7	0.000677	68.09129
28.0	23.0	36.0	22.0	4.6	29	27.55	28.08464	37.8	0.000677	65.22355
24.0	21.0	33.0	20.0	4.2	26.5	25.175	24.85967	29.8	0.000676	76.44939
24.0	22.0	33.5	19.0	4.0	26.25	24.9375	26.42913	29.8	0.000677	84.00153
25.0	21.0	31.5	18.5	3.6	25	23.75	24.85967	31.7	0.000676	69.84594
24.0	22.0	31.0	20.5	5.2	25.75	24.4625	26.42913	29.8	0.000677	84.00153
25.0	23.5	32.0	22.0	4.0	27	25.65	28.9459	31.7	0.000678	88.14596
24.5	24.0	33.0	22.5	3.6	27.75	26.3625	29.83017	30.7	0.000678	95.92881
27.0	22.5	35.5	24.0	7.0	29.75	28.2625	27.24588	35.6	0.000677	67.76871
27.0	22.0	35.5	23.0	6.0	29.25	27.7875	26.42913	35.6	0.000677	64.52074
25.5	20.0	35.5	22.0	6.2	28.75	27.3125	23.37244	32.6	0.000675	60.10415
25.0	24.0	35.0	21.5	6.0	28.25	26.8375	29.83017	31.7	0.000678	92.02124
24.5	19.0	35.0	21.0	6.4	28	26.6	21.96376	30.7	0.000674	59.22739
26.0	23.0	33.5	21.0	6.0	27.25	25.8875	28.08464	33.6	0.000677	77.43824
26.0	23.0	34.0	22.0	6.0	28	26.6	28.08464	33.6	0.000677	77.43824
25.5	24.0	34.0	22.5	6.0	28.25	26.8375	29.83017	32.6	0.000678	88.27046
26.5	26.0	34.0	23.5	4.6	28.75	27.3125	33.60787	34.6	0.00068	96.09519
28.0	26.0	35.0	23.0	6.0	29	27.55	33.60787	37.8	0.00068	85.27259
28.0	27.0	34.0	24.0	4.0	29	27.55	35.6487	37.8	0.00068	92.49224
27.0	24.0	33.0	22.5	4.6	27.75	26.3625	29.83017	35.6	0.000678	77.89502
27.5	25.0	33.0	32.0	5.4	32.5	30.875	31.66983	36.7	0.000679	81.58716
27.0	25.0	36.0	23.0	6.0	29.5	28.025	31.66983	35.6	0.000679	84.97893
27.0	24.0	34.0	22.5	6.0	28.25	26.8375	29.83017	35.6	0.000678	77.89502
28.0	26.5	34.0	23.0	6.4	28.5	27.075	34.61515	37.8	0.00068	88.84717
28.5	26.0	34.5	23.5	6.0	29	27.55	33.60787	38.9	0.00068	81.94242
28.0	25.0	34.0	22.5	5.4	28.25	26.8375	31.66983	37.8	0.000679	78.32897
27.5	26.0	35.5	23.5	6.0	29.5	28.025	33.60787	36.7	0.00068	88.73759
28.5	26.0	35.5	23.5	3.0	29.5	28.025	33.60787	38.9	0.00068	81.94242
28.5	26.0	33.0	23.0	5.0	28	26.6	33.60787	38.9	0.00068	81.94242
27.5	25.0	34.0	22.5	6.0	28.25	26.8375	31.66983	36.7	0.000679	81.58716
26.0	25.0	35.0	23.0	6.5	29	27.55	31.66983	33.6	0.000679	92.18632
28.5	27.5	35.0	24.5	6.0	29.75	28.2625	36.70908	38.9	0.000681	92.56407
29.0	26.0	35.0	23.5	6.0	29.25	27.7875	33.60787	40.1	0.00068	78.74159
29.5	28.5	37.0	24.5	6.0	30.75	29.2125	38.91271	41.2	0.000682	92.70256
29.0	26.0	36.0	24.5	6.0	30.262	28.7489	33.60787	40.1	0.00068	78.74159
29.0	27.0	35.5	24.0	7.0	29.75	28.2625	35.6487	40.1	0.00068	85.55195
29.0	26.5	34.5	24.0	5.6	29.25	27.7875	34.61515	40.1	0.00068	82.11351
28.5	26.5	35.0	24.5	6.0	29.75	28.2625	34.61515	38.9	0.00068	85.414
29.0	26.5	34.5	24.0	4.0	29.25	27.7875	34.61515	40.1	0.00068	82.11351
29.0	27.0	35.0	25.0	5.2	30	28.5	35.6487	40.1	0.00068	85.55195
30.5	27.0	36.0	25.0	5.6	30.5	28.975	35.6487	43.7	0.00068	76.10852

29.0	26.5	34.5	24.0	6.0	29.25	27.7875	34.61515	40.1	0.00068	82.11351
29.5	28.0	35.0	24.5	5.6	29.75	28.2625	37.79689	41.2	0.000681	89.16012
29.5	28.0	35.5	24.5	6.0	30	28.5	37.79689	41.2	0.000681	89.16012
29.5	28.5	35.0	24.0	5.4	29.5	28.025	38.91271	41.2	0.000682	92.70256
29.5	26.5	35.5	24.0	5.0	29.75	28.2625	34.61515	41.2	0.00068	78.94036
29.0	26.0	34.5	24.0	4.0	29.25	27.7875	33.60787	40.1	0.00068	78.74159
29.5	26.5	35.0	24.5	2.2	29.75	28.2625	34.61515	41.2	0.00068	78.94036
29.0	27.5	37.0	22.5		29.75	28.2625	36.70908	40.1	0.000681	89.05834
28.0	26.5	37.0	25.0	2.0	31	29.45	34.61515	37.8	0.00068	88.84717
29.0	26.0	33.5	23.0	6.0	28.25	26.8375	33.60787	40.1	0.00068	78.74159
28.0	24.0	34.5	21.0		27.75	26.3625	29.83017	37.8	0.000678	71.64971
29.5	24.5	36.0	20.0	7.2	28	26.6	30.73797	41.2	0.000679	66.21265
29.0	25.0	35.5	23.0	4.6	29.25	27.7875	31.66983	40.1	0.000679	72.19169
26.5	26.0	34.5	22.0	5.0	28.25	26.8375	33.60787	34.6	0.00068	96.09519
29.5	26.5	33.0	24.0	5.4	28.5	27.075	34.61515	41.2	0.00068	78.94036
30.0	27.0	34.0	24.5	4.0	29.25	27.7875	35.6487	42.4	0.00068	79.13431
30.5	27.0	35.0	25.0	5.4	30	28.5	35.6487	43.7	0.00068	76.10852
29.5	25.5	34.0	23.5	4.5	28.75	27.3125	32.62628	41.2	0.000679	72.45268
27.0	24.5	33.5	21.0	9.2	27.25	25.8875	30.73797	35.6	0.000679	81.4027
29.0	26.0	33.0	23.5	4.0	28.25	26.8375	33.60787	40.1	0.00068	78.74159
29.5	26.0	33.5	24.0	4.0	28.75	27.3125	33.60787	41.2	0.00068	75.66489
30.0	26.5	34.0	23.5	4.0	28.75	27.3125	34.61515	42.4	0.00068	75.88941
30.0	27.0	34.0	24.0	4.0	29	27.55	35.6487	42.4	0.00068	79.13431
29.5	26.5	34.0	24.5	6.0	29.25	27.7875	34.61515	41.2	0.00068	78.94036
29.5	27.0	34.0	25.5	4.0	29.75	28.2625	35.6487	41.2	0.00068	82.28045
29.5	26.5	34.0	25.0	4.8	29.5	28.025	34.61515	41.2	0.00068	78.94036
29.5	27.0	35.0	25.0	4.2	30	28.5	35.6487	41.2	0.00068	82.28045
29.5	24.5	35.0	22.0	3.8	28.5	27.075	30.73797	41.2	0.000679	66.21265
29.5	24.5	35.5	22.0	2.0	28.75	27.3125	30.73797	41.2	0.000679	66.21265
28.0	26.0	33.0	22.0	2.0	27.5	26.125	33.60787	37.8	0.00068	85.27259
28.0	26.0	32.5	22.0	1.8	27.25	25.8875	33.60787	37.8	0.00068	85.27259
29.0	26.5	32.0	25.0	4.0	28.5	27.075	34.61515	40.1	0.00068	82.11351
27.0	25.0	33.0	22.5	4.0	27.75	26.3625	31.66983	35.6	0.000679	84.97893
28.5	25.0	32.0	24.0	6.0	28	26.6	31.66983	38.9	0.000679	75.19889
29.0	27.0	34.0	24.0	4.0	29	27.55	35.6487	40.1	0.00068	85.55195
29.0	27.0	34.0	21.5	2.8	27.75	26.3625	35.6487	40.1	0.00068	85.55195
27.0	26.0	32.5	24.5	1.8	28.5	27.075	33.60787	35.6	0.00068	92.34314
29.5	26.5	33.0	23.5	10.0	28.25	26.8375	34.61515	41.2	0.00068	78.94036
30.0	27.5	33.0		2.0	16.5	15.675	36.70908	42.4	0.000681	82.44337
28.5	26.0	33.0		8.0	16.5	15.675	33.60787	38.9	0.00068	81.94242
30.0	27.0	33.0		2.0	16.5	15.675	35.6487	42.4	0.00068	79.13431
29.5	27.0	33.5		6.0	16.75	15.9125	35.6487	41.2	0.00068	82.28045
29.5	25.5	33.5		6.0	16.75	15.9125	32.62628	41.2	0.000679	72.45268
29.5	26.0	32.5		4.0	16.25	15.4375	33.60787	41.2	0.00068	75.66489
30.0	26.5	33.0		5.0	16.5	15.675	34.61515	42.4	0.00068	75.88941
30.0	27.0	30.5		4.0	15.25	14.4875	35.6487	42.4	0.00068	79.13431

