MAKERERE UNIVERSITY

SCHOOL OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

PROJECT REPORT

DESIGN AND CONSTRUCTION OF A DIGITAL WATER LEVEL CONTROLLER THAT AUTOMATICALLY CONTROLS, MONITORS AND ENSURES A CONTINUOUS RESERVE OF WATER IN THE STORAGE TANK

SUBMITTED IN PARTIAL FULFILLMENT OF THE AWARD OF DEGREE OF BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

By

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AUTHOR DECLARATION

I declare that this report titled **"DESIGN AND CONSTRUCTION OF A DIGITAL WATER LEVEL CONTROLLER THAT AUTOMATICALLY CONTROLS, MONITORS AND ENSURES A CONTINUOUS RESERVE OF WATER IN THE STORAGE TANK"** is the result of my own research except as cited in references. The report has not been accepted in candidature of any other award.

Signature……………………………………………………

Ibrahim KIKOMEKO

Date…13th/ January/ 2022……………………………

SUPERVISOR DECLARATION

I hereby declare that I read this thesis and came to an agreement that it is sufficient in terms of scope and quality for the award of degree of BSc. in Mechanical Engineering.

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DEDICATION

I dedicate this report to my parents, Mr. Joseph SSEMAMBO (majorly) and Ms. Susan BABIRYE; my granny, Mrs. Scholastic NALWANDEKA BATTE; my uncles, Dr. Emmanuel NTAMBI, Mr. Richard BATTE, Mr. Fred SSEGUJJA and Mr. Charles GALABUZI; my aunties, Mrs. Cecilia NAKIBUULE SSEMAMBO, Mrs. Stella NALWADDA, Mrs. Olivia NAKATTE, Mrs. Harriet NABATTE and Mrs. Lillian NAMANZE; my dear brothers, Mr. Jefferson SSENYONDO, Mr. Simon NTAMBI, Mr. Julius MUTALE and Mr. Brian LUTAAKOME.

May God reward them abundantly.

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ABSTRACT

This project's goal was to design and construct a digital water level controller that automatically controls, monitors and ensures a continuous reserve of water in the storage tank. System included a microcontroller (AT Mega 328p) and a circuit (HC-SR04 sensors, pump, solenoid valve, relays, 0.91-inch OLED display, DC power supply, perforated board, and wires) which worked together in monitoring and controlling the water level in a tank. Sound reflection (echo) was used to indicate water level in the main and reservoir tank i.e., ultrasonic sensor was installed on top of both tanks to send and receive sound waves – where time taken was converted to distance by microcontroller so as to give respective digital outputs that indicate water level in the tanks via OLED display. Desired water level inputs of the controller were 10cm and 28cm in main tank and reservoir tank respectively. When there is not enough water in the main tank (reading > 10cm from ultrasonic sensor) and yet there is enough water in the reservoir tank (reading < 28cm from ultrasonic sensor), the pump turns on to start operation. Otherwise, the pump goes off and solenoid valve opens provided main tank reading is still > 10cm from ultrasonic sensor. Both the pump and solenoid valve stopped supplying water to the main tank as long as it possessed enough water (main tank reading < 10cm from ultrasonic sensor). System stability was achieved utilizing PID values automatically tuned from MATLAB™. This was intended to sustainably manage water resources with minimum or no human involvement.

The main goal of the project was attained through meeting the specific objectives of; determining system design specifications, developing a conceptual design for the system, developing a detailed design of the system, constructing and evaluating a prototype for the system.

The project started with the study and research. With the information gathered from literature study and google forms, customer needs were filtered thus generating their designs concepts respectively. Most suitable and final design concepts were selected using a concept scoring matrix. Furthermore, a prototype to the final detailed design of the system was constructed to assess technical feasibility i.e., generation of CAD model using SolidWorks™ software, and electrical circuit design using EAGLE™ software.

Keywords: Digital water level controller, sensor, concept, storage tank, OLED and circuit.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

CAD	Computer Aided Design
DC	Direct Current
EAGLE	Easily Applicable Graphics Layout Edition
I/O	Input Output
IC	Integrated Circuit
IMC	Internal Model Control
LCD	Liquid Crystal Display
LED	Light Emitting Diode
MATLAB	Matrix Laboratory
NPHC	National Population and Housing Census
PC	Personal Computer
PI	Proportional-Integral
PIC	Programmable Interface Controller
PID	Proportional-Integral-Derivative
PLC	Programmable Logic Controller
PVC	Polyvinyl Chloride
UGX	Ugandan Shillings
WfP	Water for production

CHAPTER 1 : INTRODUCTION

1.1 Background

Water is an ultimate human need. It is regularly utilized by numerous households, industries, and agricultural farms. However, due to the uncertainty of constant water supply, individuals resort to storing it in storage tanks for later use.

As of 2016, Uganda's functionality rate of water for production (WfP) [1]facilities stood at 84.4% and 0.5% for individuals relying on rain harvesting [1]. Additionally, the National Population and Housing Census (NPHC) 2014, shows that 77% of the targeted Ugandans had access to the water supply piped network [2]. This implies that a certain fraction of the above-mentioned percentage possesses storage tanks, whose water levels require control and monitoring.

Water storage tanks are filled up either by a pump or directly by a tap from a water supply source. Human-physical supervision is the most common control method of the water level during the tank filling process, i.e., turn on water supply after inspecting that water level in the tank is low and turning water supply off when the tank's water level is high. Such control approach is associated with time consumption, water wastage, seepage of walls and roofs, and extra power expenditure when the tank overflows. This is attributed to stressful conditions and the lack of attention of human nature.

In adequacy of water level management, different water level controllers have been made. However, they strictly focus on controlling either the pump or the stop valve separately rather than both of them. Therefore, there is need for more interventions that sustainably manage water resources since less than 1% of water on earth is suitable for human usage [3].

As such, a digital water level controller – that controls both the pump and the stop valve in automating the tank filling process i.e., controlling, monitoring, and maintaining the tank water level was proposed in this study. This was to ensure a continuous reserve of water in the tank with minimum or no human involvement.

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[1] **Water for Production (WfP)** refers to development and utilization of water resources for productive use in crop irrigation, livestock, aquaculture, rural industries and other commercial uses.

1.2 Problem Statement

Water storage tanks are a vital assurance of smooth water supply for households, industries, and agricultural farms. However, the tanks are usually susceptible to inadequate water level management. This is due to human monitoring and control whereby an individual will hardly get the tank's water levels right i.e., the tank running short of water unexpectedly, wastage of water and power when the tank runs full to the overflow extent. Additionally, water losses due to tank overflow threaten the strength of structural buildings.

1.3 Objectives

1.3.1 Main Objective

To develop a digital water level controller that automatically controls, monitors and ensures a continuous reserve of water in the storage tank.

1.3.2 Specific Objectives

a) To determine the design specifications and requirements for the system.
b) To develop a conceptual design for the system.
c) To develop a detailed design of the system.
d) To construct and evaluate a prototype of the system.

1.4 Scope

The project was limited to water storage tanks which intake water supply either by turning on an electric pump or opening a stop valve. The digital water level controller was to be able to automatically control, monitor and ensure a continuous reserve of water in the storage tank. A prototype was constructed to determine the system performance.

1.5 Justification

The fourth industrial revolution's tide has put automation of industrial processes at the forefront. As it is the case, automated control has gradually been superseding human control in the past decades. This is because automated control is more accurate, consistent and flexible via monitoring the process and controlling its parameters in a desired way. Different industries i.e., dairy, beverages, food processing, power generation, agricultural farms, water storage facilities and waste water treatment plants use water storage tanks at some point whose water levels require monitoring and control. As such, process automation such as digital water level controller is a serious consideration to survive and conquer the tide of the 4th industrial revolution.

Water storage tanks are important in conserving water for later use. However, human-manual control is the most used method for monitoring and controlling the water level in these tanks i.e., turn on water supply after inspecting that water level in the tank is low and turning water supply off when the tank's water level is high. Such a control approach is associated with time consumption, water wastage, seepage of walls besides roofs, and extra power expenditure when the tank overflows. This is because we as humans live a busy life and the stressful conditions make it hard for us to judge the tank's water levels right i.e., when full to avoid overflow and prior emptiness to avoid unexpected water supply blackout. Therefore, there is need of a flexible digital water level controller that automatically controls the tank's water level at the user's desired set parameters. Besides saving water, time and energy, this will ensure sustainable utilization of water resources and a continuous reserve of water in the tank with minimum or no human involvement.

With the current trends, most of the controllers have swapped from analogue to digital control system. This is because digital systems provide a high accuracy and their measurements are done quickly compared to the latter. Therefore, the proposed digital water level controller provides data in digital form so that it's easier to read by the user.

Lastly, water level controllers exist in the Ugandan market. However, they are not easily come across except in considerate industries such as power generation plants. This is because the available water level controllers are imported calling for an increment in their overall purchase price. The proposed water level controller is friendly to the Ugandan market in terms of both reliability and affordability.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

Automation is key in making systems smart so as to reduce time wastage and the regular human intercession. With that, the consequence of inadequate water level management due to human control cannot be understated. Therefore, for this project; an interest is strategized in digital water level control i.e., automatically controlling, monitoring and ensuring a continuous reserve of water in the storage tank.

This chapter introduces the theory about the digital water level control technologies, designs used, and the strategies of controlling water level in storage tanks which is considered in this study.

There are a large number of studies about digital water level control. However, since focus of the project is on water storage tanks, these studies have not been reviewed in detail and were only referred to as appropriate.

2.2 Project theoretical background

2.2.1 Water level control technology

A water level controller is a product or device that automatically controls water level thus ensuring a continuous reserve of water in a storage tank. The controller monitors the water level in the water storage tank and as well automatically fills it before it runs fully-empty. This is done with the help of electronics i.e., sensors, relay, integrated circuit, and LED indicator.

2.2.1.1 Classification of water level controllers and their working principle

The classification and working principle of water level controllers is fundamentally based on the type of sensors used in detecting the water level. This is elaborated as follows below;

a) Float Switch Sensor water level controller

The controller will do the same as a paper that floats on water. When water level is very low, the control element rests on the floor or on the ground of the water storage tank.

The controller is connected to an electric motor which turns on to fill the tank for a given amount of time. The time at which the motor is switched on can be adjusted.

Figure 2.1: Float Switch Sensor water level controller[4]

b) Probe Level Sensor water level controller

The controller utilizes probe sensors to switch on and off the motor basing on the assigned water levels in the tank. This happens whenever the probe(s) hit such water levels due to the help of water's electrical conductivity. The sensor can be connected in a way that it triggers on the LED light for different water levels in the tank. For example; when the water level is full – no action is taken, dropping of the water level to the reference probe triggers an alarm, triggering the fill start probe automatically fills the water in the tank, and when the tank runs full – fill stop probe is triggered to automatically stop the pump.

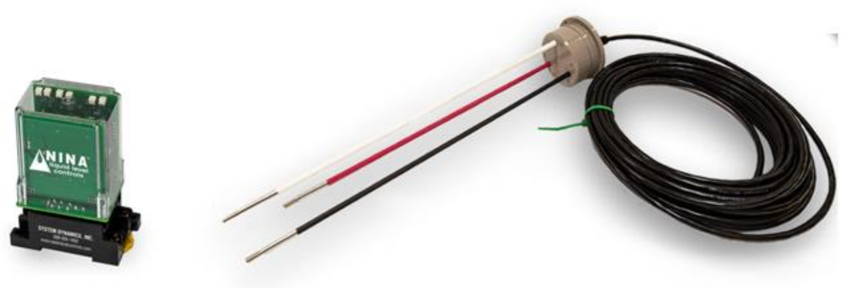


Figure 2.2: Probe Level Sensor water level controller [5]

The water level controller's probes work hand in hand so as to manage the water levels within the storage tank. Some water level controllers are made having 3 probes while others can go up to 7. More probes imply that the alarms are embedded within the controller i.e., low and high alarm to indicate when water levels become high or low.

c) Ultrasonic Level Sensor water level controller

The controller majorly utilizes two components i.e., ultrasonic sensor and a relay board. The distance (from the sensor to the water level) has to be specified in order for the motor to switch on and off. This is through execution of a distinct program in relation to the sensor. The system involves components such as; regulated DC power supply, an ultrasonic module consisting of an ultrasonic transmitter and a receiver to sense the water level status in the tank, a microcontroller acting as a control unit, a transistor, a relay to control the electric pump, and a pump acting as the electric load. Other parts include; resistors, circuit boards, capacitors, and semi-conductors. In contrast to the above-mentioned types, ultrasonic water level controller does not call for any contact with the water to be controlled.

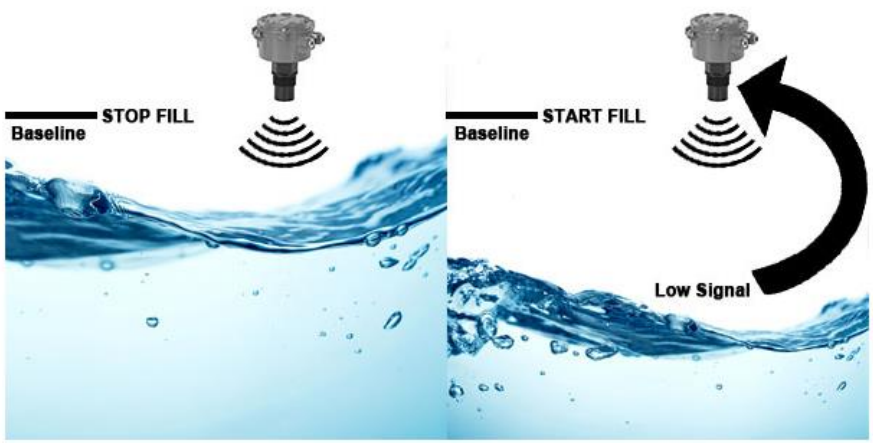


Figure 2.3: Ultrasonic Level Sensor water level controller [6]

The ultrasonic sensor detects the water level in the tank by transmitting ultrasonic signals towards it. The ultrasonic signals are then reflected back to the receiver from the water level in the tank. Received signals or echoes are converted to electric signal pulses that are sent to the Microcontroller for the tank's water level signification. When the water level decreases below a set level, the ultrasonic module gives feedback through the electric signal and a microcontroller accordingly influences the relay to switch on the pump. When the water level is rather above the threshold level, the microcontroller accordingly influences the relay (through the transistor), in order to turn off the pump.

2.2.1.2 HC SR04 Ultrasonic Sensor

The sensor provides non-contact measurements ranging from 2cm - 400cm. Its accuracy possibly reaches up to 3mm. The component includes a transmitter, receiver and control circuit. This is shown in the Figure 2.4.

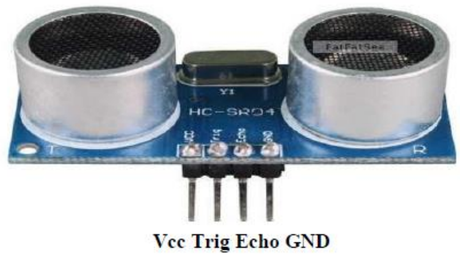


Figure 2.4: HC SR04 Ultrasonic Sensor

2.2.1.3 Arduino UNO

The Arduino Uno consists of a high-performance Microchip 8-bit AVR RISC-based microcontroller combines 32KB ISP flash memory with read-while-write capabilities, 1KB EEPROM, 2KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, 6-channel 10-bit A/D converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and five software selectable power saving modes. The device operates between 1.8-5.5 volts.

Note: *AVR does not stand for an acronym but are modified Harvard architecture 8-bit RISC microcontrollers*

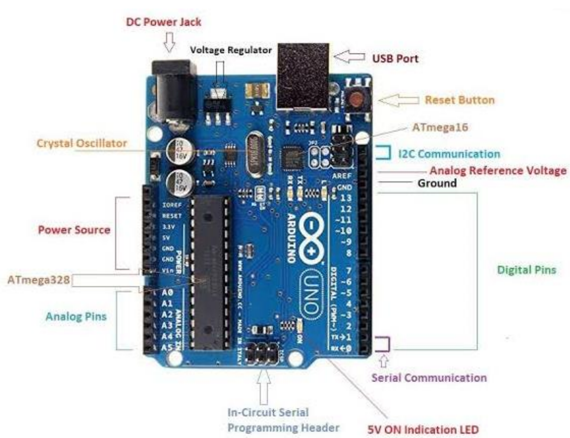


Figure 2.5: Arduino UNO

2.2.1.4 OLED 0.91-inch screen

This is a monochrome graphic display module with a built-in 0.91 inch, 128X32 high-resolution display. Its display color is usually white. Terminals include: GND-Power Ground, VCC-Power, SCL-Clock Line, and SDA-Data Line. OLED 0.91 inch is able to work despite the absence of backlight. In a dark environment, contrast of OLED display is higher than LCD display. This device is I^2C or SPI compatible. Due to its capability in displaying, it is often used in various application for instances, smart watch, MP3, function cellphone, portable health device and many others.

Figure 2.6: OLED 0.91-inch screen

2.2.1.5 Relay

A relay is an electromechanical device that is used for controlling high voltage but is itself powered using a low voltage. It is made up coils which get magnetised when a current is passed through them and it completes the circuit or opens it when no current flows through it depending on the selected configuration. They are of varying input voltages which include 5v, 6v, 12v, 9v or even greater. Application of relays is in switching circuits, automation projects, controlling heavy loads, safety circuits, and automobile electronics.

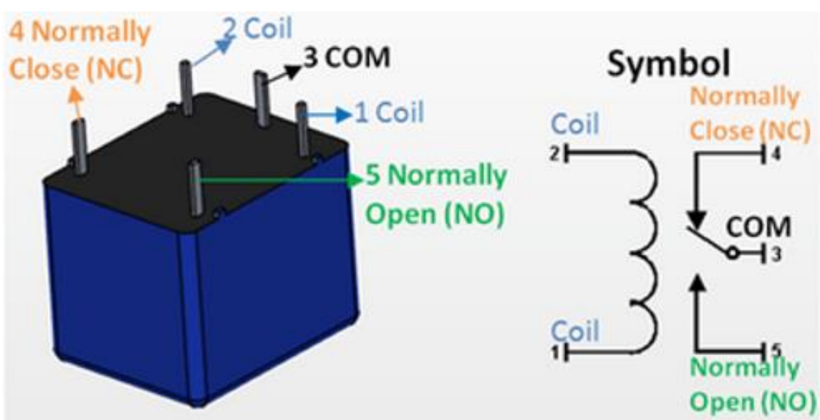


Figure 2.7: Relay Switch

The relay has up to 5 terminals each having a different purpose as discussed below.