29.0	26.5	36.0	25.0	4.0	30.5	28.975	34.61515	40.1	0.00068	82.11351
31.0	27.0	33.5	25.5	4.0	29.5	28.025	35.6487	44.9	0.00068	73.19826
31.0	27.5	34.0	26.0	6.0	30	28.5	36.70908	44.9	0.000681	76.3224
32.0	28.0	34.5	27.0	4.8	30.75	29.2125	37.79689	47.6	0.000681	73.66618
31.0	28.0	35.0	27.0	2.0	31	29.45	37.79689	44.9	0.000681	79.50843
27.5	26.0	35.0	25.0	2.8	30	28.5	33.60787	36.7	0.00068	88.73759
29.5	27.0	34.5	25.0	6.0	29.75	28.2625	35.6487	41.2	0.00068	82.28045
30.0	27.0	34.5	25.5	2.0	30	28.5	35.6487	42.4	0.00068	79.13431
24.0	24.0	34.5	22.0	61.6	28.25	26.8375	29.83017	29.8	0.000678	100
25.5	24.0	34.5	22.0	25.2	28.25	26.8375	29.83017	32.6	0.000678	88.27046
24.5	24.0	34.5	22.0	4.4	28.25	26.8375	29.83017	30.7	0.000678	95.92881
28.0	25.0	34.5	22.0	9.1	28.25	26.8375	31.66983	37.8	0.000679	78.32897
28.5	25.5	31.5	23.5	1.6	27.5	26.125	32.62628	38.9	0.000679	78.53786
29.5	27	32.5	25.5	2	29	27.55	35.6487	41.2	0.00068	82.28045
28.5	27	32	24	0.4	28	26.6	35.6487	38.9	0.00068	88.95405
28.5	26.5	32	25	7	28.5	27.075	34.61515	38.9	0.00068	85.414
29.5	27	33	26	3	29.5	28.025	35.6487	41.2	0.00068	82.28045
28.5	26	33	23.5	3.8	28.25	26.8375	33.60787	38.9	0.00068	81.94242
28.5	26.5	32	24.5	6	28.25	26.8375	34.61515	38.9	0.00068	85.414
27.5	26	31.5	23.5	3.2	27.5	26.125	33.60787	36.7	0.00068	88.73759
27.5	26	29.5	23.5	16	26.5	25.175	33.60787	36.7	0.00068	88.73759
28.5	25.5	30.5	23.5	7.2	27	25.65	32.62628	38.9	0.000679	78.53786
25.5	25.5	31.5	23.5	3	27.5	26.125	32.62628	32.6	0.000679	100
25.5	25.5	32	23.5	1	27.75	26.3625	32.62628	32.6	0.000679	100
25.5	25	28	24	12.2	26	24.7	31.66983	32.6	0.000679	96.01415
25	25	30	23.5	11.2	26.75	25.4125	31.66983	31.7	0.000679	100
24	25	27.5	23.5	2.2	25.5	24.225	31.66983	29.8	0.000679	108.4734
24.5	24	29	23	2	26	24.7	29.83017	30.7	0.000678	95.92881
25	24.5	28.5	24.5	3.8	26.5	25.175	30.73797	31.7	0.000679	95.97203
24.5	24	29	23	11	26	24.7	29.83017	30.7	0.000678	95.92881
25	24	28	23	2	25.5	24.225	29.83017	31.7	0.000678	92.02124
24	25	29	23	6	26	24.7	31.66983	29.8	0.000679	108.4734
25	24	28	22.5	2	25.25	23.9875	29.83017	31.7	0.000678	92.02124
25	25	29	23		26	24.7	31.66983	31.7	0.000679	100
26	25.5	28.5	23.5	28	26	24.7	32.62628	33.6	0.000679	96.05519
27	25.5	27.5	23.5	24	25.5	24.225	32.62628	35.6	0.000679	88.62523
27	25	31	24	3	27.5	26.125	31.66983	35.6	0.000679	84.97893
27	26	31	23.5	4	27.25	25.8875	33.60787	35.6	0.00068	92.34314
26.5	25.5	30	23.5	6	26.75	25.4125	32.62628	34.6	0.000679	92.26572
28	26	29.5	25.5	2.6	27.5	26.125	33.60787	37.8	0.00068	85.27259
28	27	30	26.5	2	28.25	26.8375	35.6487	37.8	0.00068	92.49224
28	27	31	25	8	28	26.6	35.6487	37.8	0.00068	92.49224
27.5	27	29.5	22	3	25.75	24.4625	35.6487	36.7	0.00068	96.17223
24	24	29.5	22	8	25.75	24.4625	29.83017	29.8	0.000678	100
24	24	26	22.5		24.25	23.0375	29.83017	29.8	0.000678	100
24	24	29	23		26	24.7	29.83017	29.8	0.000678	100

24	23.5	26	23	4	24.5	23.275	28.9459	29.8	0.000678	95.88444
26	24.5	30	23.5	6.4	26.75	25.4125	30.73797	33.6	0.000679	88.39177
27	26	30	23.5	8	26.75	25.4125	33.60787	35.6	0.00068	92.34314
25.5	25	30	23	3	26.5	25.175	31.66983	32.6	0.000679	96.01415
25	25	29	22.5	3	25.75	24.4625	31.66983	31.7	0.000679	100
25	25	29.5	23	3	26.25	24.9375	31.66983	31.7	0.000679	100
25	25	30	23	5	26.5	25.175	31.66983	31.7	0.000679	100
24.5	24	30	23	8	26.5	25.175	29.83017	30.7	0.000678	95.92881
26.5	26	30	24	7.2	27	25.65	33.60787	34.6	0.00068	96.09519
25	25	29.5	24	7.8	26.75	25.4125	31.66983	31.7	0.000679	100
26.5	26	30	24	3.8	27	25.65	33.60787	34.6	0.00068	96.09519
26.5	24	30	26	8.8	28	26.6	29.83017	34.6	0.000678	81.21346
23.5	23.5	28	22.5		25.25	23.9875	28.9459	28.9	0.000678	100
25	24.5	28	22.5		25.25	23.9875	30.73797	31.7	0.000679	95.97203
26.5	25.5	29.5	24	18	26.75	25.4125	32.62628	34.6	0.000679	92.26572
24	24	30	23	4	26.5	25.175	29.83017	29.8	0.000678	100
24	23.5	27	22.5	8	24.75	23.5125	28.9459	29.8	0.000678	95.88444
24	23.5	29	22.5	10	25.75	24.4625	28.9459	29.8	0.000678	95.88444
24.5	24.5	28.5	23	6	25.75	24.4625	30.73797	30.7	0.000679	100
25.5	24.5	30	24	2	27	25.65	30.73797	32.6	0.000679	92.10485
23	23	28.5	22		25.25	23.9875	28.08464	28.1	0.000677	100
25	24.5	28.5	22.5	13.2	25.5	24.225	30.73797	31.7	0.000679	95.97203
25.5	25	29	24	4	26.5	25.175	31.66983	32.6	0.000679	96.01415
23.5	23.5	27	23	6	25	23.75	28.9459	28.9	0.000678	100
25.5	25	29	23	4	26	24.7	31.66983	32.6	0.000679	96.01415
25.5	24	28	23.5	8.8	25.75	24.4625	29.83017	32.6	0.000678	88.27046
25	24.5	30	24	6	27	25.65	30.73797	31.7	0.000679	95.97203
25	24.5	30	23	2	26.5	25.175	30.73797	31.7	0.000679	95.97203
23.5	23	28	22	5.2	25	23.75	28.08464	28.9	0.000677	95.83887
25	24.5	26.5	22.5	4.4	24.5	23.275	30.73797	31.7	0.000679	95.97203
24.5	24	27.5	22.5	3.8	25	23.75	29.83017	30.7	0.000678	95.92881
25.5	25	30	23.5	6.2	26.75	25.4125	31.66983	32.6	0.000679	96.01415
24	24.5	29	22.5	6.7	25.75	24.4625	30.73797	29.8	0.000679	104.1957
24	23	29	22	4	25.5	24.225	28.08464	29.8	0.000677	91.8473
25	24	29	23	8	26	24.7	29.83017	31.7	0.000678	92.02124
26	25.5	29	23.5	6	26.25	24.9375	32.62628	33.6	0.000679	96.05519
23.5	23.5	28.5	23.5		26	24.7	28.9459	28.9	0.000678	100
26	24	29	22.5	13	25.75	24.4625	29.83017	33.6	0.000678	84.66995
26.5	25.5	28	22.5	6	25.25	23.9875	32.62628	34.6	0.000679	92.26572
26	25.5	29	23.5	4	26.25	24.9375	32.62628	33.6	0.000679	96.05519
27	25.5	30	23.5	2	26.75	25.4125	32.62628	35.6	0.000679	88.62523
27	26	30.5	24	4	27.25	25.8875	33.60787	35.6	0.00068	92.34314
27	26	30.5	23.5	3	27	25.65	33.60787	35.6	0.00068	92.34314
27	26	30.5	25	1	27.75	26.3625	33.60787	35.6	0.00068	92.34314
27.5	26	31	24.5	6	27.75	26.3625	33.60787	36.7	0.00068	88.73759
27.5	26	31	24.5	4	27.75	26.3625	33.60787	36.7	0.00068	88.73759

25.5	25	30	23	3	26.5	25.175	31.66983	32.6	0.000679	96.01415
25	25	30.5	23.5	4	27	25.65	31.66983	31.7	0.000679	100
24.5	24	27	23	8	25	23.75	29.83017	30.7	0.000678	95.92881
26.5	25	29	23	4	26	24.7	31.66983	34.6	0.000679	88.51
27	25.5	30.5	24	5	27.25	25.8875	32.62628	35.6	0.000679	88.62523
26	25.5	30.5	23	6	26.75	25.4125	32.62628	33.6	0.000679	96.05519
24	23.5	29	22	6	25.5	24.225	28.9459	29.8	0.000678	95.88444
25.5	25	30	23	7	26.5	25.175	31.66983	32.6	0.000679	96.01415
24.5	23.5	28.5	22	8	25.25	23.9875	28.9459	30.7	0.000678	91.93542
25.5	24.5	30	24	7	27	25.65	30.73797	32.6	0.000679	92.10485
24	23.5	30	23	3	26.5	25.175	28.9459	29.8	0.000678	95.88444
24	24	29	22	9	25.5	24.225	29.83017	29.8	0.000678	100
24	24	28.5	22.5	4	25.5	24.225	29.83017	29.8	0.000678	100
27	26	29.5	23.5	3	26.5	25.175	33.60787	35.6	0.00068	92.34314
27	26	30	24.5	4	27.25	25.8875	33.60787	35.6	0.00068	92.34314
26	25	30.5	23	4	26.75	25.4125	31.66983	33.6	0.000679	92.18632
27	26	31	25	8	28	26.6	33.60787	35.6	0.00068	92.34314
26	24.5	30	24	6	27	25.65	30.73797	33.6	0.000679	88.39177
26.5	26	31	25	4	28	26.6	33.60787	34.6	0.00068	96.09519
24	24	30	23.5	5	26.75	25.4125	29.83017	29.8	0.000678	100
24	24	28.5	23.5	6	26	24.7	29.83017	29.8	0.000678	100
26	25	28.5	23		25.75	24.4625	31.66983	33.6	0.000679	92.18632
24	24	29.5	24	6	26.75	25.4125	29.83017	29.8	0.000678	100
23.5	23.5	29.5	23	4	26.25	24.9375	28.9459	28.9	0.000678	100
24	24	28.5	23.5	4	26	24.7	29.83017	29.8	0.000678	100
27	26	28	25	6	26.5	25.175	33.60787	35.6	0.00068	92.34314
29	27	30	25.5	2	27.75	26.3625	35.6487	40.1	0.00068	85.55195
29	27.5	29.5	26	3	27.75	26.3625	36.70908	40.1	0.000681	89.05834
28.5	26	30	24.5	6	27.25	25.8875	33.60787	38.9	0.00068	81.94242
25	24.5	29	23.5	6	26.25	24.9375	30.73797	31.7	0.000679	95.97203
24	24	26	23.5	16	24.75	23.5125	29.83017	29.8	0.000678	100
24.5	24	26.5	23.5	6	25	23.75	29.83017	30.7	0.000678	95.92881
27.5	26.5	30.5	24	4	27.25	25.8875	34.61515	36.7	0.00068	92.41862
28	26.5	30	24.5	2	27.25	25.8875	34.61515	37.8	0.00068	88.84717
27	26	30	24	4	27	25.65	33.60787	35.6	0.00068	92.34314
27	26	30	24	2	27	25.65	33.60787	35.6	0.00068	92.34314
26	24.5	30.0	24.0	6.0	27	25.65	30.73797	33.6	0.000679	88.39177
27	25.5	29.5	23.0	2.0	26.25	24.9375	32.62628	35.6	0.000679	88.62523
26	25.0	30.5	23.5	2.0	27	25.65	31.66983	33.6	0.000679	92.18632
26.5	25.5	30.5	24.5	2.0	27.5	26.125	32.62628	34.6	0.000679	92.26572
26	24.5	30.5	23.0	3.0	26.75	25.4125	30.73797	33.6	0.000679	88.39177
24	24.0	30.0	22.5	3.0	26.25	24.9375	29.83017	29.8	0.000678	100
28	26.0	31.0	23.5	2.0	27.25	25.8875	33.60787	37.8	0.00068	85.27259
25.5	24.5	30.5	23.0	2.0	26.75	25.4125	30.73797	32.6	0.000679	92.10485
26	24.5	30.5	23.0	4.0	26.75	25.4125	30.73797	33.6	0.000679	88.39177
26	25.0	30.5	24.0	4.0	27.25	25.8875	31.66983	33.6	0.000679	92.18632