Table 2.1: Pin Configuration of a Relay

Pin Number	Pin Name	Description
1	Coil End 1	Triggers the relay either ON or OFF with one end either connected to Ground or VCC.
2	Coil End 2	Triggers the relay either ON or OFF with one end either connected to ground or VCC.
3	Common (COM)	Connected to one end of the Load that is to be controlled
4	Normally closed (NC)	This connection causes the load to remain connected before trigger.
5	Normally open (NO)	This connection causes the load to remain disconnected before trigger.

2.2.1.6 Solenoid valve

This is an electro-mechanical device that controls the flow of liquid or gas. When powered, the valve opens and allows flow. However, when not powered, the valve does not allow flow through it. Major advantage of the solenoid valve is automated remote operation especially for the case of hazardous places.

The component consists of a coil, plunger and sleeve assembly. In normally closed valves, a plunger-return spring holds the plunger against the orifice and prevents flow. Once the solenoid coil gets energized, the resultant magnetic field raises the plunger, enabling flow. For normally open valve, energizing the solenoid coil rather makes the plunger seal off the orifice thus prevents flow.

Solenoid valve operates in a positive, fully -closed or fully-open mode. The valve either opens or closes an orifice in the valve body, which implies allowing or preventing flow through the valve. A plunger opens or closes the orifice by raising or lowering within a sleeve tube by energizing the coil.

There are various types of solenoid valves. Some of them include; pilot-operated, twelve-volt, direct-acting, stainless steel, and high pressure. Most used are pilot-operated valves and have a line pressure which opens and closes the main orifice of the valve body. For applications in systems of low flow capacities, direct operated valves are utilized.

Figure 2.8: 12v Solenoid valve

2.2.1.7 Breadboard and Perforated board

These boards provide an appropriate platform for prototyping electronic circuits. It is a quick and easy means to mount and connect electronic components thus easily changeable for testing of new configurations. Soldering can be introduced in the boards for more permanent connections.

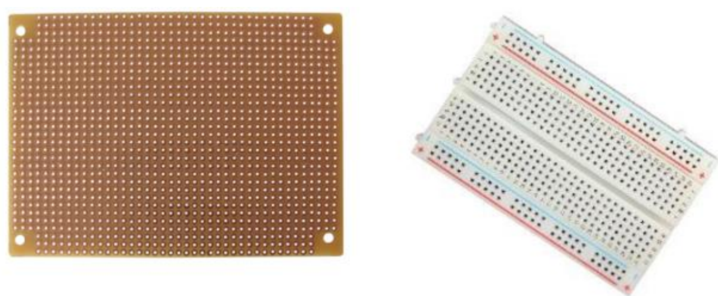


Figure 2.9: Perforated board and Breadboard respectively

2.2.2 Dynamic and Control Systems Engineering

A system is an assemblage or a combination of individual elements interacting with one another and whose total behavior is distinct from the individual behavior of its pieces or components. Examples of systems include: mechanical, electrical, fluidic, and thermal systems.

Dynamic systems engineering is an interdisciplinary branch of engineering that deals with understanding the changing behavior of complete systems over time, whereas, **Control systems engineering** is an interdisciplinary branch of engineering which is concerned with understanding and controlling segments of dynamic systems, so as to provide useful economic products for society.

The control system helps in providing a desired output/system response. It consists of a controller and a plant (the process being controlled). If the controller is a person, the control system is manual compared to automatic when the controller is rather a device, electronic circuit, computer, or mechanical linkage.

2.2.3 Open Loop Control System

The basis for analysis of a system is the foundation provided by linear system theory, which assumes a cause-effect relationship for the components of a system. Therefore, a component or process to be controlled can be represented by a block as shown in figure below.

Figure 2.10: Block diagram of a process

The input-output relationship represents the cause-and-effect relationship of the process, which in turn represents a processing of the input signal to provide an output signal variable, often with a power amplification. Therefore, a control system will comprise of; the objectives of the system or inputs or actuating signals, the results of the system also called outputs, or the control variables and the control system components.

An open-loop control system utilizes an actuating device to control the process directly without using feedback. It uses a controller and an actuator to obtain the desired response, as shown in Figure 2.11.

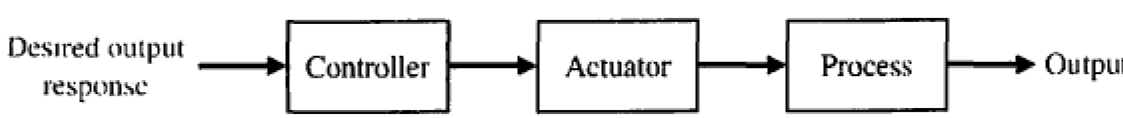


Figure 2.11: Open loop Control System

An example of open loop control system is an electric kettle which is switched on to boil water but does not switch itself off when the boiling water is ready at 100°C.

2.2.3.1 Basic Elements of an Open Loop Control System

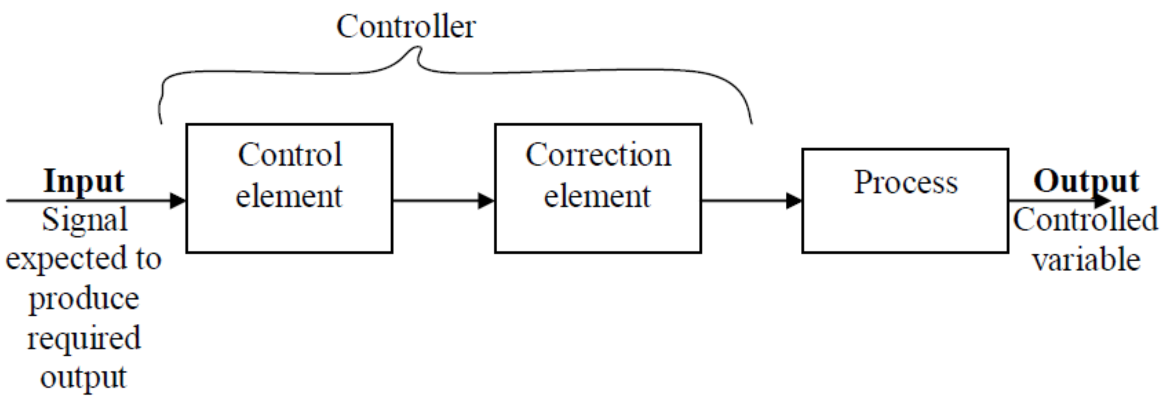


Figure 2.12: Elements of an Open Loop Control System

Control element: This element determines what action is to be taken in view of the input to the Control system.

Correction element: This element responds to the input from the control element and initiates the action to change the variable being controlled to the required value.

Process: The process or plant is the system of which whose variable is being controlled.

For example, in an open loop-controlled speed motor; the variable is the motor speed, process is the motor, correction element is the switch, and control element is the person making decisions based on experience of the speeds produced by switching on the motor.

2.2.4 Closed Loop Control System

In contrast to an open-loop control system, a closed-loop control system utilizes an additional measure of the actual output so as to compare the actual output with the desired output response (reference or command). The measure of the output is called the feedback signal. A simple closed-loop feedback control system is shown in Figure 2.13.

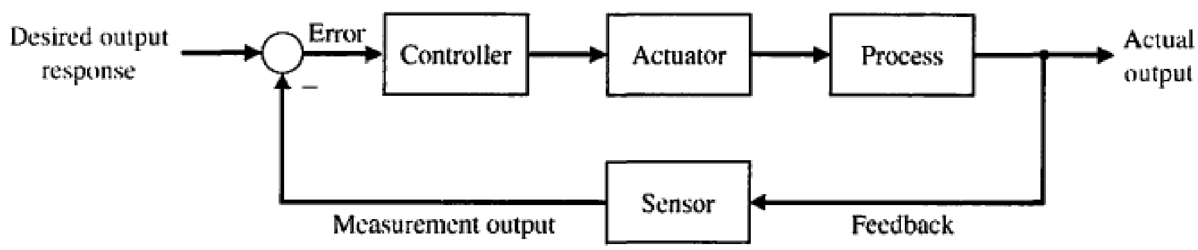


Figure 2.13: Simple closed-loop feedback control system

An example of a closed-loop control system is a person steering an automobile (assuming his or her eyes are open) by looking at the vehicle's location on the road and making the appropriate adjustments.

2.2.4.1 Basic Elements of a Closed Loop Control System

The overall input to the control system is the required value of the variable and the outcome is the actual value of the variable.

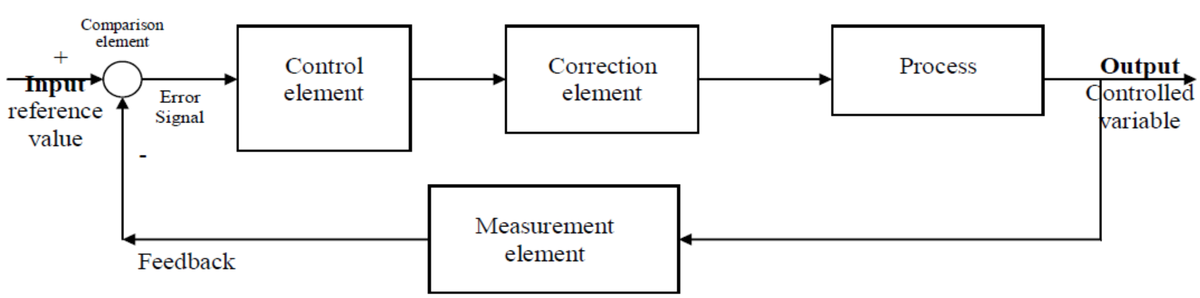


Figure 2.14: Elements of a Closed Loop Control System

Comparison element: This compares the required or reference value of the variable being controlled with the measured value of that being achieved thus produce an error signal. The error signal indicates how far the value of what is being achieved is from the required value.

Error signal = ref value signal – measured value signal

Control element: This decides what action to take when it receives an error signal. The term controller is often used for an element incorporating the control element and the correction unit.

Correction element: This is often called an actuator and is used to produce a change in the process so as to remove the error.

Process element: This is the system of which the variable is being controlled.

Measurement element: This produces a signal related to the variable condition being controlled and provides the signal fed back to the comparison element to determine if there is an error.

Negative feedback occurs when the signal fed back is subtracted from the reference value i.e., Error signal = ref value – feedback signal. On the other hand, **Positive feedback** occurs when the signal fed back is added to the reference value i.e., Error signal = ref. value + feedback signal.

For example, in an automatic shaft speed control; controlled variable is the rotational speed of the shaft, reference value is the voltage setting for the required speed, comparison element is the differential amplifier, error signal is the difference between the reference value voltage and the feedback voltage, control element is the amplifier, correction element is the motor, process is the rotating shaft, feedback is negative, and measuring device is the tacho generator.

A closed-loop feedback control system can be a single-loop or multiloop (cascaded i.e., containing more than one feedback loop). Feedback systems in Figures 2.13 and 2.14 are single-loop feedback systems.

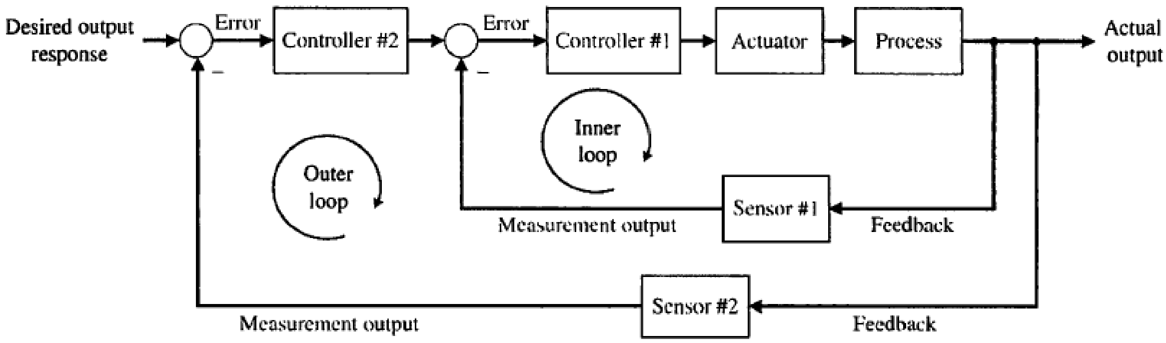


Figure 2.15: Multiloop or Cascaded feedback system[7]

A common multiloop feedback control system is illustrated in Figure 2.15 with an inner loop and an outer loop. In this scenario, both the inner and outer loop have a controller and a sensor.

Introduction of feedback in a control system enables us to control a desired output and improve its accuracy. However, it requires attention to the issue of stability of response.

2.2.4.2 Advantage comparison amid open loop and closed loop control systems

Open loop control systems have the advantage of being relatively simple and costing consequently low with generally a good reliability. However, they are often inaccurate since there is no correction for the error.

Closed loop control has many advantages over open-loop control including; being able to match the actual to the required values (improved reduction of the steady-state error of the system), decreased sensitivity of the system to variations in the parameters of the process, ability to reject external disturbances and improve measurement noise attenuation. However, problems can arise if there are delays in the system. Such delays cause the corrective action to be taken too late and can as a consequence, lead to oscillations of the input and instability. Disturbances and measurement noise are incorporated in the block diagram as external inputs, as illustrated in Figure 2.16. External disturbances and measurement noise are inevitable in real-world applications and indeed must be addressed in practical control system designs.

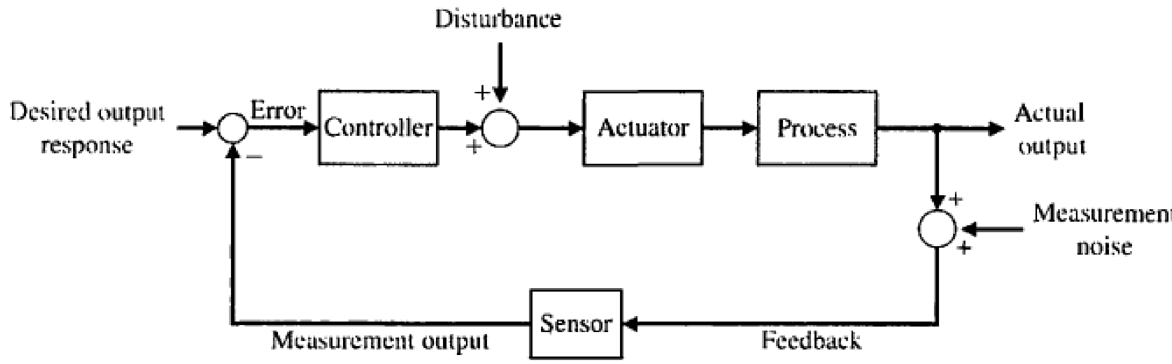


Figure 2.16: Illustration of External disturbances and measurement noise

In a meanwhile, control systems can be represented in form of either a block diagram or a signal-flow graph. This is shown in the figures 2.17 and 2.18 respectively.

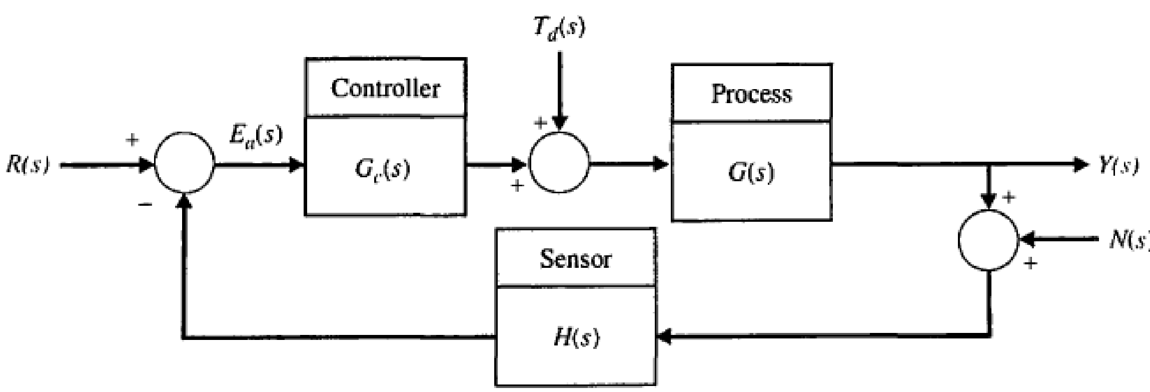


Figure 2.17: Block diagram of a Control System

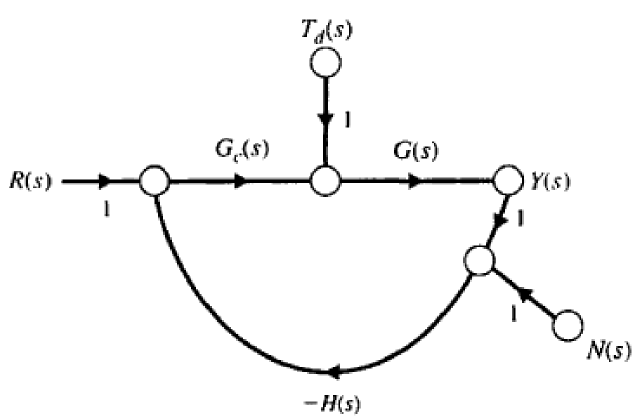


Figure 2.18: Signal flow graph of a Control System

2.2.4.3 Costs of feedback Control

Adding feedback to a control system results in the advantages mentioned just above. However, these advantages have an attendant cost.

The first cost of feedback is complexity in the system and an increased number of components with a greater chance of breakdown. To add the feedback, it is necessary to consider several feedback components; the measurement component (sensor) is the key one. The sensor is often the most expensive component in a control system. Furthermore, the sensor introduces noise and inaccuracies into the system.
The second cost of feedback is the loss of gain. For example, in a single-loop system, the open-loop gain is $G_c(s)G(s)$ and is reduced to $G_c(s)G(s)/\ (1 + G_c(s)G(s))$ in a unity negative feedback system. The closed-loop gain is smaller by a factor of $1/\ (1 + G_c(s)G(s))$, which is exactly the factor that reduces the sensitivity of the system to parameter variations and disturbances. It's important to note that it is the gain of the input-output transmittance that is reduced.

The final cost of feedback is the introduction of the possibility of instability. Whereas the open-loop system is stable, the closed-loop system may not be always stable.

The addition of feedback to dynamic systems causes more challenges for the designer. However, for most cases, the advantages far outweigh the disadvantages, and a feedback system is desirable. Therefore, it is necessary to consider the additional complexity and the problem of stability when designing a control system.

During control system analysis, the target wanted is for the output of the system, $Y(s)$, to equal the input, $R(s)$. However, a question arises as to, why not simply set the transfer function $G(s) = Y(s)/R(s)$ equal to 1? (Assuming disturbance, $T_d(s) = 0$). The answer to this question is apparent since $G(s)$ equal to 1, implies that the output is directly connected to the input. It is crucial to note that a specific output (such as temperature, shaft rotation, or engine speed), can be desired, whereas the input can be a potentiometer setting or a voltage. As such, $G(s)$ is necessary to represent the real physical process and therefore we must settle for a practical transfer function since $G(s) = 1$ is unrealizable.

2.2.4.4 Stability of Linear Closed-Loop Feedback Systems

Stability of closed-loop feedback systems is fundamental in control system design. A stable system should exhibit a bounded output if the corresponding input is bounded. This is known as bounded-input-bounded-output stability.

A system is stable for example if when it is subjected to an impulse input, the output dies away to zero as time tends to infinity. If the output tends to infinity as time tends to infinity, then the system is said to be unstable. If the output does not die away to zero or increase to infinity but rather tends to some finite-non zero value, then the system is said to be marginally or critically stable. Therefore, in terms of the convolution integral for a bounded input i.e., $\int_{0}^{\infty}|g_{(t)}|dt$, output must be finite for stability.

Stability of a feedback system is directly related to; 1) the location of the roots of the characteristic equation for the system transfer function; and 2) the location of the eigenvalues of the system matrix for a system in state variable format.

Some techniques used in determining stability of a closed loop control system include the following;

a) Routh-Hurwitz stability criterion

The Routh-Hurwitz method is introduced as a useful tool for assessing system stability. The technique enables us to compute the number of roots of the characteristic equation in the right half plane without actually computing the values of the roots. This gives a design method for determining values of certain system parameters that will lead to closed-loop stability.

The determination for stability of a system given its transfer function, involves the determination of the roots for the denominator of the function and considering whether any of them is positive.

The characteristic function is of the form;

$$q(s) = a_n s^n + a_{n-1}s^{n-1} + a_{n-2}s^{n-2} + \cdots + a_1 s + a_0$$

With n more than 3, it may be hard to determine the roots. This criterion presents a method which can be used in such situations.

During the Routh-Hurwitz analysis, the coefficients in the characteristic function are first inspected;

i. If they are all positive and non are zero, then the system is stable.
ii. If any coefficient is negative, then the system is unstable.
iii. If any coefficient is zero, then at best system is critically stable.

Routh Hurwitz criterion is valid only if the characteristic equation is algebraic with real coefficients. If any one of the coefficients is complex, or if the equation is not algebraic, such as containing exponential functions or sinusoidal functions of s, the criterion then cannot be applied.

b) Relative stability

For stable systems, the notion of relative stability is introduced so as to characterize the degree of stability. The relative real part of each root of a pair of roots is used in measuring the property.

If a system satisfies the Routh –Hurwitz criterion and is absolutely stable, it is desirable to determine the relative stability i.e., it is necessary to investigate the relative damping of each root of the characteristic function. This is done by shifting the axis to the left by same magnitude obtained on a trial-and-error basis. The shift of the axis to $-\sigma$ means that in the denominator of the transfer function, all the values of s are replaced by $(r-\sigma)$ where the equation in r is now to be tested for stability.

The shifting of the s –plane axis in order to ascertain the relative stability of a system is a very useful approach, particularly for higher order systems with several pairs of closed loop complex conjugate roots.

c) Stability using poles

For linear systems the stability requirement can be defined in terms of the poles of the closed loop transfer function. The location of the poles in the s-plane of a system indicate the resulting transient response. The poles in the left-hand position of the s- plane results in a decreasing response for disturbance inputs. The poles on the jw-axis and in the right-hand planes result in a neutral and an increasing response, respectively, for a disturbance input. Therefore, a necessary and sufficient requirement for stability of a feedback system is that all poles of the systems transfer function should have negative real parts.

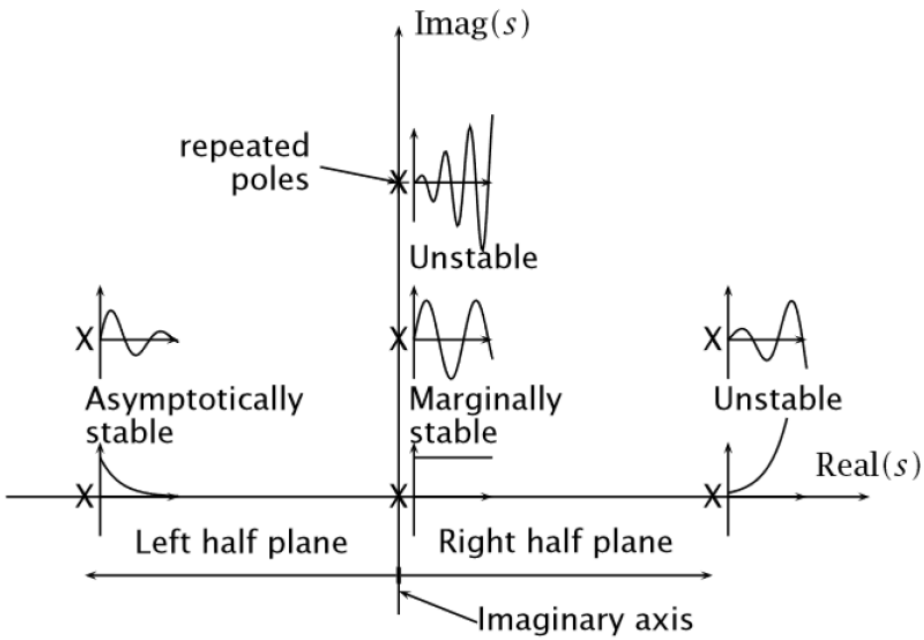


Figure 2.19: Stability analysis using poles on an s-plot

2.2.5 Continuous and Discrete Time Control Systems

Continuous time control systems are systems (whether linear or nonlinear) where all of their variables are continuous signals i.e., are in analogue form say for the input and output. Analogue inputs can be oven temperature, fluid pressure, and fluid flow rate, whereas analogue outputs can be fluid valve position, motor position and velocity. Figure 2.20 shows a typical continuous time control system.

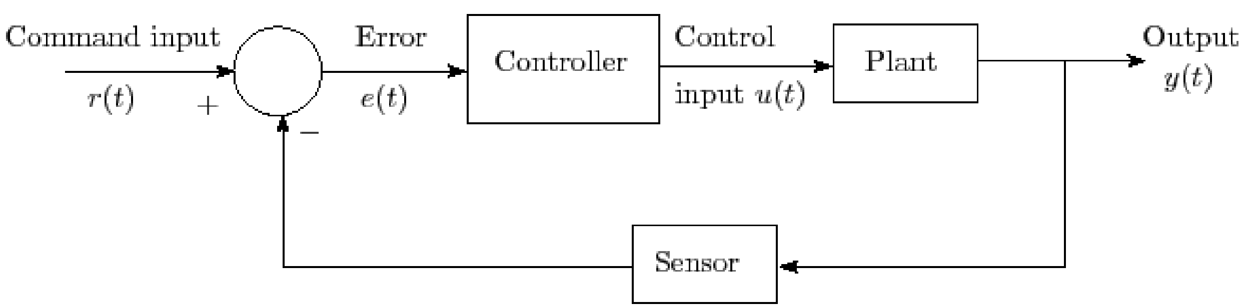


Figure 2.20: Continuous time control system

On the other hand, Discrete-time control systems are control systems where one or more inputs change only at discrete time instants, i.e., the inputs are effectively on-off signals and are in digital form rather than the analogue form. This form of control is often called sequential control and involves logic control functions.

An example of sequential control include is an automatic kettle i.e., when the kettle is switched on, the water heats up and continues heating until a sensor indicates that boiling is occurring. The sensor gives an on-off signal for the kettle to automatically switch off. The heating element of the kettle is not continuously controlled but rather only given start and stop signals. Figure 2.21 shows logical and continuous values.

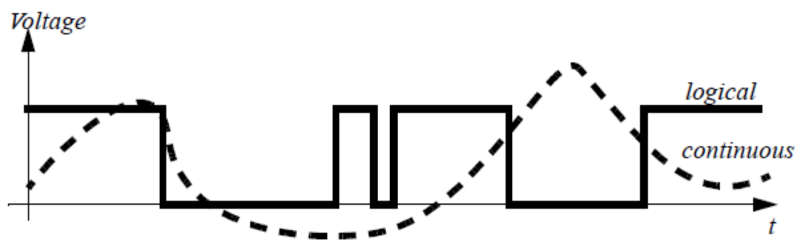


Figure 2.21: Logical and Continuous representation[8]

Analog to digital and digital to analog conversion uses integers within the computer. Integers limit the resolution of the numbers to a discrete, or quantized range. The effect of using integers is shown in Figure 2.22 where the desired or actual analog value is continuous, but the possible integer values are quantified with a 'staircase' set of values. Consider when a continuous analog voltage is being read, it must be quantized into an available integer value. Likewise, a desired analog output value is limited to available quantized values. In general, the difference between the analog and quantized integer value is an error based upon the resolution of the analog I/O.

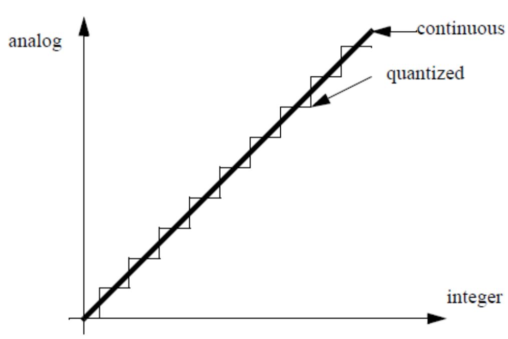


Figure 2.22: Analog - Digital relationship

2.2.5.1 Sampling Continuous Time Signals

Sampling involves taking a small quantity of something as a sample for testing or analysis. However, in the context of control systems, sampling means that a continuous-time signal is replaced by a sequence of numbers, which represents the values of that signal at certain times. Sampling is an important aspect in control systems in that it helps in analogue conversion into digital representation for processing.

In ideal sampling, the sampled signal is represented by the equation;

$$f^*(t) = \sum_{k=-\infty}^{\infty} f(kT)\delta(t-kT)$$

Where; $\boldsymbol{\delta(t-kT)}$ is the unit impulse function occurring at $\boldsymbol{t = kT}$, and continuous signal is $\boldsymbol{f(t)}$ at sampling time $\boldsymbol{T}$. Figure 2.23 shows a sampling process.

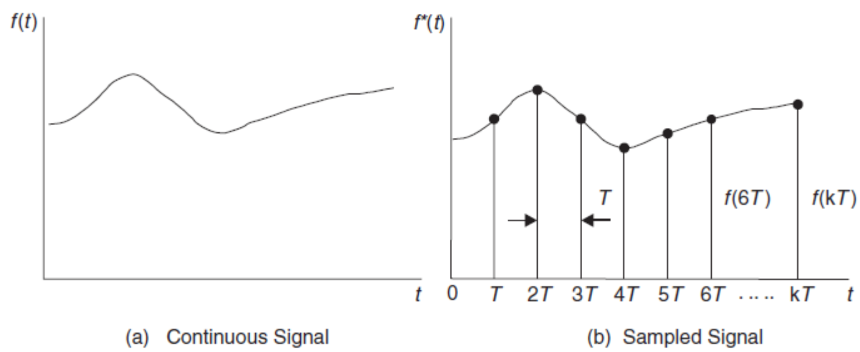


Figure 2.23: Sampling Continuous Signal

2.2.6 PID Control Strategy

PID controllers are used to control a vast range of industrial processes. In fact, they are a very common control algorithm. PID term stands for Proportional-Integral-Derivative which are all considered as control elements.

The three controllers can be either combined or used individually so as to effectively reduce the error signal. Back then, the error signal was in continuous form. However, with the increase in computer technology today, discrete digital PID controllers have come up in that the continuous error signals are sampled and converted into digital form. The digital output can be reconverted to analogue form so as to continuously supply the process. Devices such as Programmable Logic Controllers (PLC) utilize PID control algorithms due to their reliability and flexibility. Process variables controlled include; pressure, temperature, speed and flow. Figure 2.24 shows a block diagram of a basic PID controller.

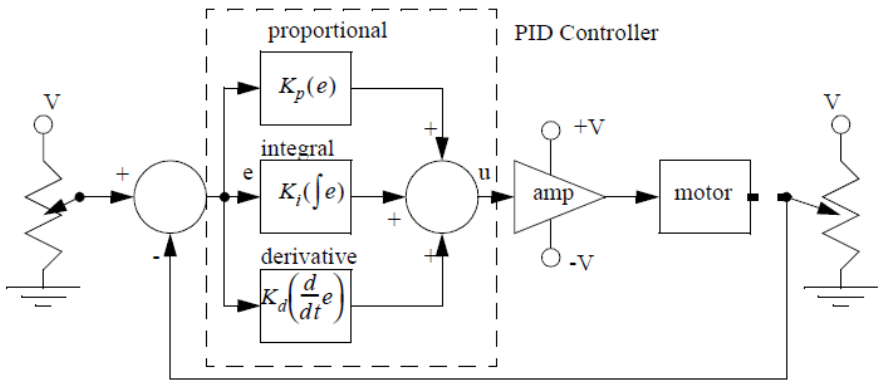


Figure 2.24: Block diagram of a basic PID controller[9]

PID controller algorithm can be defined as;

$$u(t) = K_p.e(t) + K_i.\int_0^t e(t)dt + K_d\frac{de(t)}{dt}$$

And its discrete form is;

$$u(k) = K_p\left\{e(k) + \frac{T}{\tau_i}.\sum_{k=0}^{n} e(k) + \frac{\tau_d}{T}[e(k) - e(k-1)]\right\}$$

Where;

$u(t), u(k)$ = output signal

$e(t)$ = error signal

K_p = proportional gain

K_i = integral gain

K_d = derivative gain

τ_i = integrative time

τ_d = derivative time

T = time constant

2.3 Some of the previous research on digital water level control

Simulation, Design and Practical Implementation of IMC tuned Digital PID controller for liquid level control system, Sandip A. Mehta, Jatin Katrodiya and Bhargav Mankad; the paper is mainly concerned on Liquid level control systems which are commonly used in many process control applications to control, for example, the level of liquid in a tank. Liquid enters the tank using a pump, and after some processing within the tank the liquid leaves from the bottom of the tank. The requirement in this system was to control the rate of liquid delivered by the pump so that the level of liquid within the tank is at the desired set point. Internal Model Control (IMC) tuned PID algorithm was implemented in MICROC programming language and loaded into the PIC microcontroller. The controller generated the output according to the error signal and derived the system towered the zero error. It was also interfaced with PC through MAX232 and DB9 connector for system identification and the observation of output of the system. DC pump was used in the system to reduce its cost and bulkiness. The IMC based digital PID controller with auto-tuned parameters had a much better system response than conventional PID controller and open loop system i.e., system response had fewer oscillations, less settling time, less rise time and no steady state [10].

Design of Automatic Controlling System for Tap-Water Using Floatless Level Sensor, S.A.M. Matiur Rahmani, Md. Abdullah Al Mamun, Nizam Uddin Ahamed, N. Ahmed, Md. Sharafat Ali and Md. Monirul Islam; their paper aimed at the design and development process of an automatic control system for tap water using floatless water level sensor which can save wastage of water without the presence of any operator physically. The sensing system utilized a combination of a solenoid valve, electromagnetic relay (a type of electrical switch), floatless level controller (61F) and copper electrodes (used to sense the watery level electrically). The developed system could automatically control the tap water accordingly when level sensor sensed the lower or upper level of the water tank. The system had ability to activate or deactivate the relay and solenoid valve so as to control tap water flow when lower or upper level was sensed in the tank. The system had a low-cost compared to other commercial systems and was tested to assess the success rate of the development. The result was satisfactory and proved the monitoring system to be robust and autonomous i.e., relatively simple to install [11].

Automatic Water Level Sensor and Controller System, Beza Negash Getu and Hussain A. Attia; their research paper investigates the design of a water level sensor device that is able to detect and control the level of water in a certain water tank or a similar water storage system. The system firstly senses the amount of water available in the tank by the electrode resistive sensors and then adjusts the state of the water pump in accordance to the water level information. Their system's electronic design achieves automation through sequential logic implemented using a flip flop. A digital logic processing circuit, seven-segment display and a relay-based motor pump driving circuit were part of this integrated design. The electronic system was designed to automatically control and display water levels from zero to nine i.e., the water pump automatically turns on and starts filling the tank when the water level is empty or level ONE, turns-off to stop filling the tank when water level reaches maximum-level NINE and remains in its standstill state from level EIGHT down to TWO when the level is decreasing due to water consumption. The proposed system achieved proper water management and automated productivity by eliminating manual monitoring and control for home, agricultural or industrial users. Furthermore, their design methodology recommended extension of the system design to control any other required number of water levels [12].

Ultrasonic Water Level Indicator and Controller Using AVR Microcontroller, C. Jestop Jeswin, B. Marimuthu and K. Chithra; the main objective of their project paper was to attain accurate water level measurement and have safe control over it. For example, HC-SR04 sensor was used to measure the tank water level and an AVR Microcontroller to control it from overflow. The ultrasonic sensor module "HC-SR04" used a technique called "ECHO" i.e., something you get when sound reflects back after striking with a surface. The output signal of the sensor was considered proportional to the distance based on the echo and got processed according to the high-level programming language – embedded into the microcontroller ATMega 16. According to their system design, the ultrasonic sensor output is given to the AVR microcontroller as an input for processing according to codes that are actually fed into the microcontroller to provide a desired output. A 2*16 LCD screen under four-bit mode was used to display the processed output. The controlled variable was also sent to the motor whenever there was need to excite it. This excitation of the motor was done with the help of a 5v relay switch. PLCs were avoided since they are expensive, bulky and not easily adapted to high speed I/O. Also compared to other noncontact type of level measurement, ultrasonic sensor was embraced since it produces no radiations and harmful effects to the environment. Finally, a conclusion was made that level measurement in industries using the embedded systems concept can lead to very low costs, very less man power and more compatibility for different environments [13].