28	26.5	31.5	24.5	2.0	28	26.6	34.61515	37.8	0.00068	88.84717
28.5	26.5	31.5	24.5	2.0	28	26.6	34.61515	38.9	0.00068	85.414
28.5	27.0	31.5	24.5	3.0	28	26.6	35.6487	38.9	0.00068	88.95405
28	26.5	31.5	24.0	2.0	27.75	26.3625	34.61515	37.8	0.00068	88.84717
27.5	26.0	31.0	24.0	2.0	27.5	26.125	33.60787	36.7	0.00068	88.73759
27	26.0	32.5	23.0	3.0	27.75	26.3625	33.60787	35.6	0.00068	92.34314
24	24.0	31.5	23.0	2.0	27.25	25.8875	29.83017	29.8	0.000678	100
25	24.0	32.0	23.0	2.0	27.5	26.125	29.83017	31.7	0.000678	92.02124
27	25.0	31.0	22.5	4.0	26.75	25.4125	31.66983	35.6	0.000679	84.97893
23	23.0	30.5	22.0		26.25	24.9375	28.08464	28.1	0.000677	100
27	24.0	26.5	22.5	8.0	24.5	23.275	29.83017	35.6	0.000678	77.89502
27	25.0	30.0	23.0	6.0	26.5	25.175	31.66983	35.6	0.000679	84.97893
26	24.5	30.0	23.0	3.0	26.5	25.175	30.73797	33.6	0.000679	88.39177
26	24.5	31.0	23.5	2.0	27.25	25.8875	30.73797	33.6	0.000679	88.39177
25	24.0	30.5	23.5	3.0	27	25.65	29.83017	31.7	0.000678	92.02124
28	24.5	31.5	23.0	4.0	27.25	25.8875	30.73797	37.8	0.000679	74.95701
27.5	25.0	31.0	23.5	2.0	27.25	25.8875	31.66983	36.7	0.000679	81.58716
25.5	24.0	32.0	22.5	3.0	27.25	25.8875	29.83017	32.6	0.000678	88.27046
24.5	24.0	30.0	23.0	4.0	26.5	25.175	29.83017	30.7	0.000678	95.92881
26	24.5	29.5	23.0	2.0	26.25	24.9375	30.73797	33.6	0.000679	88.39177
28.5	26.0	31.0	23.0	1.0	27	25.65	33.60787	38.9	0.00068	81.94242
26.5	25.5	31.5	24	2	27.75	26.3625	32.62628	34.6	0.000679	92.26572
26	25	30.5	24.5	4	27.5	26.125	31.66983	33.6	0.000679	92.18632
28	25.5	29.5	25.5	2.6	27.5	26.125	32.62628	37.8	0.000679	81.76702
27	25	33	24	3	28.5	27.075	31.66983	35.6	0.000679	84.97893
28	25.5	30	24	1	27	25.65	32.62628	37.8	0.000679	81.76702
28	27	32.5	22		27.25	25.8875	35.6487	37.8	0.00068	92.49224
27	25	32.5	23	2.4	27.75	26.3625	31.66983	35.6	0.000679	84.97893
27	25.5	29.5	23	2	26.25	24.9375	32.62628	35.6	0.000679	88.62523
27.5	25	33	24	3	28.5	27.075	31.66983	36.7	0.000679	81.58716
27	24	33.5	23	1	28.25	26.8375	29.83017	35.6	0.000678	77.89502
27	24	33	22.5	1	27.75	26.3625	29.83017	35.6	0.000678	77.89502
27	23	33	18.5	4	25.75	24.4625	28.08464	35.6	0.000677	71.07947
24	20	33	18.5	4	25.75	24.4625	23.37244	29.8	0.000675	69.17807
25	21.5	33	19	2	26	24.7	25.63388	31.7	0.000676	73.36764
26	22	32.5	18.5	2	25.5	24.225	26.42913	33.6	0.000677	70.47894
26	23	32.5	22	4	27.25	25.8875	28.08464	33.6	0.000677	77.43824
28	26	32	23	4	27.5	26.125	33.60787	37.8	0.00068	85.27259
27	24	33.5	24	4	28.75	27.3125	29.83017	35.6	0.000678	77.89502
28	24	33.5	24	4	28.75	27.3125	29.83017	37.8	0.000678	71.64971
27	24	34	23	4	28.5	27.075	29.83017	35.6	0.000678	77.89502
27	24.5	34	24.5	4	29.25	27.7875	30.73797	35.6	0.000679	81.4027
26	24	33.5	20	3.5	26.75	25.4125	29.83017	33.6	0.000678	84.66995
25	24	33.5	19	3	26.25	24.9375	29.83017	31.7	0.000678	92.02124
27	23.5	34	22	2.8	28	26.6	28.9459	35.6	0.000678	74.45443
27	23	33	21.5	4	27.25	25.8875	28.08464	35.6	0.000677	71.07947

27	28.5	34	23.5	3.8	28.75	27.3125	38.91271	35.6	0.000682	112.0622
27	24	33.5	22	2	27.75	26.3625	29.83017	35.6	0.000678	77.89502
27	25	33	23.5	3	28.25	26.8375	31.66983	35.6	0.000679	84.97893
26	25	33.5	23.5	3	28.5	27.075	31.66983	33.6	0.000679	92.18632
26.5	25.5	33	23	2.8	28	26.6	32.62628	34.6	0.000679	92.26572
26.5	25	33	23	2.6	28	26.6	31.66983	34.6	0.000679	88.51
26	25	33	22.5	2.8	27.75	26.3625	31.66983	33.6	0.000679	92.18632
26	25	33	22.5	3	27.75	26.3625	31.66983	33.6	0.000679	92.18632
26.5	25	33.5	23	2.8	28.25	26.8375	31.66983	34.6	0.000679	88.51
26.5	25.5	33.5	23.5	3	28.5	27.075	32.62628	34.6	0.000679	92.26572
26.5	25	34	23	3	28.5	27.075	31.66983	34.6	0.000679	88.51
26.5	25	34	22	2.2	28	26.6	31.66983	34.6	0.000679	88.51
26	24.5	33.5	22.5	2.6	28	26.6	30.73797	33.6	0.000679	88.39177
26	24	33.5	23	2.6	28.25	26.8375	29.83017	33.6	0.000678	84.66995
27	26	34	23	2	28.5	27.075	33.60787	35.6	0.00068	92.34314
27	26	34	24	3	29	27.55	33.60787	35.6	0.00068	92.34314
27	26	34	24	3	29	27.55	33.60787	35.6	0.00068	92.34314
26.5	26	33.5	23.5	2.8	28.5	27.075	33.60787	34.6	0.00068	96.09519
26.5	26	33.5	22	3	27.75	26.3625	33.60787	34.6	0.00068	96.09519
26.5	26	34.5	21.5	2.8	28	26.6	33.60787	34.6	0.00068	96.09519
24	23	32.5	22.5	2	27.5	26.125	28.08464	29.8	0.000677	91.8473
27	25	32	23	2.8	27.5	26.125	31.66983	35.6	0.000679	84.97893
26.5	25	33	23	2.8	28	26.6	31.66983	34.6	0.000679	88.51
26	25	33	23	3	28	26.6	31.66983	33.6	0.000679	92.18632
27	26	34	23.5	3.2	28.75	27.3125	33.60787	35.6	0.00068	92.34314
26.5	25	34	24	3	29	27.55	31.66983	34.6	0.000679	88.51
26	24	33.5	22.5	2	28	26.6	29.83017	33.6	0.000678	84.66995
27	23	33.5	21.5	2	27.5	26.125	28.08464	35.6	0.000677	71.07947

4.3.4 Development of Relation between ET, RH and Temperature

ET obtained in section 4.3.1, temperature obtained in section 4.3.2 and RH calculated in section 4.3.3 is plotted as shown below. An equation connecting ET, humidity and temperature was generated using statistical software "Stastistica". R^2 indicates the accuracy of the equation in connecting the three parameters. A value of 1 for R^2 is the ideal one in which the equation generated has perfect fit.

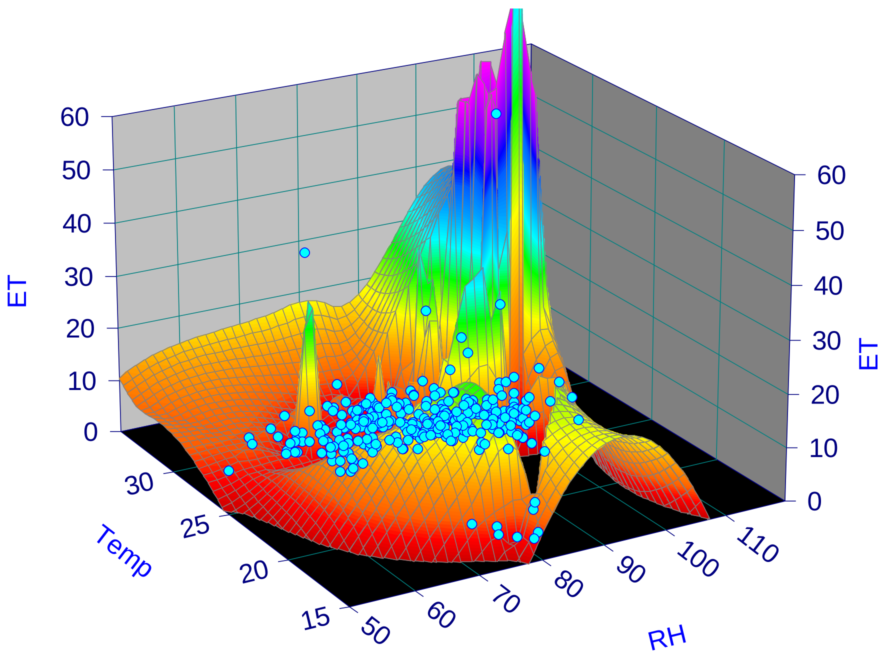


Fig.4.9 Graphical representation of equations connecting ET, humidity and temperature

Sl.no.	R^2	Rank	Equation
1	0.5285410834	272	ChebyshevX, LnY Bivariate Polynomial Order 10
2	0.5221069712	267	Chebyshev X,Y Bivariate Polynomial Order 10
3	0.5156661219	278	ChebyshevLnX,LnY Bivariate Polynomial Order 10
4	0.5083303674	272	ChebyshevLnX,Y Bivariate Polynomial Order 10
5	0.4843103019	315	Cosine Series Bivariate Order 10
6	0.4644945488	277	Fourier Series Bivariate Order 2x5
7	0.4352475177	232	ChebyshevX,LnY Bivariate Polynomial Order 9
8	0.4330112814	226	Chebyshev X,Y Bivariate Polynomial Order 9
9	0.4237592703	530	Sigmoid Series Bivariate Order 10
10	0.4055905598	32	z=a+LORX(b,c,d)+LORY(e,f,g)+LORX(h,c,d)*LORY(1,f,g)
11	0.4006037071	13	z=a+LORX(b,c,d)*LORY(1,e,f)
12	0.4002131373	92	**z**=a+EXTRVALX(b,c,d)+EXTRVALY(e,f,g)+EXTRVALX(h,c,d)*EXTRVALY(1,f,g)
13	0.372911103	270	Cosine Series Bivariate Order 9
14	0.3710320273	237	ChebyshevLnX,LnY Bivariate Polynomial Order 9
15	0.3668949001	232	ChebyshevLnX,Y Bivariate Polynomial Order 9
16	0.3116663261	460	Sigmoid Series Bivariate Order 9
17	0.2992002021	189	Chebyshev X,Y Bivariate Polynomial Order 8
18	0.2949991622	194	ChebyshevX,LnY Bivariate Polynomial Order 8
19	0.2484174486	200	ChebyshevLnX,LnY Bivariate Polynomial Order 8
20	0.2478423168	194	ChebyshevLnX,Y Bivariate Polynomial Order 8
21	0.2359057076	393	Sigmoid Series Bivariate Order 8
22	0.2264241739	228	Cosine Series Bivariate Order 8
23	0.2255635713	198	Fourier Series Bivariate Order 2x4
24	0.2070406332	154	Chebyshev X,Y Bivariate Polynomial Order 7
25	0.2044764691	160	ChebyshevX,LnY Bivariate Polynomial Order 7
26	0.1739786156	160	ChebyshevLnX,Y Bivariate Polynomial Order 7
27	0.1734770365	165	ChebyshevLnX,LnY Bivariate Polynomial Order 7
28	0.1297426456	190	Cosine Series Bivariate Order 7
29	0.1281084454	330	Sigmoid Series Bivariate Order 7

30	0.1248670777	44	z=a+EXTRVALX(b,c,d)*EXTRVALY(1,e,f)
31	0.1144778322	123	Chebyshev X,Y Bivariate Polynomial Order 6
32	0.1073291689	129	ChebyshevX,LnY Bivariate Polynomial Order 6
33	0.1009922397	131	Fourier Series Bivariate Order 2x3
34	0.0932169172	154	Cosine Series Bivariate Order 6
35	0.0873687087	129	ChebyshevLnX,Y Bivariate Polynomial Order 6
36	0.0818056152	134	ChebyshevLnX,LnY Bivariate Polynomial Order 6
37	0.0757177696	269	Sigmoid Series Bivariate Order 6
38	0.0736688196	334	Fourier Series Simple Order 2x10
39	0.072393896	300	Fourier Series Simple Order 2x9
40	0.064316551	30	$z=(a+b\ln x+c(\ln x)^2+d(\ln x)^3+e\ln y+f(\ln y)^2)/(1+g\ln x+h(\ln x)^2+i(\ln x)^3+j\ln y)$
41	0.0625375341	95	Chebyshev X,Y Bivariate Polynomial Order 5
42	0.0618987679	101	ChebyshevX,LnY Bivariate Polynomial Order 5
43	0.0572638832	122	Cosine Series Bivariate Order 5
44	0.0551543139	267	Fourier Series Simple Order 2x8
45	0.0539183395	234	Fourier Series Simple Order 2x7
46	0.0530058793	21	z=a+GAUSSX(b,c,d)*GAUSSY(1,e,f)
47	0.0499771294	101	ChebyshevLnX,Y Bivariate Polynomial Order 5
48	0.0497318531	212	Sigmoid Series Bivariate Order 5
49	0.049578813	106	ChebyshevLnX,LnY Bivariate Polynomial Order 5
50	0.0481099866	93	Cosine Series Bivariate Order 4
51	0.0474173597	44	z=a+EXTRVALX(b,c,d)*EXTRVALY(1,e,d)
52	0.0470971575	25	$z=(a+b\ln x+c(\ln x)^2+d(\ln x)^3+ey+fy^2)/(1+g\ln x+h(\ln x)^2+i(\ln x)^3+jy)$
53	0.0469047588	158	Sigmoid Series Bivariate Order 4
54	0.0355591471	200	Fourier Series Simple Order 2x6
55	0.0346960226	22	$z=(a+b\ln x+c(\ln x)^2+d(\ln x)^3+ey)/(1+f\ln x+g(\ln x)^2+h(\ln x)^3+iy)$
56	0.0346507292	27	$z=(a+b\ln x+c(\ln x)^2+d(\ln x)^3+e\ln y)/(1+f\ln x+g(\ln x)^2+h(\ln x)^3+i\ln y)$

57	0.0345920173	21	z=a+GAUSSX(b,c,d)*GAUSSY(1,e,d)
58	0.0317753845	67	Cosine Series Bivariate Order 3
59	0.0294544959	167	Fourier Series Simple Order 2x5
60	0.0286663557	70	Chebyshev X,Y Bivariate Polynomial Order 4
61	0.0278582448	76	ChebyshevX,LnY Bivariate Polynomial Order 4
62	0.027780101	77	Fourier Series Bivariate Order 2x2
63	0.027583355	76	ChebyshevLnX,Y Bivariate Polynomial Order 4
64	0.0268505511	81	ChebyshevLnX,LnY Bivariate Polynomial Order 4
65	0.0252656156	134	Fourier Series Simple Order 2x4
66	0.0195200126	54	ChebyshevX,LnY Bivariate Polynomial Order 3
67	0.0195200126	28	$z=a+bx+clny+dx^2+e(lny)^2+fxlny+gx^3+h(lny)^3+ix(lny)^2+jx^2lny$
68	0.0195193716	107	Sigmoid Series Bivariate Order 3
69	0.019429397	48	Chebyshev X,Y Bivariate Polynomial Order 3
70	0.019429397	23	$z=a+bx+cy+dx^2+ey^2+fxy+gx^3+hy^3+ixy^2+jx^2y$
71	0.0191347438	100	Fourier Series Simple Order 2x3
72	0.0186729486	54	ChebyshevLnX,Y Bivariate Polynomial Order 3
73	0.0186729485	28	$z=a+blnx+cy+d(lnx)^2+ey^2+fylnx+g(lnx)^3+hy^3+iy^2lnx+jy(lnx)^2$
74	0.0186180264	59	ChebyshevLnX,LnY Bivariate Polynomial Order 3
75	0.0186180253	33	$z=a+blnx+clny+d(lnx)^2+e(lny)^2+flnxlny+g(lnx)^3+h(lny)^3+ilnx(lny)^2+j(lnx)^2lny$

The equation to find ET with the largest R2 value was taken to find out the time left for next irrigation. It was incorporated in the code, by using humidity and temperature data from the sensors.