Design and Fabrication of a Prototype Digital Water Level Controller using Ultrasonic Sensor Interfaced with Microcontroller, Sylvester Emeka Abonyi, Paul C. Okolie, Anthony A. Okafor and Chinagorom Makutus Nawdike; the work in their paper presents the design and fabrication of a prototype for a digital water level controller using an ultrasonic sensor interfaced with a microcontroller. Components of their system were grouped into; reservoirs, frame, pump, power supply unit, sensors, control and display unit, pipe, valves and pipe fittings. Ultrasonic sensor interfaced with the micro-controller was to do the automation required. From the control panel display unit, the water level in the tank could be observed. The supply and overhead tanks were designed and fabricated using fiber glass of thickness 5mm. The electric pump was selected basing on the capacity of the overhead tank and its distance from the supply source. Polyvinyl Chloride (PVC) pipes were selected due to their low carbon content, low cost, chemical resistance and ease of joining. The electronic circuit was designed and built using an ultrasonic sensor, microcontroller, transistors and relays. Result obtained on testing shows that the controller regulates the ON and OFF of the pump depending on the different water levels in the overhead tank. Furthermore, it was found out that at a lower pump discharge, it takes longer time to fill the tank, while at high discharge the time taken to fill the overhead tanks is reduced. The proposed control system was considered useful in various homes, offices or industry to regulate water supply thus eliminating human effort and time in operating the pump during water discharge into the overhead tank [14].

Simulation of Automatic Water Level Control System by using Programmable Logic Controller, Mrs. Yin Yin Mon, Mrs. Win Moet Moet Htwe and Mrs. Khin Ei Ei Khine; their research paper focuses on the design and implementation of a PLC-based water level control system. The research had three primary objectives i.e., the water level indicator circuit design, manual water level control system by relay and the PLC based automatic water level control. The proposed system comprised of a Siemens S7-1200 PLC, a Star-delta based induction motor starting control and the AND gate IC based water level sensor circuits. Induction motor was used to drive the pump and its starting method was selected according to the power rating, type and nature of application. Ladder diagram programming was used for 10 inputs and 10 outputs in the proposed automatic water level control. Float switches could not be used to indicate multi water levels in the desired control system. Therefore, the AND gate based digital electronic water sensor was invented and used in the proposed not only manual water level control but also PLC based automatic water level control i.e., eight steps of water level were considered as the sample water level indicators. PLC based water level control in industrial water supply was considered the most reliable and best control for sequential process [15].

Development of Real Time Digital Controller for a Liquid Level System using ATMEGA32 Microcontroller, Amruta Patra; the project describes how to implement a digital controller algorithm i.e., PI controller in real time using the ATMEGA32 microcontroller to control a model prototype for a liquid level system. The PI controller was developed in discrete domain and its parameters were determined using the open loop Ziegler Nichols tuning method. The discretized control algorithm was then implemented in the microcontroller using C language for coding. Furthermore, discretized model of the liquid level system got simulated in MATLAB Simulink so as to observe the nature of its output i.e., a comparison with the model simulation output of the uncontrolled liquid level system was done. The liquid level sensor (rotary potentiometer) detected the liquid level of the tank in terms of the voltage across it and then responded to the microcontroller. The control action generated by the microcontroller was then amplified through a suitable amplifier which actuated the pump thus control of its flow output. The operator had to set the desired level in the microcontroller and the feedback control in the real time would accordingly get operated to achieve the desired level. An attempt was also made to develop a dummy representation of the actual prototype model for automatic liquid level control in order to know the proper functioning of the algorithm. Experimental results were compared with the simulated results to show the similarity and accuracy of the controller i.e., the testing gave approximately expected results aligning with those during the implementation of the controller algorithm. This led to fine and accurate control of level of liquid at the desired height. The liquid level controller was considered useful for several industrial and household applications i.e., boiler level control and household water tanks [16].

Microcontroller Based Automatic Control for Water Pumping Machine with Water Level Indicators using Ultrasonic sensor, Joseph E. Okhaifoh, Charles Igbinoba and KO Eriaganoma; the paper presents the design, construction and testing of a Microcontroller Based Automatic Control for Water Pumping Machine and Level Indicator (MBACWPMLI). Reflection of sound (echo) was used to give the indication of water level in a storage tank i.e., the MBACWPMLI used an ultrasonic sensor installed at the top of a tank to send and receive sound waves, and the time taken was converted to distance by the microcontroller to give corresponding digital outputs which indicate the level of water in the storage tank. The microcontroller also gave digital output to turn ON the water pump (when the water in the tank was at a preset minimum level of 0.27 metres) or turn OFF the water pump (when the water went above the chosen maximum level of 0.05 metres). When the MBACWPMLI was tested, it turned ON or OFF the water pump at the preset minimum and maximum level and also the required LEDs were turned ON at the corresponding water level [17].

Construction of Automatic Water Level Controller for both Overhead and Underground Tanks, Ogbidi Joseph Abang, 2013; the paper presents the design and construction of an automatic water level controller for both overhead and underground tank to monitor the water level. The system displays the level of water and when it is at the lowest level; a pump is activated automatically to refill the tank. When the tank is filled to its maximum capacity, the pump gets automatically de-energized. Several circuits were put together to ensure proper working of the design, and the block diagram included the supply unit, the micro-processor unit, the sensor unit, the display unit and the pump drives unit. The power unit was responsible for turning on the entire circuit. Some components were used to set up power unit and they included; a 15V step down transformer, a bridge rectifier circuit, a smoothening capacitor and a voltage regulator IC. The microprocessor (AT89S50) controlled virtually all the actions carried out in the design. (AT89S50) was used in the design. The sensor unit was responsible for sensing the level of water and transfer the current position of water to the microprocessor. The display unit in the circuit was used to physically show the current position of water in the tank and the properties of seven segment display were used [18].

CHAPTER 3 : METHODOLOGY

3.1 Introduction

This chapter provides relevant information about the design, construction and evaluation of a prototype for the digital water level controller. It highlights and analyzes how the project objectives were achieved through describing; the research design, data collection methods, expected system design, engineering analysis, tools and instruments used. The final design was supposed to meet the main goal through addressing the set specific objectives.

3.2 Determining design specifications and requirements for the system

The methodology applied to this project was divided into five phases. These included; information gathering, establishing target specifications, concept generation, concept selection, and setting final product specifications. They are shown in the figure below.

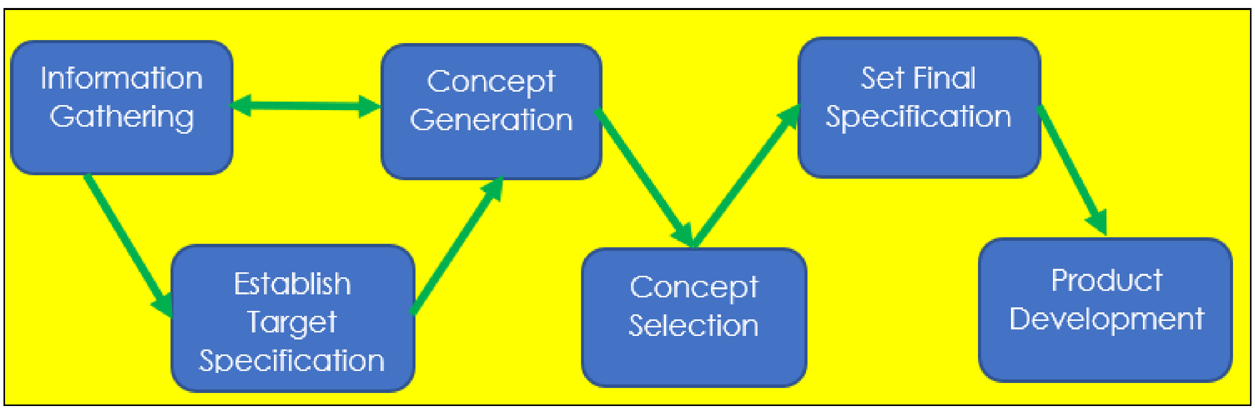


Figure 3.1: Product Design and Development phases

3.2.1 Design Information/Data Gathering

This involved carrying out research on several digital water level controllers, their designs, capacity, source of energy, operation and quality.

Research helped contribute to the final design of the digital water level controller so as it aligns with the project objective. The research instruments involved internet via a google form, mobile phone, notebook and a pen.

3.2.1.1 Primary sources of Design data

Data was collected through observations using a google form on how water level is monitored and controlled in the water storage tanks. This helped in determining a valid design for the controller.

3.2.1.2 Secondary sources of Design data

The project majorly took advantage of the necessary information from the researched available literature review in line with the project i.e., journals, published articles, and reports from google scholar that are related to digital water level control.

Visited the Makerere University electronic library, to read some related information from there, in order to gain insight into the project.

Establishment of target specifications was done basing on the customer needs generated from google form responses.

3.3 Conceptual Design of the System

After attaining the customer needs from the gathered information, concepts were generated to meet the design of the digital water level controller. This was through brainstorming intuitively, internal (individual, group) and external (lead users, literature, benchmarking) searches. The system was decomposed into critical subproblems to which concepts were generated. The generated concepts were then represented in a functional diagram and a classification tree.

3.3.1 Concept Selection

Concept scoring method was used to consider the final concepts of the project. Selection criteria was identified as they are very important in the design process towards achieving the project goals. The criteria used aligned with needs statements and included; cost of the solution, availability of solution, maintenance, ease of use/reliability, material consideration.

After identifying the design criteria, weights were assigned to each criterion in accordance to its importance to the project. Weights of the design criteria all sum up to a total of 1 or 100% and importance values (Ratings) were assigned in range of **1-5** (1 being the worst and 5 being the best).

Table 3.1: Weight of the Design criteria

Criteria	Weight
Cost of solution	0.4
Availability	0.2
Maintenance	0.25
Reliability	0.15

After the criteria being weighted, a concept scoring matrix was developed through benchmarking on existing systems so as to determine which design concept provides the best solution to the problem statement. Each design concept was given a rating for each of the criteria and the total weighted amounts (criteria weight multiplied by respective rating) was summed up.

Design concepts with the highest scores from the concept scoring matrix were taken respective to functionality. Various ways to refine and improve the design concepts were considered throughout the design process.

3.4 Embodiment Design of the System

This involved structural development of the final design concepts for the digital water level controller. Decisions were made on strength, material selection, size, shape and spatial compatibility. This was done following through product architecture, configuration design, and parametric design respectively.

3.4.1 Product Architecture of the system

This involved arrangement of the functional elements of the system so as to form an interacting physical structure. Standard parts were considered i.e., ultrasonic sensor, LED digital display, relay, controller, solenoid valve, tank, power supply, pipes and wires.

3.4.2 Configuration and Parametric Design of the system

This involved establishing spatial constraints, creating and refining the interfaces or connections between components, establishing respective critical dimensions, considering material selection and manufacturing processes basing on whether the parts are standard or special purpose. Standard parts included i.e., ultrasonic sensor, LED digital display, relay, controller, solenoid valve, tank, power supply, pipes and wires. On the other hand, special purpose part was the casing to enclose the system's circuit. The attributes obtained from configuration design became the actual design variables – affirming parametric design.

3.4.2.1 Material Selection for enclosure casing of the system's circuit

Three materials were available to choose from i.e., steel, aluminium and composite. Factors considered in the material selection process were; strength, stiffness, cost, insulation, ductility and density with insulation being considered most important and stiffness the least important of these factors. The three materials were rated as follows to the respective factors and composite material passed the screening. Suitable manufacturing process was considered as CNC technology (CAM).

Table 3.2: Material Rating

Rating	
Poor	1
Fair	2
Good	4
Excellent	5

Table 3.3: Material Weight Criteria

Factor	Weight
Strength	0.20
Cost	0.20
Insulation	0.25
Stiffness	0.05
Density	0.20
Ductility	0.10

Table 3.4: Material - Factor Evaluation

		Material – Factor Evaluation					
		Steel		**Aluminium**		**Composite**	
Criteria	**Weight**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Strength	0.20	5	1	4	0.8	5	1
Cost	0.20	4	0.8	2	0.4	2	0.4
Insulation	0.25	1	0.25	2	0.5	5	1.25
Stiffness	0.05	2	0.1	5	0.25	5	0.25
Density	0.20	1	0.20	5	1	5	1
Ductility	0.10	4	0.4	5	0.5	5	0.5
TOTAL	**1**		**2.75**		**3.45**		**4.4**

3.5 Detailed Design of the System

This involved engineering analysis i.e., application of scientific principles in an analytic way so as to assess the reality of the design. Decomposition is the basis of engineering analysis i.e.; the design is break down into parts or components and each is analyzed for operation or failure according to the scientific principles. For example, some of the components analyzed in the digital water level controller system included; the controller and the circuit.

Theoretical calculations in relation to the system design are included under this analysis. This was intended to affirm the obtained design parameters from parametric design – which is necessary for construction of the system.

MATLAB tool was utilized in mathematical modeling of the water level control system i.e., behavior simulations and continuous to discrete time transformation. For CAD model generation, Computer Aided Design software tools such as Solid Works™ and EAGLE™ were embraced during the exercise. Other tool used was the Arduino IDE environment so as to program the controller in undertaking system operation.

3.6 Construction and Evaluation for a prototype of the System

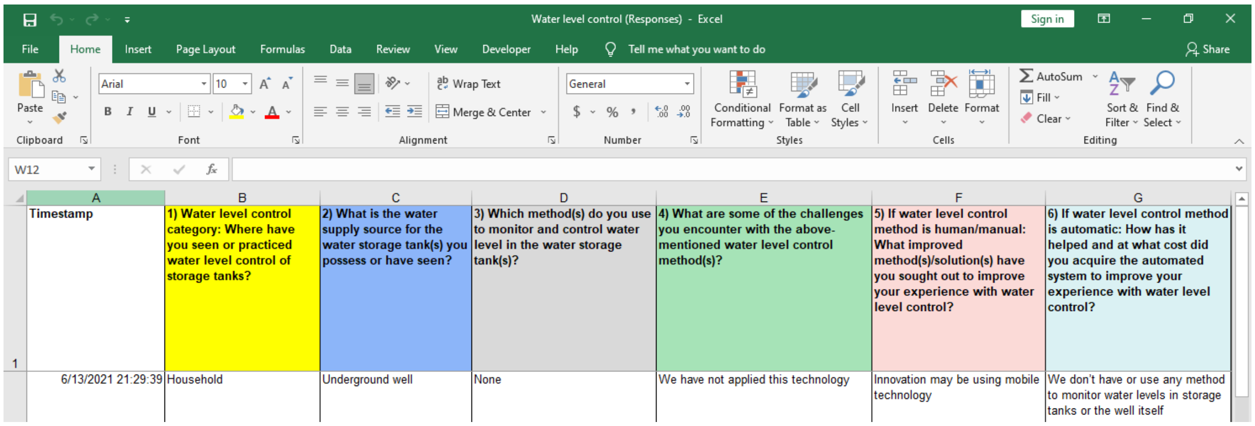
This involved producing an approximation of the final designed system so as to assess its technical feasibility. Methods such as rapid and traditional prototyping were utilized.

The materials that are to be used in the prototype construction/development were attained, finally assembled thus testing of the system's functionality. There was some refining in the design as the prototype construction went on. Observation was crucial during evaluation.

CHAPTER 4 : RESULTS AND ANALYSIS

4.1 Preliminary Design

4.1.1 Determining design specifications and requirements for the system



Timestamp	1) Water level control category: Where have you seen or practiced water level control of storage tanks?	2) What is the water supply source for the water storage tank(s) you possess or have seen?	3) Which method(s) do you use to monitor and control water level in the water storage tank(s)?	4) What are some of the challenges you encounter with the above-mentioned water level control method(s)?	5) If water level control method is human/manual: What improved method(s)/solution(s) have you sought out to improve your experience with water level control?	6) If water level control method is automatic: How has it helped and at what cost did you acquire the automated system to improve your experience with water level control?
6/13/2021 21:29:39	Household	Underground well	None	We have not applied this technology	Innovation may be using mobile technology	We don't have or use any method to monitor water levels in storage tanks or the well itself

Figure 4.1: Screenshot partly showing the google form responses

4.1.1.1 Customer needs generated from the gathered information

A list of needs statements was created basing on the google form responses. The major customer needs filtered out of the list include as follows;

a) Control both pump and national water tap supply
b) Human – Controller Interaction
c) Less power and maintenance costs of the system
d) Accurate and quick readings

4.1.1.2 Target Specifications of the system

Established target specifications basing on the generated customer needs include as follows;

Table 4.1: System Target Specifications

System Target Specifications	
Microcontroller	Arduino UNO Microcontroller
LED Digital display	0.91'' OLED
Wired Solenoid valve	12V, 0.02 – 0.8MPa, 4.8W
Ultrasonic sensor	HC – SR04
Power consumption	12V – 1A, 5V – 0.5A
Offline mobile phone control	Web app
Relay load/capacity	Maximum ratings: 10A, 250V AC
Initial time delay	50 ms
Pump dry run protection	YES