4.3.5 Calculation of Frequency of Irrigation

$$\text{Frequency of irrigation} = \frac{\text{Average available water} * (100 - \text{Soil moisture sensor value})}{\text{Area} * \text{ET}}$$

The average available water is obtained by taking the arithmetic mean value of available water taken from three samples. Here area is taken as 1 m^2. ET calculation is done using the equation which relates ET with RH and temperature and is mentioned in previous section. The value of ET will change according to the changes in RH and temperature which is sensed by the relative humidity and temperature sensor.

When the connections were completed and the program was run, the circuit functioned properly and provided the desired results. When the average soil moisture sensor readings of the three sensors went above 76.33%, the solenoid valve opened with a tick sound and water started flowing. When the value fell below 35%, the valve closed. Valve was programmed to have an operating phase lasting 10 seconds. When the pulsating duration of 10 seconds is finished, it's having a resting phase of 10 minutes.

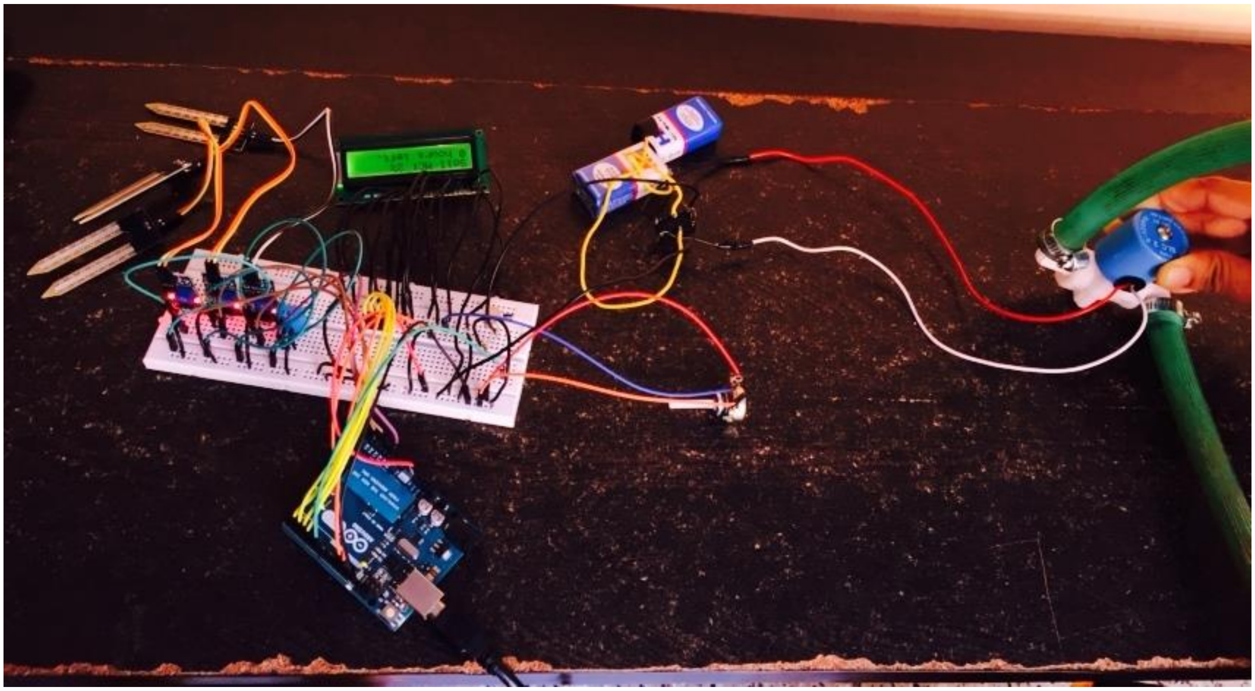


Plate 4.1 Complete circuit of the pulse irrigation system designed

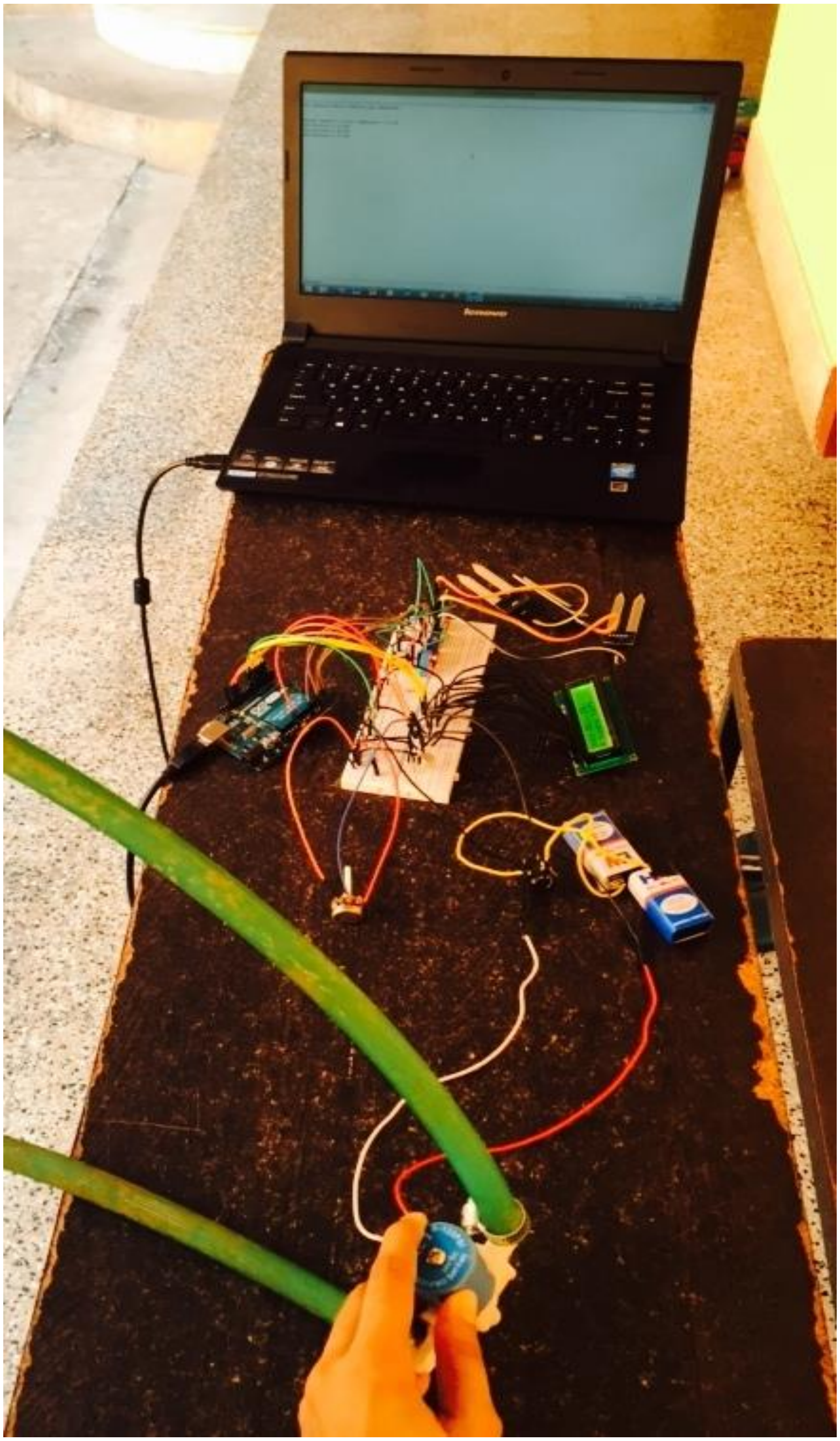


Plate 4.2 Circuit powered using a computer USB

Plate 4.3 Sample display in LCD screen

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY

The current trend in irrigation is to employ automatic operations in the irrigation system, rather than using the manual operation. Automated irrigation has many advantages such as saving of energy, reduction in labour cost and high crop yield. In field real time sensing irrigation based on varying parameters such as soil moisture, relative humidity and temperature, sudden unexpected changes in atmospheric conditions is taken into account. Thus the work on "AUTOMATION IN PULSE IRRIGATION USING ARDUINO" has been designed, developed and tested with the help of integrated features of all the hardware components used. Soil moisture characteristics were evaluated carefully and sensors were calibrated, thus contributing to the best working of the unit. The humidity and temperature sensor was used to find out the optimum duration of irrigation cycles.