4.1.2 Conceptual Design of the System

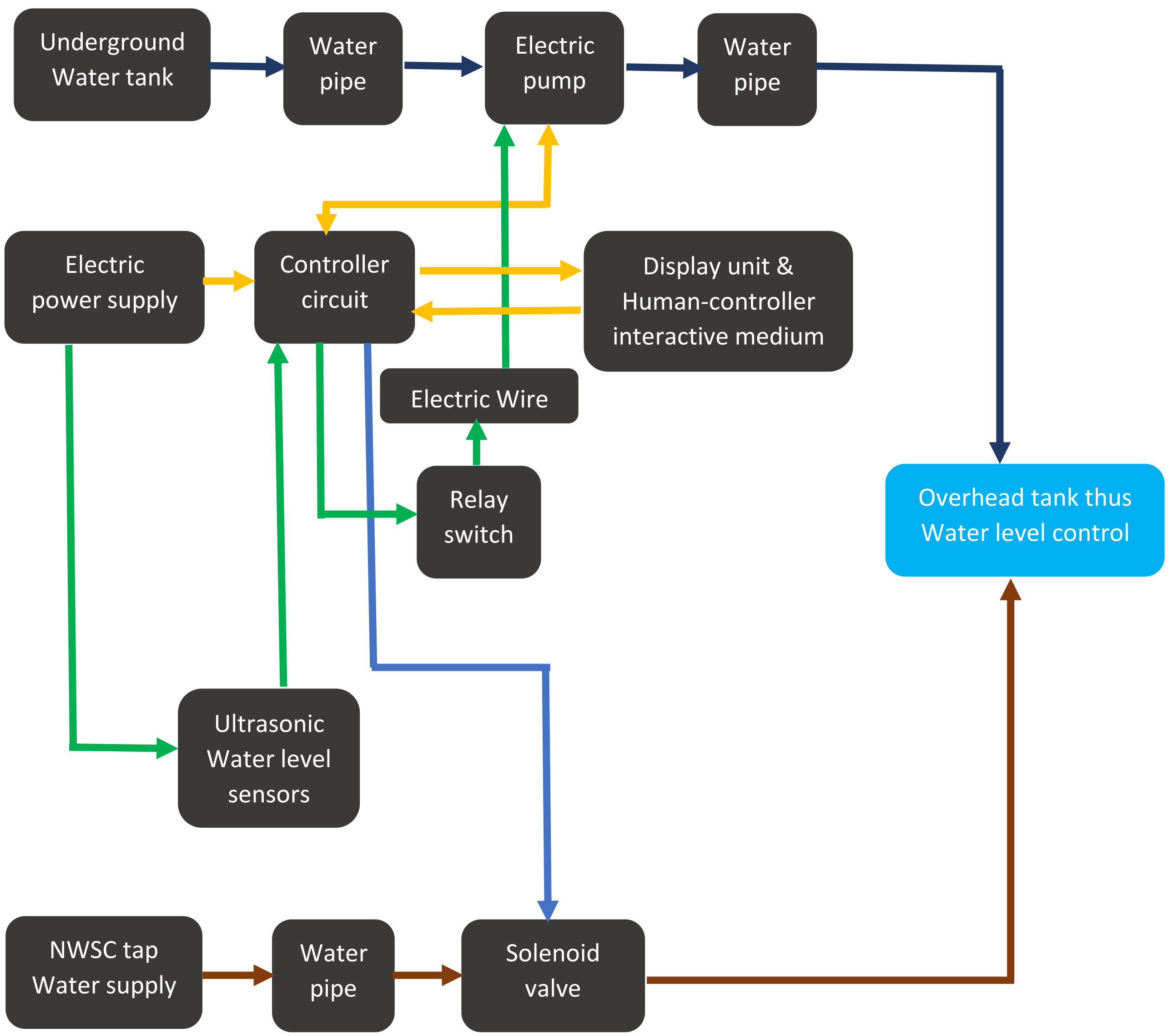


Figure 4.2: Digital Water Level Controller's Functional diagram

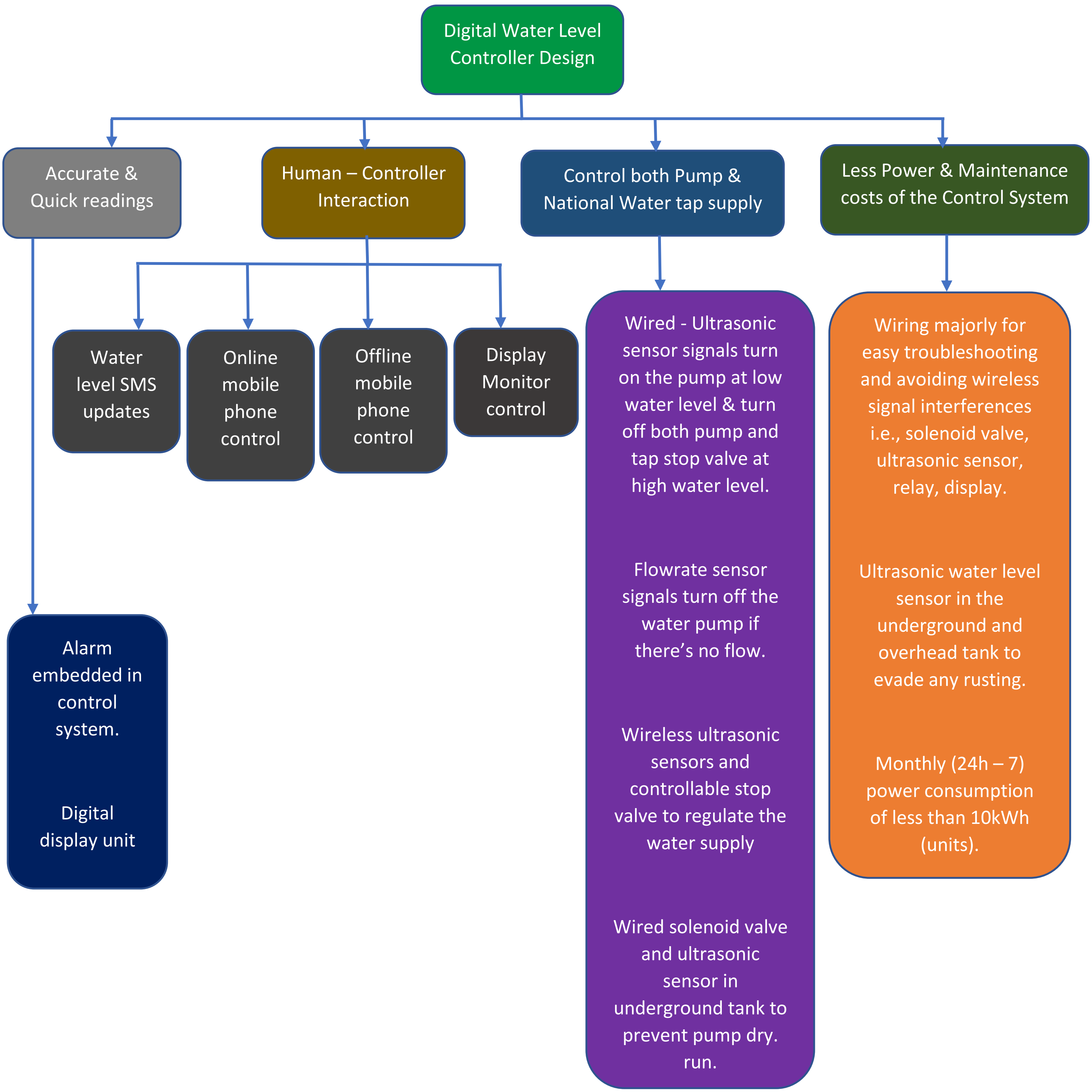


Figure 4.3: Digital Water Level Controller's Concept Classification Tree

4.1.2.1 Concept Selection

Table 4.2: Concept Scoring Matrix for Human – controller interaction concepts

		Human – controller interaction Concepts					
		SMS updates		Online mobile phone		Offline mobile phone/display panel	
Criteria	**Weight**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cost of solution	0.40	1	0.4	1	0.4	2	0.8
Availability	0.20	3	0.6	1	0.2	3	0.6
Maintenance	0.25	2	0.5	1	0.25	3	0.75
Reliability	0.15	1	0.15	2	0.3	3	0.45
TOTAL	**1**		**1.65**		**1.15**		**2.6**

Table 4.3: Concept Scoring Matrix for Control of both pump & NWSC tap supply concepts

		Control both pump & NWSC tap supply Concepts							
		Wired Flowrate sensor		Ultrasonic sensor		Wired Solenoid valve		Wireless sensors & stop valve	
Criteria	**Weight**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cost of solution	0.40	1	0.4	4	1.6	4	1.6	1	0.4
Availability	0.20	1	0.2	3	0.6	3	0.6	1	0.2
Maintenance	0.25	2	0.5	3	0.75	3	0.75	1.5	0.375
Reliability	0.15	2	0.3	3	0.45	3	0.45	1	0.15
TOTAL	**1**		**1.4**		**3.4**		**3.4**		**1.125**

Table 4.4: Final Design Concepts for the Digital Water Level Controller

Final Design Concepts
Wired – Ultrasonic water level sensor in underground and overhead tank
Wired Solenoid valve on tap supply
Digital display unit

Digital water level controller product specifications were then obtained from the final design concepts – which are originally directed to the customer needs.

Table 4.5: Digital Water Level Controller's Final Specifications

Product Specifications	
Microcontroller	Arduino UNO (AT Mega 328p) Microcontroller
LED Digital display	0.91'' OLED
Wired Solenoid valve	12V, 0.02 – 0.8MPa, 4.8W
Ultrasonic sensor in overhead tank	HC – SR04
Ultrasonic sensor in underground tank	HC – SR04
Power consumption	12V – 1A, 5V – 0.5A
Relay load/capacity	Maximum ratings: 10A, 250V AC
Initial time delay	50 ms
Pump dry run protection	YES
Wall mounting	