The moisture sensors sense the moisture level (water content) of the different the soil. If the moisture level is found to be below the desired level, the moisture sensor sends the signal to the Arduino board which triggers the solenoid valve to turn ON and supply the water. The irrigation system has an operating and resting phase which will provide the pulsating effect. When the soil moisture level reaches a cut off value, the solenoid valve is turned OFF. This functionality of the entire system was tested thoroughly and it functioned perfectly.

The study also focused on optimal irrigation scheduling with the use of relative humidity and temperature sensor. The data from this sensor was input in a suitable equation to find the time left until the next irrigation.

5.2 CONCLUSION

From the study, it can be concluded that Arduino can be effectively used for automating pulse irrigation when integrated with soil moisture sensors and humidity and temperature sensor. It is highly flexible to varying parameters and the whole system can be easily modified and improved as and when required by just making changes in the code as per the requirements.

As a follow up activity, the following details may be taken into account for field installation of the automated pulse irrigation system.

The circuit has to be printed in a PCB (Printed Circuit Board) with all the components soldered into it. A voltage regulator has to be built for the Arduino board since it has to be run on a battery in the field. This complete setup must be installed in a metal boxing in order to protect it from external interruptions. Then the valve may be connected to the water supply on one end and required pipelines on the other. Then the automated pulse irrigation system is good to go.

Hence the study titled "AUTOMATION IN PULSE IRRIGATION USING ARDUINO" has proved to be feasible and successful.

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APPENDIX I

Table x: Observatory Data

Dry bulb Temp (°C)	Wet bulb Temp (°C)	Max Temp (°C)	Min Temp (°C)	Pan Evaporation (mm)
24.0	20.0	33.0	18.5	2.0
25.0	24.5	33.0	19.0	2.0
24.5	21.0	35.0	20.0	2.0
26.0	25.0	33.5	21.0	2.2
28.0	23.0	33.0	22.0	4.0
26.0	22.5	34.0	23.0	4.0
25.5	22.0	34.0	22.0	6.4
26.0	25.0	34.5	22.5	2.0
25.0	21.5	33.5	22.5	3.4
24.5	20.5	34.5	20.5	2.6
25.0	22.0	35.0	22.0	4.0
25.0	22.5	34.0	21.0	2.3
25.0	21.5	34.0	20.5	2.0
24.0	21.0	34.0	19.5	2.2
24.0	24.0	34.0	20.0	4.0
24.0	20.5	34.0	19.0	1.8
21.0	19.0	34.0	18.5	2.0
24.0	21.0	35.0	19.5	4.0
23.0	19.5	35.0	19.0	4.2
25.5	19.0	35.0	19.0	4.2
26.0	21.5	36.0	21.0	4.0
25.0	21.5	33.5	21.0	4.0
27.0	23.0	33.5	22.0	4.0
26.0	23.50	34.0	23.0	4.0
27.0	22.5	33.5	24.0	4.0
27.5	23.00	34.4	23.0	3.6
27.0	22.5	34.5	22.0	4.2
26.0	21.5	34.5	20.0	6.0
25.5	24.0	35.0	19.5	4.4
26.0	22.0	35.0	19.5	4.0
25.0	22.5	33.0	22.0	6.0
26.5	22.5	34.0	22.0	4.0
26.0	21.0	33.0	22.0	4.0
25.0	23.0	34.0	21.0	3.4
26.5	23.0	34.5	21.0	4.0
24.0	19.5	35.5	19.5	3.8
27.0	23.0	35.0	21.0	4.0
27.0	22.5	34.5	22.0	6.0
27.5	23.0	34.0	22.0	42.0

28.0	23.0	36.0	22.0	4.6
24.0	21.0	33.0	20.0	4.2
24.0	22.0	33.5	19.0	4.0
25.0	21.0	31.5	18.5	3.6
24.0	22.0	31.0	20.5	5.2
25.0	23.5	32.0	22.0	4.0
24.5	24.0	33.0	22.5	3.6
27.0	22.5	35.5	24.0	7.0
27.0	22.0	35.5	23.0	6.0
25.5	20.0	35.5	22.0	6.2
25.0	24.0	35.0	21.5	6.0
24.5	19.0	35.0	21.0	6.4
26.0	23.0	33.5	21.0	6.0
26.0	23.0	34.0	22.0	6.0
25.5	24.0	34.0	22.5	6.0
26.5	26.0	34.0	23.5	4.6
28.0	26.0	35.0	23.0	6.0
28.0	27.0	34.0	24.0	4.0
27.0	24.0	33.0	22.5	4.6
27.5	25.0	33.0	32.0	5.4
27.0	25.0	36.0	23.0	6.0
27.0	24.0	34.0	22.5	6.0
28.0	26.5	34.0	23.0	6.4
28.5	26.0	34.5	23.5	6.0
28.0	25.0	34.0	22.5	5.4
27.5	26.0	35.5	23.5	6.0
28.5	26.0	35.5	23.5	3.0
28.5	26.0	33.0	23.0	5.0
27.5	25.0	34.0	22.5	6.0
26.0	25.0	35.0	23.0	6.5
28.5	27.5	35.0	24.5	6.0
29.0	26.0	35.0	23.5	6.0
29.5	28.5	37.0	24.5	6.0
29.0	26.0	36.0	24.5	6.0
29.0	27.0	35.5	24.0	7.0
29.0	26.5	34.5	24.0	5.6
28.5	26.5	35.0	24.5	6.0
29.0	26.5	34.5	24.0	4.0
29.0	27.0	35.0	25.0	5.2
30.5	27.0	36.0	25.0	5.6
29.0	26.5	34.5	24.0	6.0
29.5	28.0	35.0	24.5	5.6
29.5	28.0	35.5	24.5	6.0
29.5	28.5	35.0	24.0	5.4
29.5	26.5	35.5	24.0	5.0
29.0	26.0	34.5	24.0	4.0

29.5	26.5	35.0	24.5	2.2
29.0	27.5	37.0	22.5	
28.0	26.5	37.0	25.0	2.0
29.0	26.0	33.5	23.0	6.0
28.0	24.0	34.5	21.0	
29.5	24.5	36.0	20.0	7.2
29.0	25.0	35.5	23.0	4.6
26.5	26.0	34.5	22.0	5.0
29.5	26.5	33.0	24.0	5.4
30.0	27.0	34.0	24.5	4.0
30.5	27.0	35.0	25.0	5.4
29.5	25.5	34.0	23.5	4.5
27.0	24.5	33.5	21.0	9.2
29.0	26.0	33.0	23.5	4.0
29.5	26.0	33.5	24.0	4.0
30.0	26.5	34.0	23.5	4.0
30.0	27.0	34.0	24.0	4.0
29.5	26.5	34.0	24.5	6.0
29.5	27.0	34.0	25.5	4.0
29.5	26.5	34.0	25.0	4.8
29.5	27.0	35.0	25.0	4.2
29.5	24.5	35.0	22.0	3.8
29.5	24.5	35.5	22.0	2.0
28.0	26.0	33.0	22.0	2.0
28.0	26.0	32.5	22.0	1.8
29.0	26.5	32.0	25.0	4.0
27.0	25.0	33.0	22.5	4.0
28.5	25.0	32.0	24.0	6.0
29.0	27.0	34.0	24.0	4.0
29.0	27.0	34.0	21.5	2.8
27.0	26.0	32.5	24.5	1.8
29.5	26.5	33.0	23.5	10.0
30.0	27.5	33.0		2.0
28.5	26.0	33.0		8.0
30.0	27.0	33.0		2.0
29.5	27.0	33.5		6.0
29.5	25.5	33.5		6.0
29.5	26.0	32.5		4.0
30.0	26.5	33.0		5.0
30.0	27.0	30.5		4.0
29.0	26.5	36.0	25.0	4.0
31.0	27.0	33.5	25.5	4.0
31.0	27.5	34.0	26.0	6.0
32.0	28.0	34.5	27.0	4.8
31.0	28.0	35.0	27.0	2.0
27.5	26.0	35.0	25.0	2.8