4.2 Embodiment Design

4.2.1 Product Architecture of the system

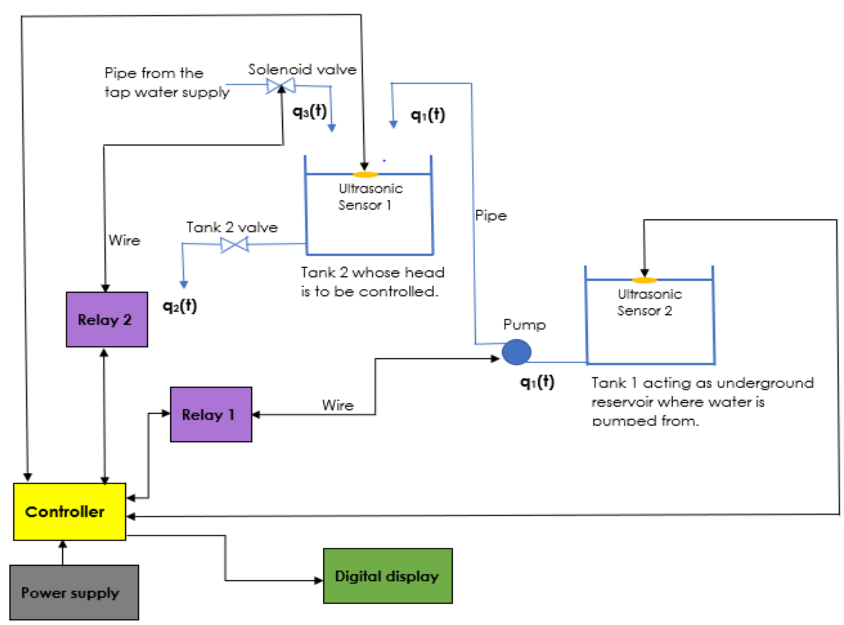


Figure 4.4: Product Architecture of the Water level Control System

4.2.2 Configuration and Parametric Design of the system

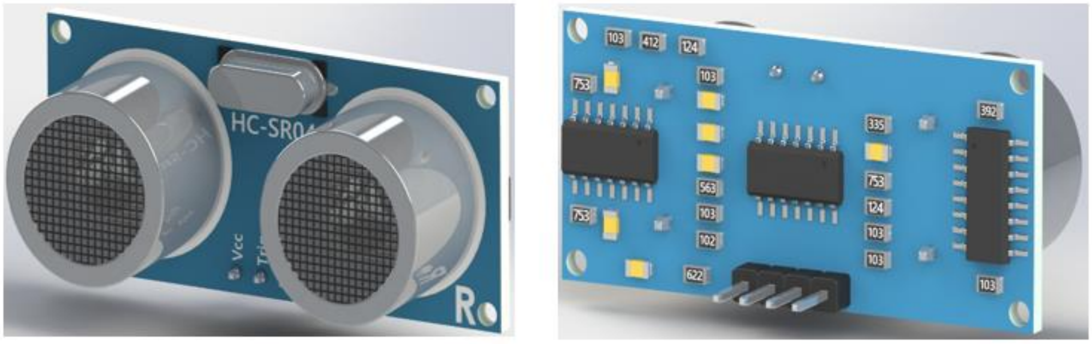


Figure 4.5: Solid CAD Model for the HC SR04 sensor

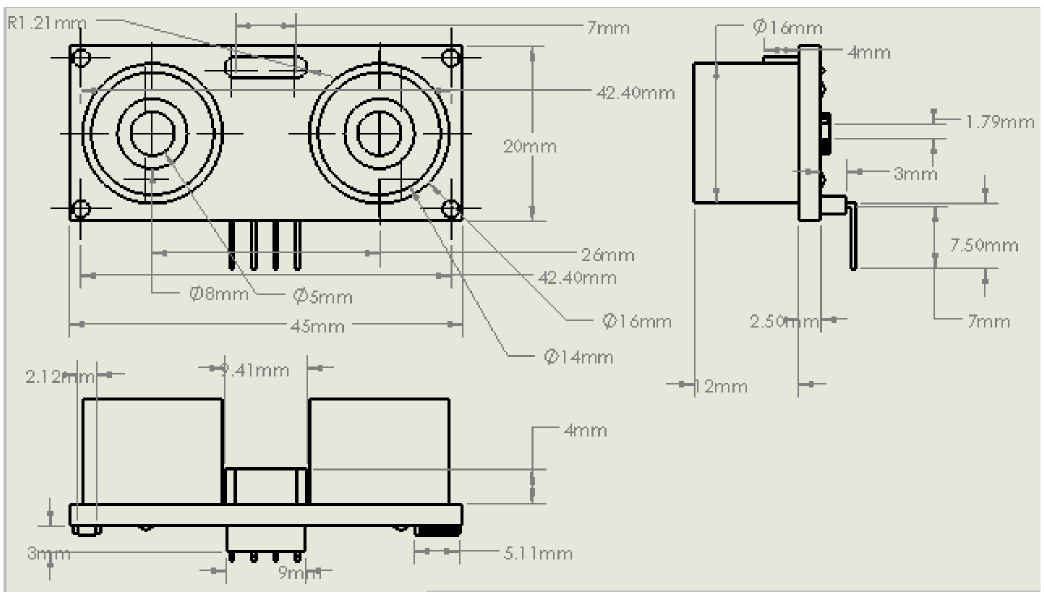


Figure 4.6: Production drawing for the HC SR04 sensor

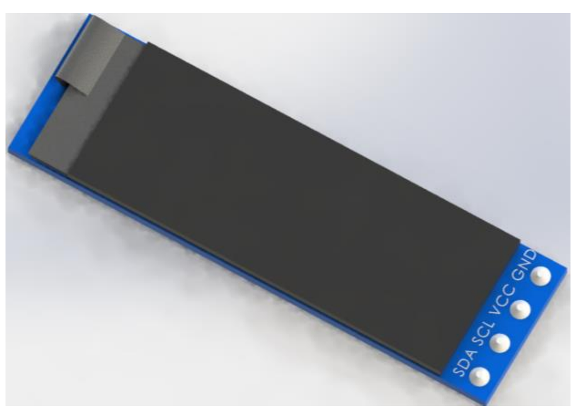


Figure 4.7: Solid CAD Model for OLED 0.91-inch screen

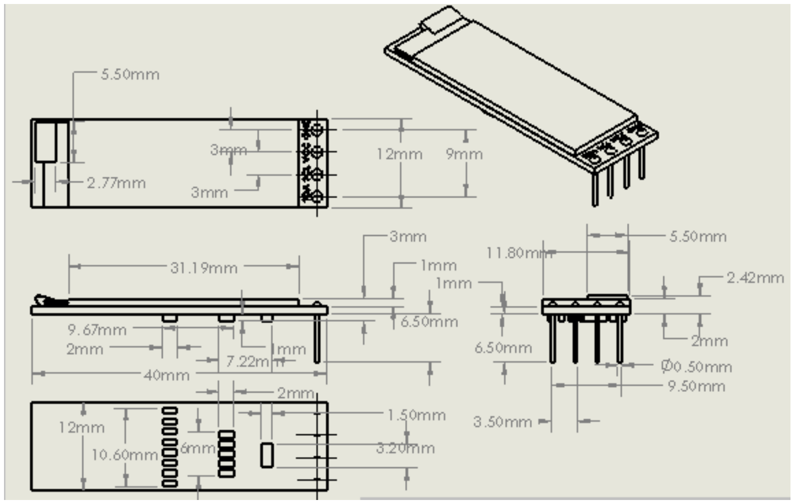


Figure 4.8: Production drawing for OLED 0.91-inch screen

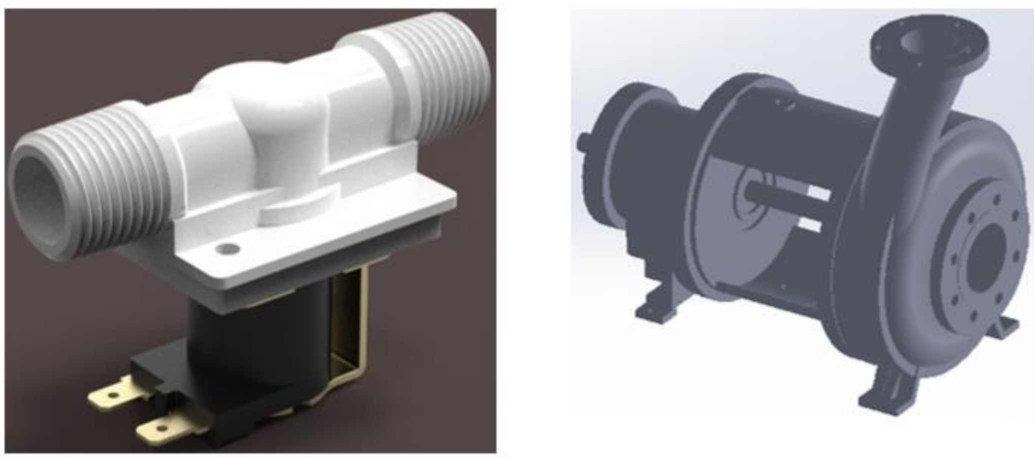


Figure 4.9: Solid CAD Models of Solenoid valve and Water pump respectively

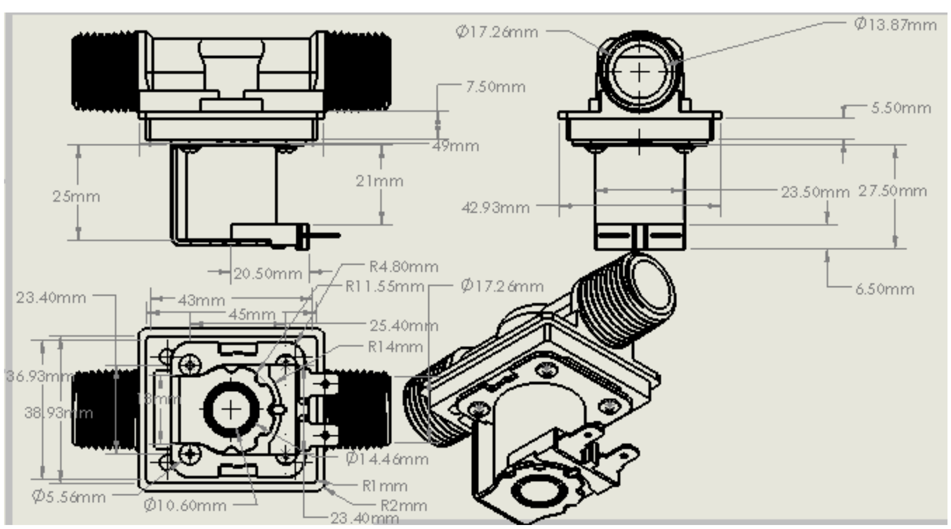


Figure 4.10: Production drawing of a Solenoid valve

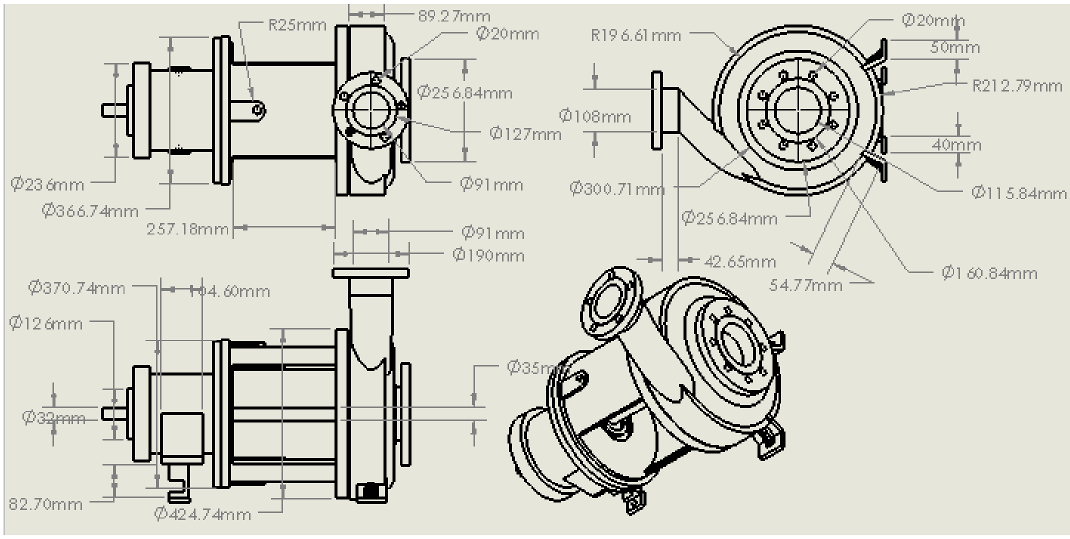


Figure 4.11: Production drawing of a Water pump

Figure 4.12: Solid CAD Model of a water tank and its cover

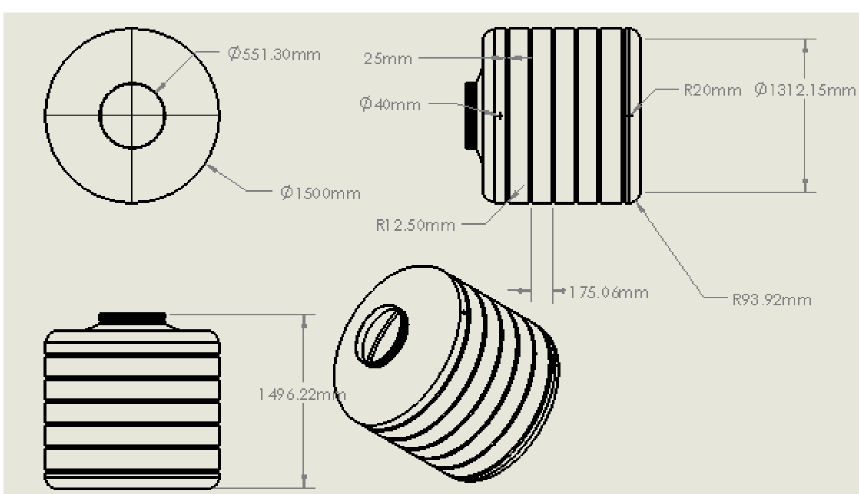


Figure 4.13: Production drawing of a water tank

4.3 Detailed Design of the System

4.3.1 Mathematical model for the design of the digital water level control system

The control system is of a cascading type i.e., controller 2 gets input from controller 1 (despite it having another step input). Ultrasonic sensor 1 sends signal (head level, h_2 in tank 2) to controller 1 whereas ultrasonic sensor 2 sends signal (head level, h_1 in tank 1) to controller 2. Controller 1 has a step input (required head level, h_2 in tank 2 to prevent overflow and water run out. And then, controller 2 has two inputs i.e., one is output from controller 1 and another is a step input (required head level, h_1 in tank 1 to prevent pump dry run).

Controller 2 checks to see if h_2 (from controller 1) is below the set minimum or required head level and if another head level, h_1 (water level in the underground reservoir) is below its set or required minimum value. If h_1 turns out to be above while h_2 below the set minimum value, controller 1 switches on the pump through a relay and controller 2 keeps the solenoid valve closed using a relay too. However, if both h_1 and h_2 is rather below the set/desired minimum value, then controller 1 keeps the pump switched off through a relay and controller 2 opens the solenoid valve through a relay also. Finally, if h_2 reaches the set maximum value, controller 1 switches off the pump and controller 2 closes the solenoid valve simultaneously.

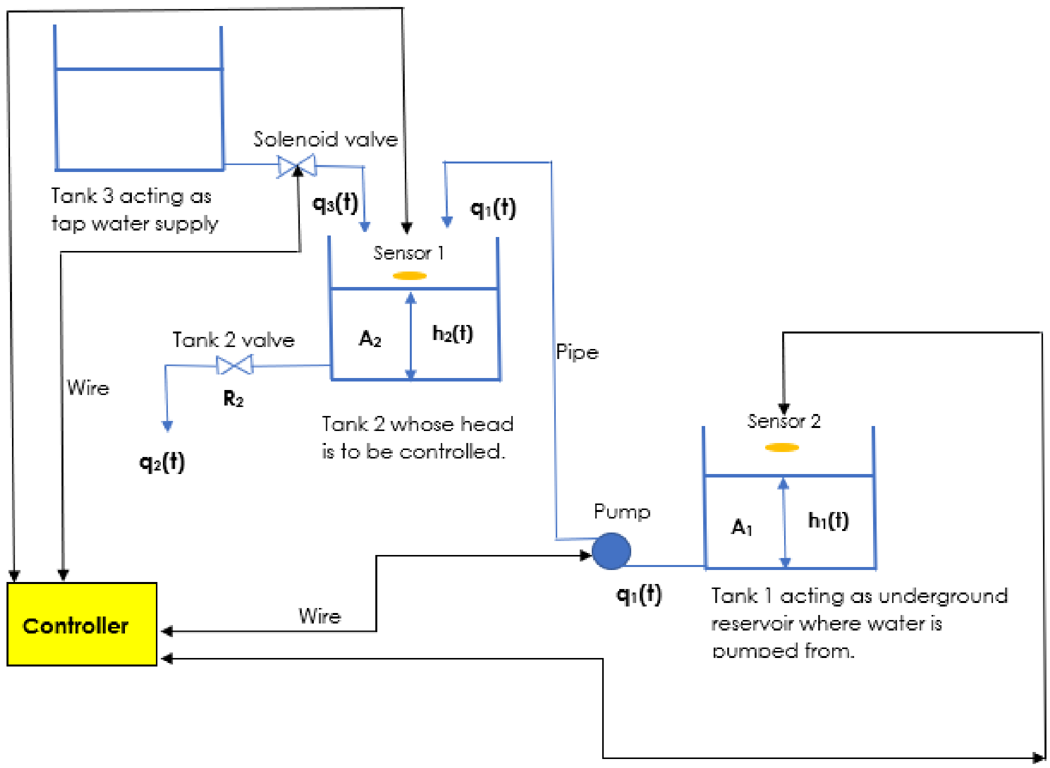


Figure 4.14: Schematic diagram for modeling the control system

Assume that h_3 is the input head level from tank 3 entering into tank 2.

Tank 1

$$C_1\frac{dh_1}{dt} = 0 - q_1 = -q_1 \qquad \ldots\ldots\ldots\ldots..eqtn\ 1$$

Tank 2

$$C_2\frac{dh_2}{dt} = (q_3 + q_1) - q_2 \qquad \ldots\ldots\ldots\ldots..eqtn\ 2$$

$h_2 = R_2q_2$ and $h_3 = R_3q_3$ therefore $q_2 = \frac{h_2}{R_2}$ and $q_3 = \frac{h_3}{R_3}$

Substituting q_2 into $eqtn\ 2$

$$C_2\frac{dh_2}{dt} + \frac{h_2}{R_2} = q_3 + q_1 \qquad \ldots\ldots\ldots\ldots..eqtn\ 3$$

Equation 3 is the input/output or mathematical model of the proposed control system where input is q_3 and q_1 while output is h_2. However, we need to get the inputs in terms of head i.e., h_3 and h_1

Firstly, assume $q_1 = 0$ and substitute q_3 into $eqtn\ 3$

C is capacitance of water tanks but is equal to area A since pressure is represented inform of head.

$$A_2 \frac{dh_2}{dt} + \frac{h_2}{R_2} = \frac{h_3}{R_3} \qquad \ldots\ldots\ldots\ldots..eqtn\ 4$$

Getting its transfer function, we get the Laplace transform of $eqtn\ 4$ in order to transform its time domain into an s domain. Zero initial conditions are assumed in doing so.

$$A_2[sH_2(s)] + \frac{1}{R_2}[H_2(s)] = \frac{1}{R_3}[H_3(s)]$$

$$H_2(s)\left[R_3A_2s + \frac{R_3}{R_2}\right] = H_3(s)$$

$$G_1(s) = \frac{H_2(s)}{H_3(s)} = \frac{\frac{1}{R_3A_2}}{s + \frac{1}{A_2R_2}}$$

Secondly, when $q_3 = 0$ differentiate through $eqtn\ 3$

$$C_2 \frac{d^2h_2}{dt^2} + \frac{1}{R_2}\frac{dh_2}{dt} = \frac{dq_1}{dt} \qquad \ldots\ldots\ldots\ldots..eqtn\ 5$$

Pipe Inertance due to long pipes from the pump and tap supply

$I\frac{dq_1}{dt} = h_1 - 0$ but inertance is ignored due to insignificance.

Therefore $\frac{dq_1}{dt} = h_1$

Substituting $\frac{dq_1}{dt}$ and $C_2 = A_2$ into $eqtn\ 5$

$$A_2 \frac{d^2h_2}{dt^2} + \frac{1}{R_2}\frac{dh_2}{dt} = h_1 \qquad \ldots\ldots\ldots\ldots..eqtn\ 6$$

Getting its transfer function, we get the Laplace transform of $eqtn\ 6$ in order to transform its time domain into an s domain. Zero initial conditions are assumed in doing so.

$$A_2[s^2H_2(s)] + \frac{1}{R_2}[sH_2(s)] = H_1(s)$$

$$H_2(s)\left[A_2s^2 + \frac{1}{R_2}s\right] = H_1(s)$$

$$G_2(s) = \frac{H_2(s)}{H_1(s)} = \frac{\frac{1}{A_2}}{s^2 + \frac{1}{A_2R_2}s}$$

In prototype; area of tank 2 is taken to be, $A_2 = 0.04909\ m^2$ i.e., its diameter is, $d_2 = 0.25\ m$ Also, resistance, $R_2 = 2700$ from maximum head in tank 2 as $0.45\ m$ and flowrate as $q_2 = 10l/min$. Resistance of solenoid valve is $R_3 = 4500$ since Maximum head in tank 3 is same as that in tank 2 i.e., $h_3 = 0.45\ m$ and corresponding flowrate through the solenoid valve is, $q_3 = 0.1l/sec$. Flowrate, $q_3\ (m^3/hour)$ was obtained from, $q_3 = k_v\sqrt{\frac{\Delta p}{\rho_{SG}}}$. Where; pressure drop, $\Delta p = 1\ bar$; flow coefficient of solenoid valve, $k_v = 0.36$; and specific gravity of water, $\rho_{SG} = 1$

Therefore;

$$G_1(s) = \frac{H_2(s)}{H_3(s)} = \frac{0.004527}{s + 0.007545}$$

Then,

$$G_2(s) = \frac{H_2(s)}{H_1(s)} = \frac{20.4}{s^2 + 0.007545s}$$

$G_1(s)$ and $G_2(s)$ are transfer functions.

Since the system is to be digital, discrete form of the transfer functions was obtained by transforming them from the s to z domain. This was done with help of the MATLAB tool taking sampling time as 0.1 seconds.

```
>> M = c2d(G1,0.1)

M =

    0.0004525
    ----------
    z - 0.9992

Sample time: 0.1 seconds
Discrete-time transfer function.
```

```
>> N = c2d(G2,0.1)

N =

      0.102 z + 0.1019
   ----------------------
   z^2 - 1.999 z + 0.9992

Sample time: 0.1 seconds
Discrete-time transfer function.
```

Figure 4.15: Transformation of a Continuous-to-Discrete time transfer function in MATLAB

$$G_1(z) = \frac{0.004525}{z - 0.9992}$$

Then,

$$G_2(z) = \frac{0.102z + 0.1019}{z^2 - 1.999z + 0.9992}$$

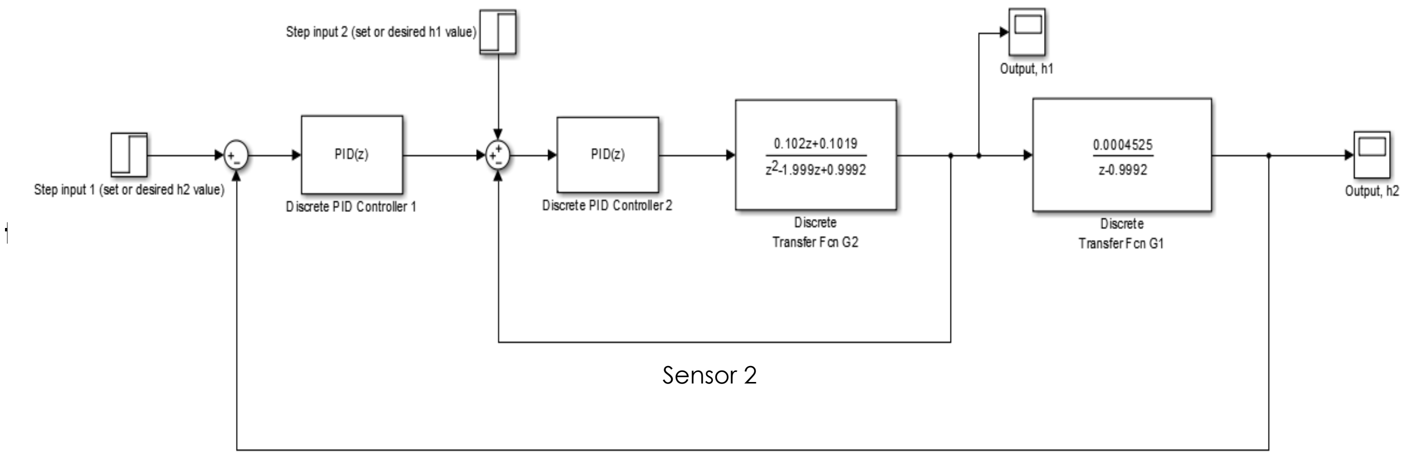


Figure 4.16: Control System block diagram

600000 seconds – MATLAB simulations for the system in absence and presence of the controllers included as follows. Simulations for controllers' absence show that the system is unstable for both output h_2 and h_1. However, on introduction of tuned PID controllers i.e.; controller 1 – (Proportional control, kp = 3.4904, Integral control, ki = 0.02248, and Derivative control, kd = 133.64305 with coefficient, N = 1.58356); and controller 2 – (Proportional control, kp = 5.69005e-06, Integral control, ki = 6.6182e-10, and Derivative control, kd = 0.000521 with coefficient, N = 0.02312), 6000 – seconds simulations showed that the system becomes stable with an average settling time of 800 seconds.

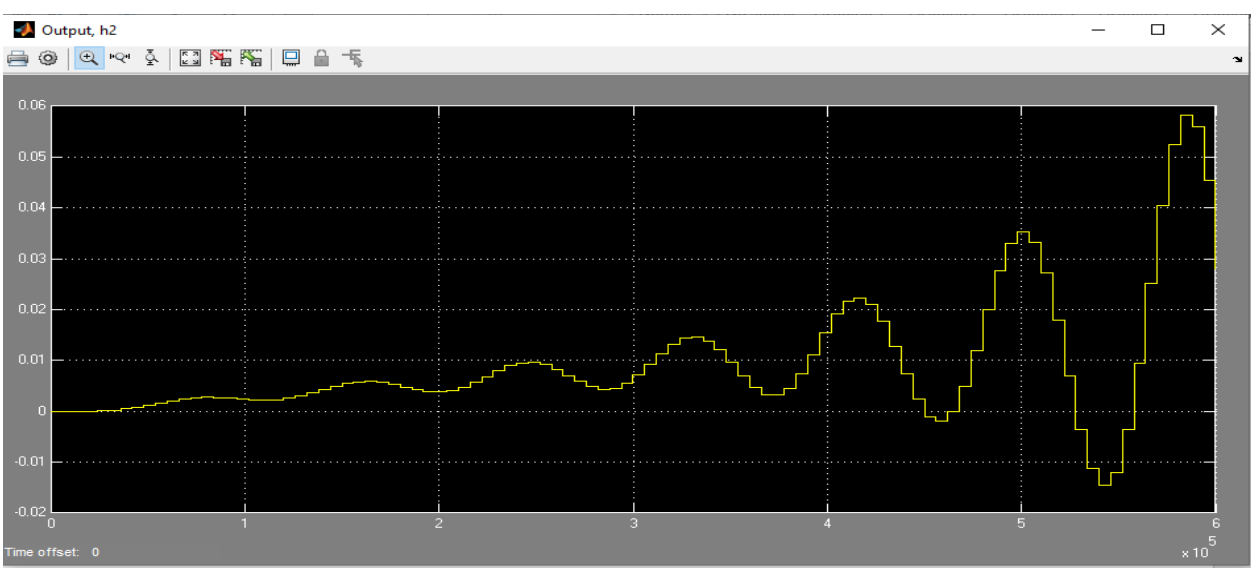


Figure 4.17: Output h_2 in absence of both PID controllers

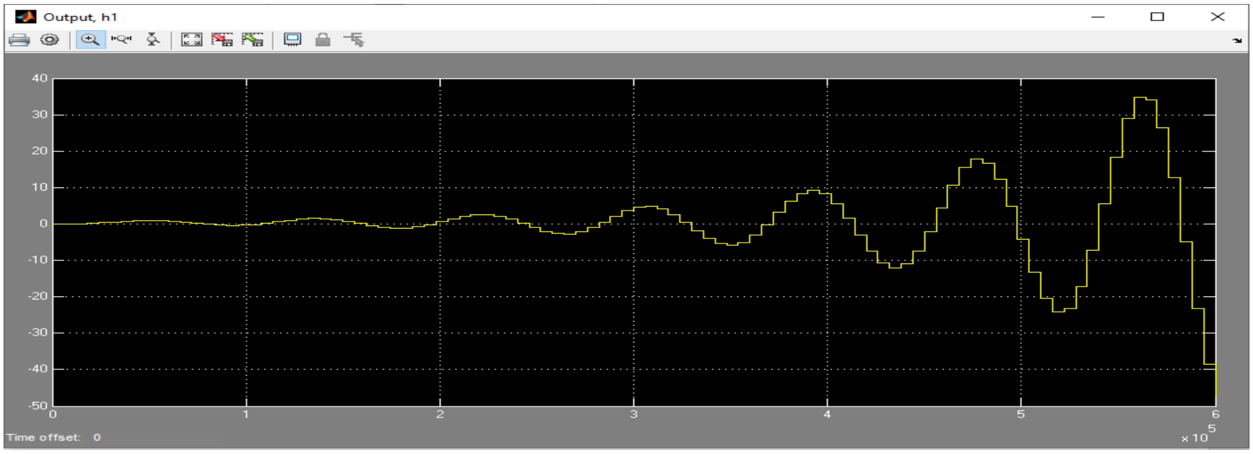


Figure 4.18: Output h_1 in absence of both PID controllers

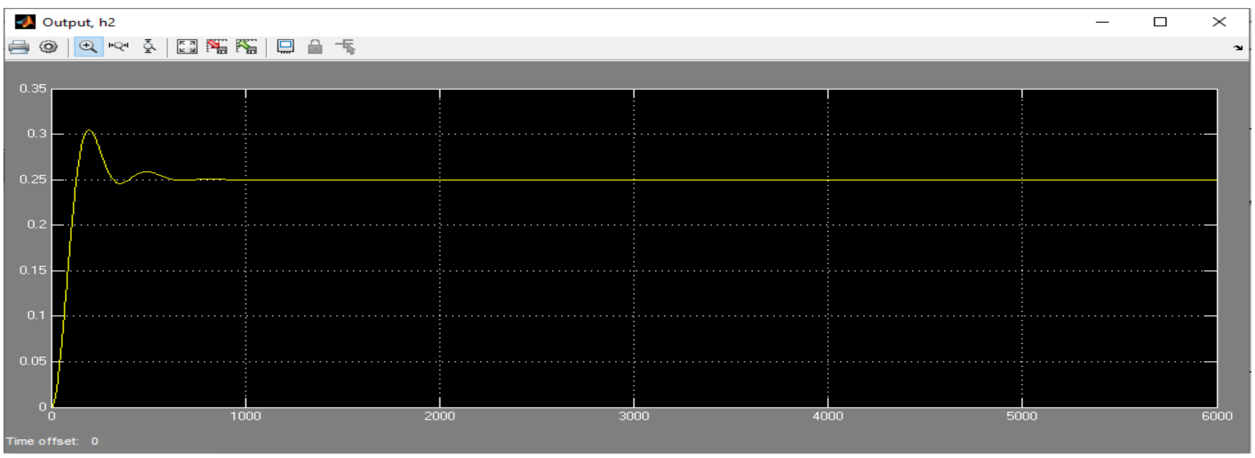


Figure 4.19: Output h_2 in presence of both PID controllers

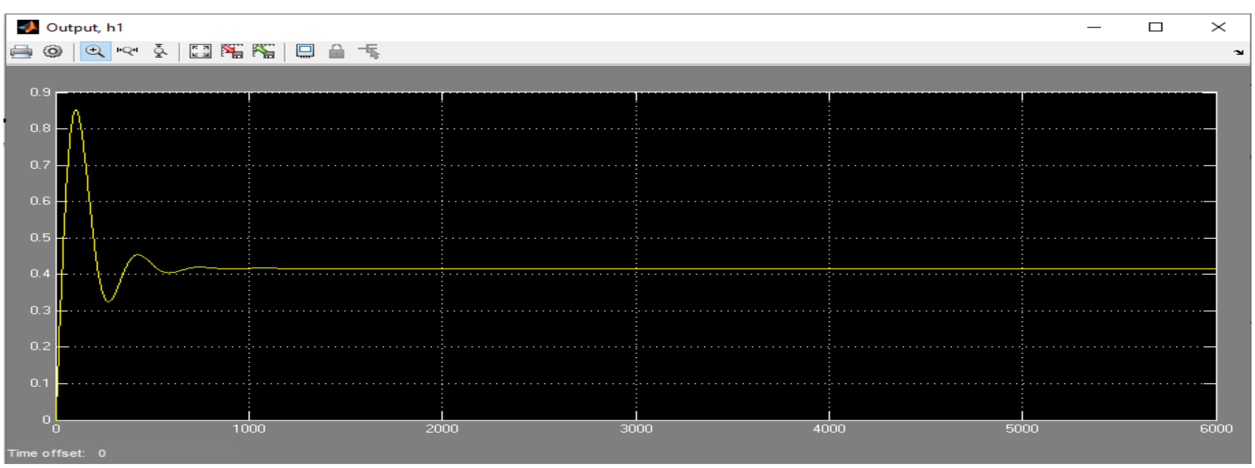


Figure 4.20: Output h1 in presence of both PID controllers

4.3.2 Expected Design of the System for the Digital Water Level Controller

This involved generation of a CAD model so as to have a pictorial view of the system (digital water level controller) designed. Some simulations above were used in describing the design in detail. Computer Aided Design software tools such as Solid Works™, EAGLE™ and MATLAB were embraced during the exercise.

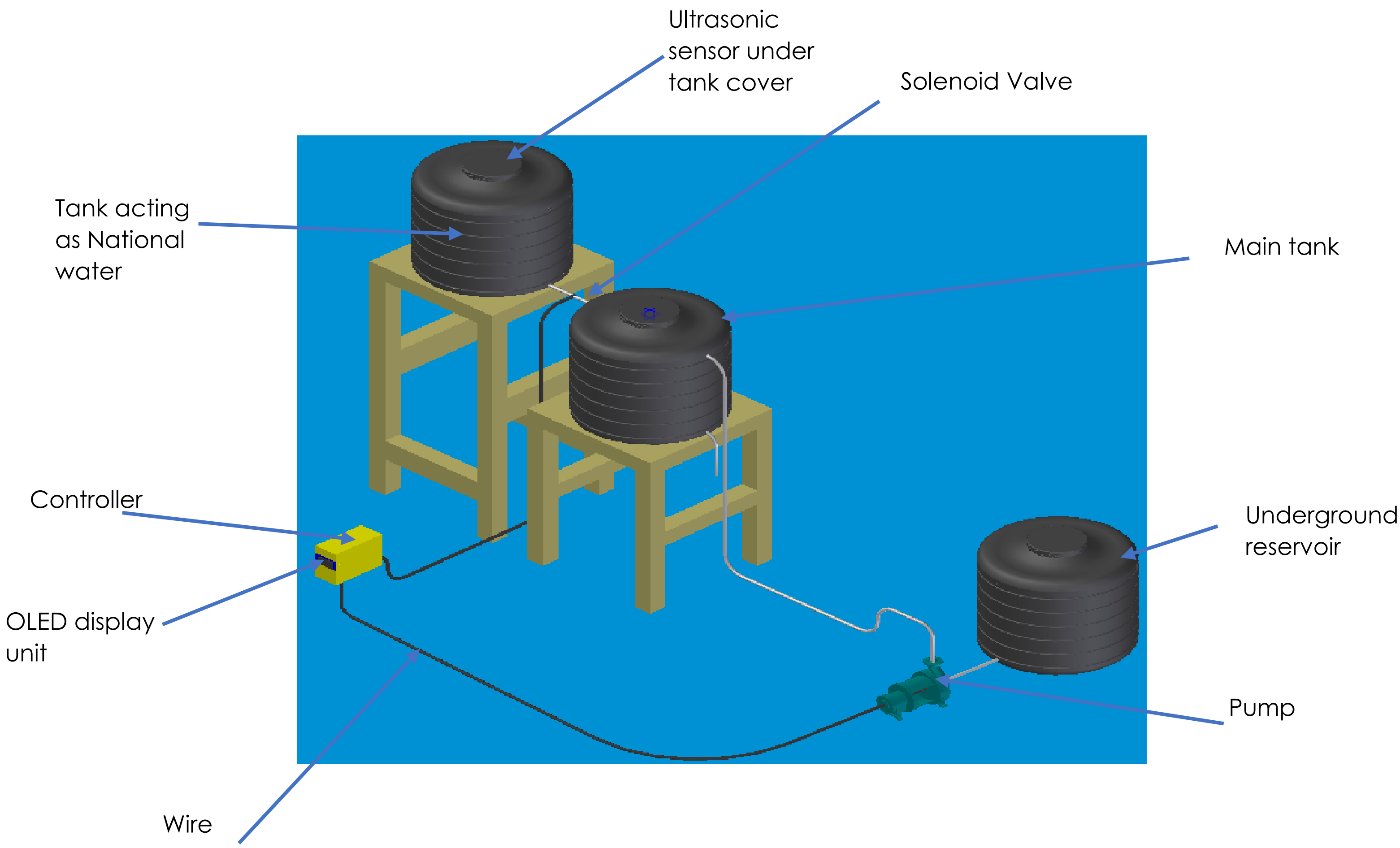


Figure 4.21: Solid CAD Model for the Digital Water Level Control System

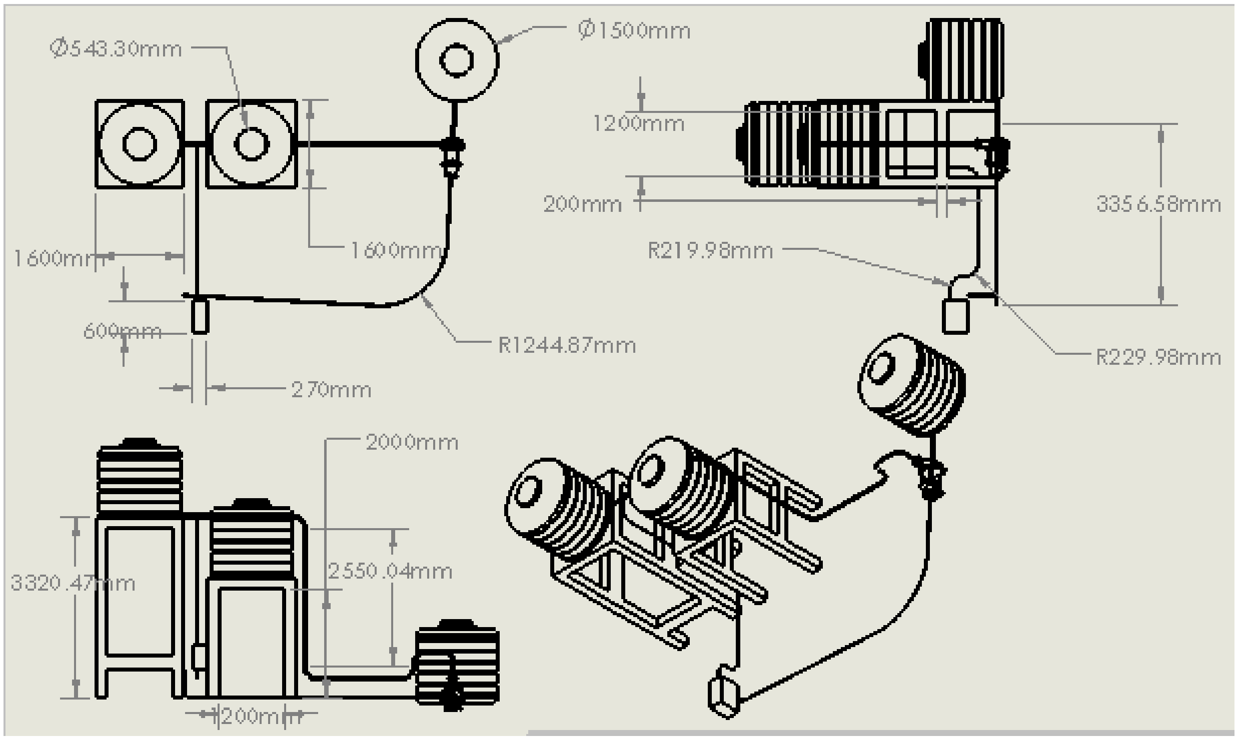


Figure 4.22: Production drawing for the Digital Water Level Control System

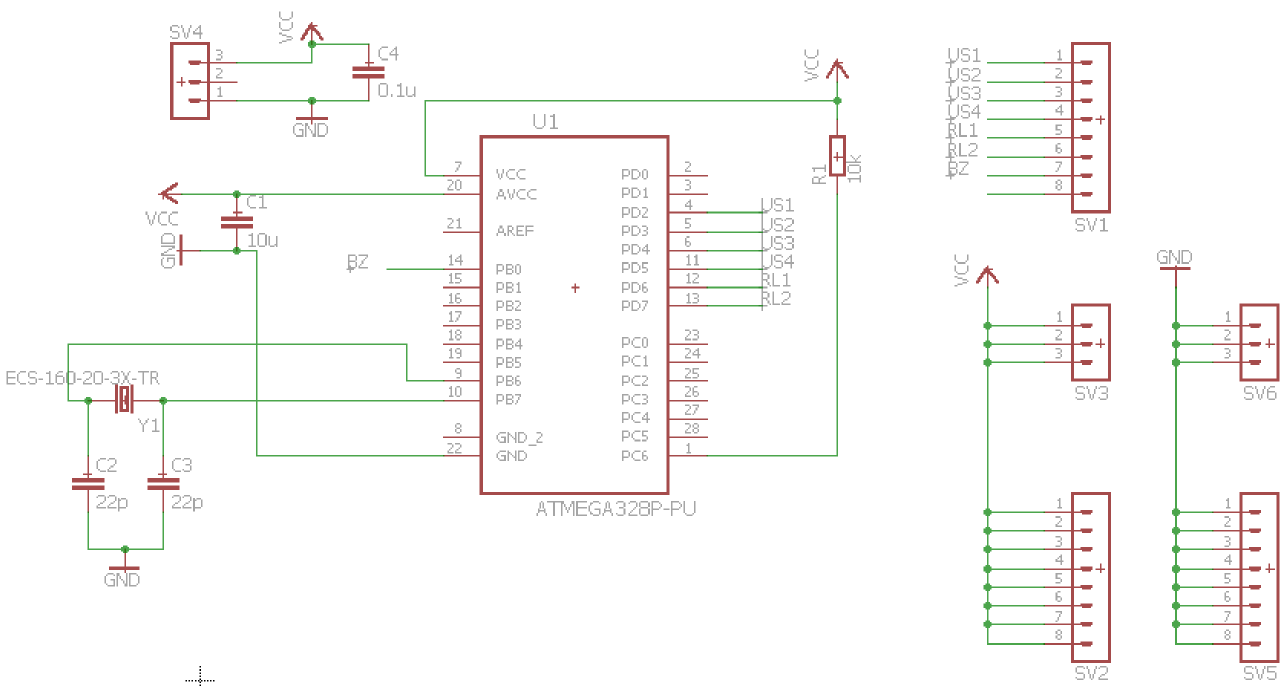


Figure 4.23: Schematic diagram of the proposed circuit for the system

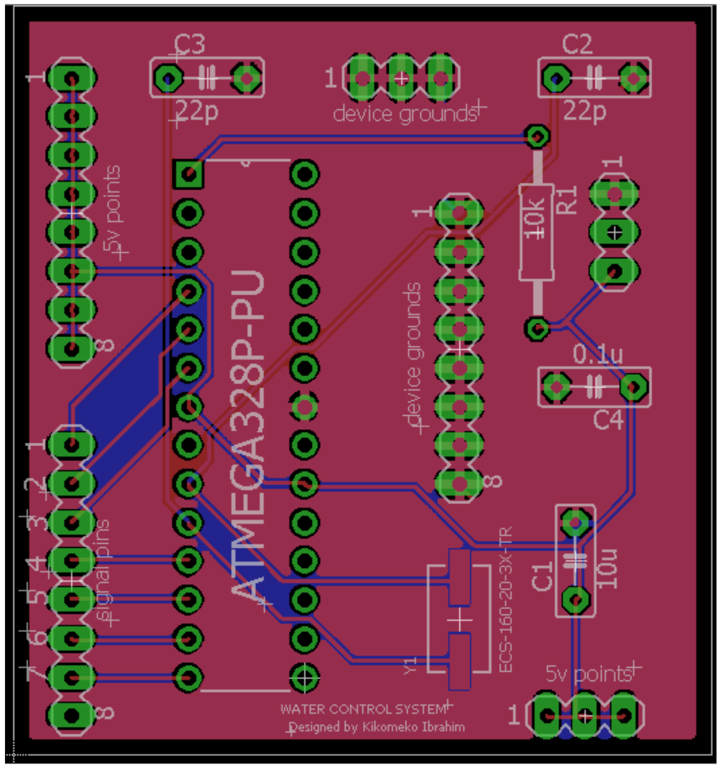


Figure 4.24: Electric CAD model of the proposed circuit for the system

4.3.3 Programming the controller to undertake system operation

A flow chart was created to help in generating the program to perform the system's desired tasks by the Arduino UNO microcontroller. The program (source code) was written, compiled, debugged, and run using the Arduino IDE environment.

The automatically tuned PID parameters from MATLAB i.e., for Controller 1 and Controller 2 were embedded into the written Arduino code. This was done so as to achieve system stability of the desired 10cm mark in the main tank.