29.5	27.0	34.5	25.0	6.0
30.0	27.0	34.5	25.5	2.0
24.0	24.0	34.5	22.0	61.6
25.5	24.0	34.5	22.0	25.2
24.5	24.0	34.5	22.0	4.4
28.0	25.0	34.5	22.0	9.1
28.5	25.5	31.5	23.5	1.6
29.5	27	32.5	25.5	2
28.5	27	32	24	0.4
28.5	26.5	32	25	7
29.5	27	33	26	3
28.5	26	33	23.5	3.8
28.5	26.5	32	24.5	6
27.5	26	31.5	23.5	3.2
27.5	26	29.5	23.5	16
28.5	25.5	30.5	23.5	7.2
25.5	25.5	31.5	23.5	3
25.5	25.5	32	23.5	1
25.5	25	28	24	12.2
25	25	30	23.5	11.2
24	25	27.5	23.5	2.2
24.5	24	29	23	2
25	24.5	28.5	24.5	3.8
24.5	24	29	23	11
25	24	28	23	2
24	25	29	23	6
25	24	28	22.5	2
25	25	29	23	
26	25.5	28.5	23.5	28
27	25.5	27.5	23.5	24
27	25	31	24	3
27	26	31	23.5	4
26.5	25.5	30	23.5	6
28	26	29.5	25.5	2.6
28	27	30	26.5	2
28	27	31	25	8
27.5	27	29.5	22	3
24	24	29.5	22	8
24	24	26	22.5	
24	24	29	23	
24	23.5	26	23	4
26	24.5	30	23.5	6.4
27	26	30	23.5	8
25.5	25	30	23	3
25	25	29	22.5	3
25	25	29.5	23	3

25	25	30	23	5
24.5	24	30	23	8
26.5	26	30	24	7.2
25	25	29.5	24	7.8
26.5	26	30	24	3.8
26.5	24	30	26	8.8
23.5	23.5	28	22.5	
25	24.5	28	22.5	
26.5	25.5	29.5	24	18
24	24	30	23	4
24	23.5	27	22.5	8
24	23.5	29	22.5	10
24.5	24.5	28.5	23	6
25.5	24.5	30	24	2
23	23	28.5	22	
25	24.5	28.5	22.5	13.2
25.5	25	29	24	4
23.5	23.5	27	23	6
25.5	25	29	23	4
25.5	24	28	23.5	8.8
25	24.5	30	24	6
25	24.5	30	23	2
23.5	23	28	22	5.2
25	24.5	26.5	22.5	4.4
24.5	24	27.5	22.5	3.8
25.5	25	30	23.5	6.2
24	24.5	29	22.5	6.7
24	23	29	22	4
25	24	29	23	8
26	25.5	29	23.5	6
23.5	23.5	28.5	23.5	
26	24	29	22.5	13
26.5	25.5	28	22.5	6
26	25.5	29	23.5	4
27	25.5	30	23.5	2
27	26	30.5	24	4
27	26	30.5	23.5	3
27	26	30.5	25	1
27.5	26	31	24.5	6
27.5	26	31	24.5	4
25.5	25	30	23	3
25	25	30.5	23.5	4
24.5	24	27	23	8
26.5	25	29	23	4
27	25.5	30.5	24	5
26	25.5	30.5	23	6

24	23.5	29	22	6
25.5	25	30	23	7
24.5	23.5	28.5	22	8
25.5	24.5	30	24	7
24	23.5	30	23	3
24	24	29	22	9
24	24	28.5	22.5	4
27	26	29.5	23.5	3
27	26	30	24.5	4
26	25	30.5	23	4
27	26	31	25	8
26	24.5	30	24	6
26.5	26	31	25	4
24	24	30	23.5	5
24	24	28.5	23.5	6
26	25	28.5	23	
24	24	29.5	24	6
23.5	23.5	29.5	23	4
24	24	28.5	23.5	4
27	26	28	25	6
29	27	30	25.5	2
29	27.5	29.5	26	3
28.5	26	30	24.5	6
25	24.5	29	23.5	6
24	24	26	23.5	16
24.5	24	26.5	23.5	6
27.5	26.5	30.5	24	4
28	26.5	30	24.5	2
27	26	30	24	4
27	26	30	24	2
26	24.5	30.0	24.0	6.0
27	25.5	29.5	23.0	2.0
26	25.0	30.5	23.5	2.0
26.5	25.5	30.5	24.5	2.0
26	24.5	30.5	23.0	3.0
24	24.0	30.0	22.5	3.0
28	26.0	31.0	23.5	2.0
25.5	24.5	30.5	23.0	2.0
26	24.5	30.5	23.0	4.0
26	25.0	30.5	24.0	4.0
28	26.5	31.5	24.5	2.0
28.5	26.5	31.5	24.5	2.0
28.5	27.0	31.5	24.5	3.0
28	26.5	31.5	24.0	2.0
27.5	26.0	31.0	24.0	2.0
27	26.0	32.5	23.0	3.0

24	24.0	31.5	23.0	2.0
25	24.0	32.0	23.0	2.0
27	25.0	31.0	22.5	4.0
23	23.0	30.5	22.0	
27	24.0	26.5	22.5	8.0
27	25.0	30.0	23.0	6.0
26	24.5	30.0	23.0	3.0
26	24.5	31.0	23.5	2.0
25	24.0	30.5	23.5	3.0
28	24.5	31.5	23.0	4.0
27.5	25.0	31.0	23.5	2.0
25.5	24.0	32.0	22.5	3.0
24.5	24.0	30.0	23.0	4.0
26	24.5	29.5	23.0	2.0
28.5	26.0	31.0	23.0	1.0
26.5	25.5	31.5	24	2
26	25	30.5	24.5	4
28	25.5	29.5	25.5	2.6
27	25	33	24	3
28	25.5	30	24	1
28	27	32.5	22	
27	25	32.5	23	2.4
27	25.5	29.5	23	2
27.5	25	33	24	3
27	24	33.5	23	1
27	24	33	22.5	1
27	23	33	18.5	4
24	20	33	18.5	4
25	21.5	33	19	2
26	22	32.5	18.5	2
26	23	32.5	22	4
28	26	32	23	4
27	24	33.5	24	4
28	24	33.5	24	4
27	24	34	23	4
27	24.5	34	24.5	4
26	24	33.5	20	3.5
25	24	33.5	19	3
27	23.5	34	22	2.8
27	23	33	21.5	4
27	28.5	34	23.5	3.8
27	24	33.5	22	2
27	25	33	23.5	3
26	25	33.5	23.5	3
26.5	25.5	33	23	2.8
26.5	25	33	23	2.6

26	25	33	22.5	2.8
26	25	33	22.5	3
26.5	25	33.5	23	2.8
26.5	25.5	33.5	23.5	3
26.5	25	34	23	3
26.5	25	34	22	2.2
26	24.5	33.5	22.5	2.6
26	24	33.5	23	2.6
27	26	34	23	2
27	26	34	24	3
27	26	34	24	3
26.5	26	33.5	23.5	2.8
26.5	26	33.5	22	3
26.5	26	34.5	21.5	2.8
24	23	32.5	22.5	2
27	25	32	23	2.8
26.5	25	33	23	2.8
26	25	33	23	3
27	26	34	23.5	3.2
26.5	25	34	24	3
26	24	33.5	22.5	2
27	23	33.5	21.5	2

ABSTRACT

The current trend in irrigation is to employ automatic operations in the irrigation system, rather than using the manual operation. Automated irrigation has many advantages such as saving of water and energy, reduction in labour cost and high crop yield. Pulse irrigation is an intermittent irrigation strategy based on discharge pulses followed by breaks and is usually employed in micro irrigation systems. In this study, sensors to detect soil moisture, atmospheric humidity, and temperature were used. Arduino is an open-source prototyping platform based on easy-to-use hardware and software. Arduino hardware is microcontroller-based and provides a platform for building digital devices and interactive objects that can sense and control the physical world. Arduino software is an Integrated Development Environment (IDE) used as a programming interface for the Arduino programming language. In this study functions/modules were developed in Arduino programming language for the Arduino micro-controller which acts as a controller incorporating the data from the different sensors to control on-demand high frequency micro irrigation. The Arduino micro-controller was integrated to a LCD screen which displays the status of water available in the soil profile and when irrigation is to be applied. The Arduino board controls a solenoid valve which is switched on and off based on the sensor inputs and the irrigation pulses required. It was found that Arduino can be effectively used for automating pulse irrigation when integrated with soil moisture sensors and humidity and temperature sensor. The irrigation controller developed is highly flexible to varying parameters and the whole system can be easily modified and edited to have a desired system of irrigation.