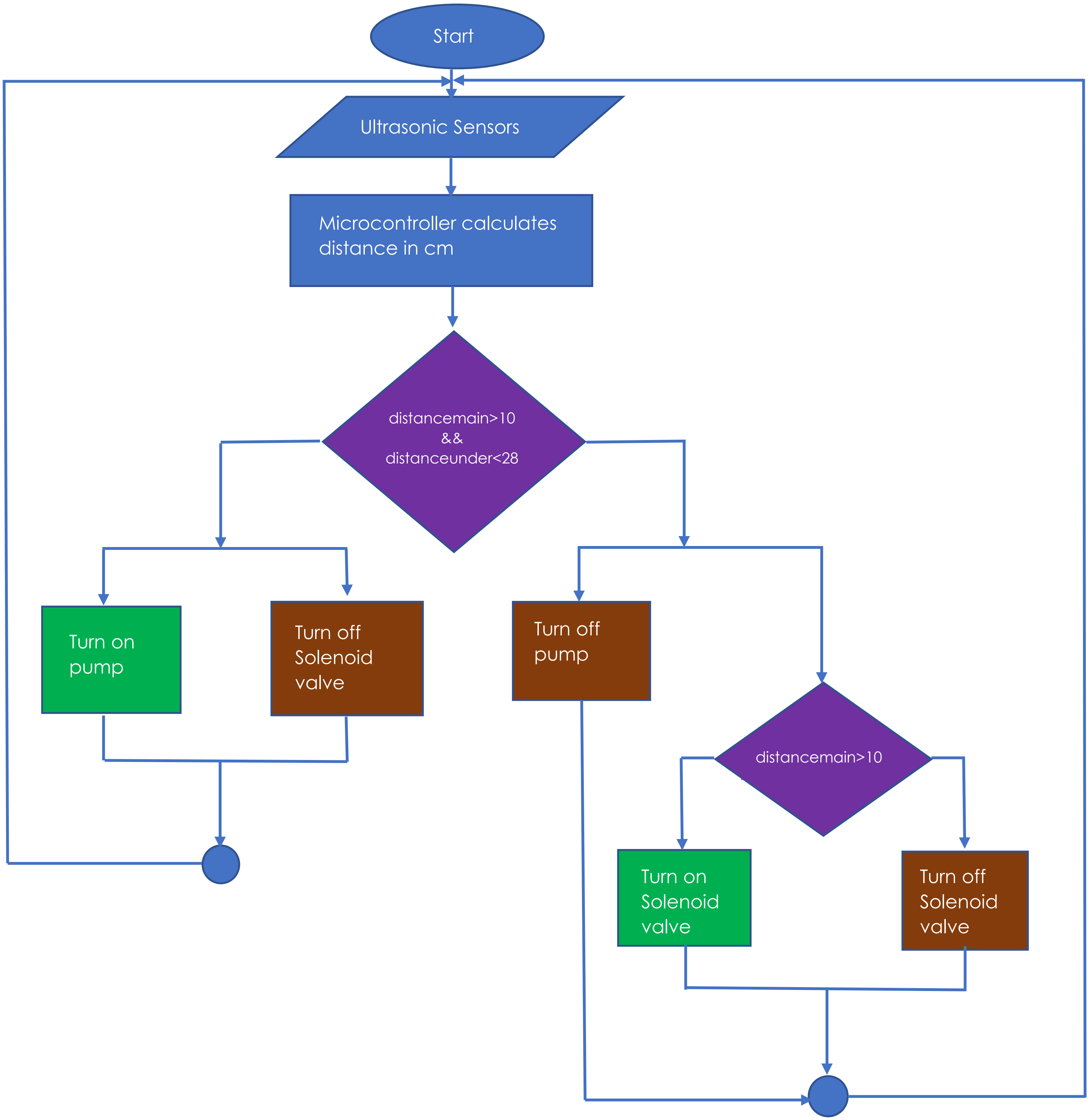


Figure 4.25: Flow chart used in programming the Water level Control System

waterlevel_control_system | Arduino 1.8.16

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Verify

waterlevel_control_system

```
#include <SPI.h>
#include <Wire.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>


#define trigPinmaintank 6 //Define the HC-SR04 triger on pin 6 on the arduino
#define echoPinmaintank 5 //Define the HC-SR04 echo on pin 5 on the arduino

#define trigPinundertank 7 //Define the HC-SR04 triger on pin 6 on the arduino
#define echoPinundertank 8 //Define the HC-SR04 echo on pin 5 on the arduino
#define solenoidrelay 10
#define pump 9 //Define the relay signal on pin 9 on the arduino

#define OLED_RESET 4
Adafruit_SSD1306 display(OLED_RESET);

void setup()
{
Serial.begin (9600); //Start the serial monitor
pinMode(trigPinmaintank, OUTPUT); //set the trigpin to output
pinMode(echoPinmaintank, INPUT); //set the echopin to input

pinMode(trigPinundertank, OUTPUT); //set the trigpin to output
pinMode(echoPinundertank, INPUT); //set the echopin to input
pinMode (pump, OUTPUT); //set the pump on pin 9 to output
pinMode (solenoidrelay, OUTPUT); //set the solenoid valve on pin 10 to output
```

waterlevel_control_system

```
display.begin(SSD1306_SWITCHCAPVCC, 0x3C); //initialize with the I2C addr 0x3C (128x64)
display.clearDisplay();

}
void loop()
{
int durationmain, distancemain, durationunder, distanceunder; //Define two intregers duration and distance to be used to save data
digitalWrite(trigPinmaintank, HIGH); //write a digital high to the trigpin to send out the pulse
delayMicroseconds(500); //wait half a millisecond
digitalWrite(trigPinmaintank, LOW); //turn off the trigpin
durationmain = pulseIn(echoPinmaintank, HIGH); //measure the time using pulsein when the echo receives a signal set it to high
distancemain = (durationmain/2) / 29.1; //distance is the duration devided by 2 becasue the signal traveled from the trigpin then back to the echo pin, then divide by 29.1 to convert to centir


digitalWrite(trigPinundertank, HIGH); //write a digital high to the trigpin to send out the pulse
delayMicroseconds(500); //wait half a millisecond
digitalWrite(trigPinundertank, LOW); //turn off the trigpin
durationunder = pulseIn(echoPinundertank, HIGH); //measure the time using pulsein when the echo receives a signal set it to high
distanceunder = (durationunder/2) / 29.1; //distance is the duration devided by 2 becasue the signal traveled from the trigpin then back to the echo pin, then divide by 29.1 to convert to cent


display.setCursor(10,20); //oled display
display.setTextSize(0.5);
display.setTextColor(WHITE);
display.println(distancemain);
display.setCursor(50,20);
display.setTextSize(0.5);
```

Figure 4.26: Arduino Microcontroller program to perform the Water level System's tasks

```
waterlevel_control_system
display.println("main tank(cm)");

display.setCursor(10,0); //oled display
display.setTextSize(0.5);
display.setTextColor(WHITE);
display.println(distanceunder);
display.setCursor(50,0);
display.setTextSize(0.5);
display.println("reserve(cm)");
display.display();

delay(500);
display.clearDisplay();

Serial.println(distancemain);
Serial.println(distanceunder);

if (distancemain > 10 && distanceunder < 28) //if the distance is greater than 10 CM in the main tank(low level) and less than 28 CM in underground tank(sufficient level)
{

digitalWrite(pump, LOW); //turn on the pump to get water from underground tank
digitalWrite(solenoidrelay, HIGH); //turn off the national water supply

}
else
{
 digitalWrite(pump, HIGH); //turn off the pump to get water from national water supply
if (distancemain > 10) //if the distance is greater than 10 CM in the main tank(low level) and less than 28 CM in underground tank(sufficient level)
```

```
{
 digitalWrite(solenoidrelay, LOW); //turn on national water supply.
}
else
{
 digitalWrite(solenoidrelay, HIGH); //turn off national water supply.
}
}


 //the default supply is national water as long as the pump is off(underground tank water levels are low) national water is on, the tank has a ball valve on national water inlet
}
```

Figure 4.27: Continuation of the Arduino Microcontroller program to perform the system's tasks

According to the block diagram in Figure 4.16, Controller 1 handled the pump whereas Controller 2 controlled the solenoid valve. This was carefully considered when embedding the respective PID parameters in the Arduino source code.

PID_FOR_SOLENOID_VALVE_SUPPLY | Arduino 1.8.16

File Edit Sketch Tools Help

PID_FOR_SOLENOID_VALVE_SUPPLY

```
/*IN THIS MODULE, WE ANALYSE THE MODULARISED CASE WHEN SOLENIOD VALVE OPENS AND FEEDS THE MAIN TANK
 THIS MEANS THE CASE WHEN THERE IN NOT ENOUGH WATER IN THE UNDERGROUND RESERVOUIR
 */

#include <PID_v1.h> //Iinclude PID library
#include <SPI.h>
#include <Wire.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>

//PID DATA

double Setpoint; //PID setpoint
double distancemainstate; //maintank level (OUTPUT)
double solenoidrelaystate; //main tank INPUT when the solenoidvalve(national water) is feeding into the main tank

double kp = 5.69005e-06, ki = 6.6182e-10, kd = 0.000521; //all main tank PID values from MATLAB

#define solenoidrelay 10 //Define the relay signal on pin 10 on the arduino
#define trigPinmaintank 6 //Define the HC-SE04 triger on pin 6 on the arduino
#define echoPinmaintank 5 //Define the HC-SE04 echo on pin 5 on the arduino

PID myPID(&distancemainstate, &solenoidrelaystate, &Setpoint, kp ,ki, kd, DIRECT); //THE PID IN FORWARD DIRECTION

void setup()
{
Serial.begin (9600); //Start the serial monitor
```

PID_FOR_SOLENOID_VALVE_SUPPLY

```
//DEFINING INPUTS AND OUTPUTS

pinMode(trigPinmaintank, OUTPUT); //set the trigpin to output
pinMode (solenoidrelay, OUTPUT); //set the solenoid valve on pin 10 to output

pinMode(echoPinmaintank, INPUT); //set the echopin to input


//PID SETUP
Setpoint = 10; //set the desired water level as 10 CM in main tank
myPID.SetMode(AUTOMATIC);
myPID.SetTunings(kp, ki, kd); //TURNS ON PID
delay(10);

}

void loop() {

//SENSOR
int durationmain, distancemain; //Define two intregers duration and distance to be used to save data
digitalWrite(trigPinmaintank, HIGH); //write a digital high to the trigpin to send out the pulse
delayMicroseconds(500); //wait half a millisecond
digitalWrite(trigPinmaintank, LOW); //turn off the trigpin
durationmain = pulseIn(echoPinmaintank, HIGH); //measure the time using pulsein when the echo receives a signal set it to high
distancemain = (durationmain/2) / 29.1; //distance is the duration devided by 2 becasue the signal traveled from the trigpin then back to the echo pin, then divide by 29.1 to convert to centi

//PID
```

Figure 4.28: PID Arduino source code for Controller 2

```
//PID
distancemainstate = digitalRead(distancemain); //RELAY WILL TURN OFF AT EXACTLY 10cm
myPID.Compute();
digitalWrite(solenoidrelay, solenoidrelaystate); //

Serial.println(distancemainstate);
```

Figure 4.29: Continuation for PID Arduino source code for Controller 2

PID_FOR_WATER_PUMP_SUPPLY | Arduino 1.8.16

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PID_FOR_WATER_PUMP_SUPPLY

```
/*IN THIS MODULE, WE ANALYSE THE MODULARISED CASE WHEN WATER PUMP TURNS ON AND FEEDS THE MAIN TANK
 THIS MEANS THE CASE WHEN THERE IS ENOUGH WATER IN THE UNDERGROUND RESERVOUIR
 */

#include <PID_v1.h> //Iinclude PID library
#include <SPI.h>
#include <Wire.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>

//PID DATA

double Setpoint; //PID setpoint
double distancemainstate; //maintank level (OUTPUT)
double pumpstate; //main tank INPUT when the  water pump is feeding into the main tank

double kp = 3.4904, ki = 0.02248, kd = 133.64305; //all main tank PID values from MATLAB

#define pump 9 //Define the relay signal on pin 9 on the arduino
#define trigPinmaintank 6 //Define the HC-SR04 triger on pin 6 on the arduino
#define echoPinmaintank 5 //Define the HC-SR04 echo on pin 5 on the arduino

PID myPID(&distancemainstate, &pumpstate, &Setpoint, kp ,ki, kd, DIRECT); //THE PID IN FORWARD DIRECTION

void setup()
{
Serial.begin (9600); //Start the serial monitor
```

PID_FOR_WATER_PUMP_SUPPLY

```
//DEFINING INPUTS AND OUTPUTS

pinMode(trigPinmaintank, OUTPUT); //set the trigpin to output
pinMode (pump, OUTPUT); //set the pump on pin 9 to output

pinMode(echoPinmaintank, INPUT); //set the echopin to input


//PID SETUP
Setpoint = 10; //set desired water level in main tank to 10 CM
myPID.SetMode(AUTOMATIC);
myPID.SetTunings(kp, ki, kd); //TURNS ON PID
delay(10);

}

void loop() {

//SENSOR
int durationmain, distancemain; //Define two intregers duration and distance to be used to save data
digitalWrite(trigPinmaintank, HIGH); //write a digital high to the trigpin to send out the pulse
delayMicroseconds(500); //wait half a millisecond
digitalWrite(trigPinmaintank, LOW); //turn off the trigpin
durationmain = pulseIn(echoPinmaintank, HIGH); //measure the time using pulsein when the echo receives a signal set it to high
distancemain = (durationmain/2) / 29.1; //distance is the duration devided by 2 becasue the signal traveled from the trigpin then back to the echo pin, then divide by 29.1 to convert to centim

//PID
```

Figure 4.30: PID Arduino source code for Controller 1

```
//PID
distancemainstate = digitalRead(distancemain); //WATER PUMP WILL TURN OFF AT EXACTLY 10cm
myPID.Compute();
digitalWrite(pump, pumpstate); //

Serial.println(distancemainstate);
```

Figure 4.31: Continuation for PID Arduino source code for Controller 1

4.4 Construction and Evaluation for a prototype of the System

First testing was done with desired water level inputs as 3cm and 28cm i.e., if (main tank level > 3cm && reservoir tank level < 28cm). The "If" condition implied that when there is not enough water in the main tank (reading > 3cm from ultrasonic sensor) and yet there is enough water in the reservoir tank (reading < 28cm from ultrasonic sensor), the pump turns on to start operation. Otherwise, the pump was to go off and solenoid valve opened provided main tank reading is still > 3cm from ultrasonic sensor. Testing worked out well as shown in Figure 4.35, however the pump stopped operating at 2cm instead of 3cm as in Figure 4.33. Attribution was to disturbances in water level when water is pouring into the main tank.

Second testing was done specifically for the solenoid valve and the desired water level inputs this time were 10cm and 28cm i.e., if (main tank level > 10cm && reservoir tank level < 28cm). The level was changed to 10cm since at 3cm, water touched the ultrasonic sensor thus interrupting readings. Test worked out well i.e., the else or otherwise part of the "If" condition was fulfilled where the solenoid valve opened to allow water flow into the main tank provided its reading is still > 10cm from ultrasonic sensor yet there is not enough water in the reservoir (reading > 28cm from ultrasonic sensor). This is shown in Figure 4.37.

Both the pump and solenoid valve were to stop supplying water to the main tank as long as it possessed enough water (main tank reading < 10cm from ultrasonic sensor). This was achieved successfully, however i.e., the solenoid valve stopped allowing water flow at 9cm instead of 10cm as in Figure 4.38. This was also attributed to disturbances in water level when water is pouring into the main tank.

Water level disturbances were handled by running the system when PID values are embedded in the program of the controller. System stability was achieved i.e., the main tank was able to successfully stop receiving water flow from either the solenoid valve or pump as soon as the desired 10cm reading from ultrasonic sensor was achieved.

For a case when main tank is empty yet there is no enough water in reservoir (reading > 28cm from ultrasonic sensor) and national water supply is not available on opening the solenoid valve, the controller kept the pump off and the solenoid valve open no matter whether national water supply was or wasn't available. This was in the name of ensuring continuous reserve of water in the main tank.

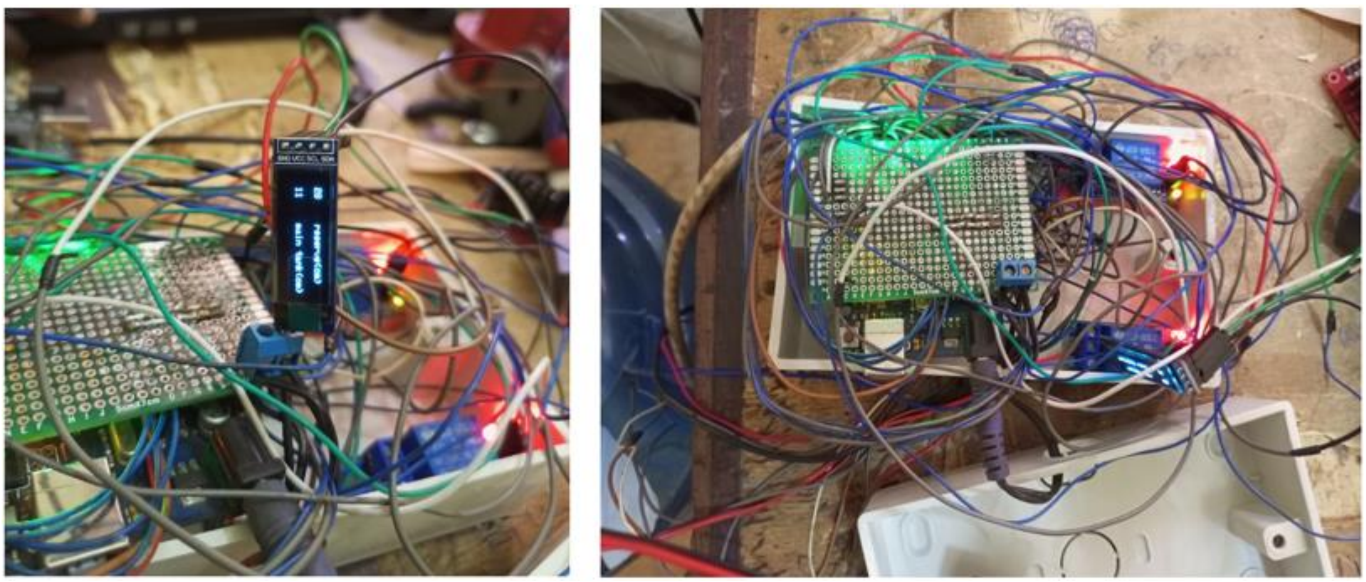

Figure 4.32: Electronic circuit of Water level System

Figure 4.33: OLED 0.91-inch display screen

Figure 4.34: Assembled-Construction of Digital Water Level Control System

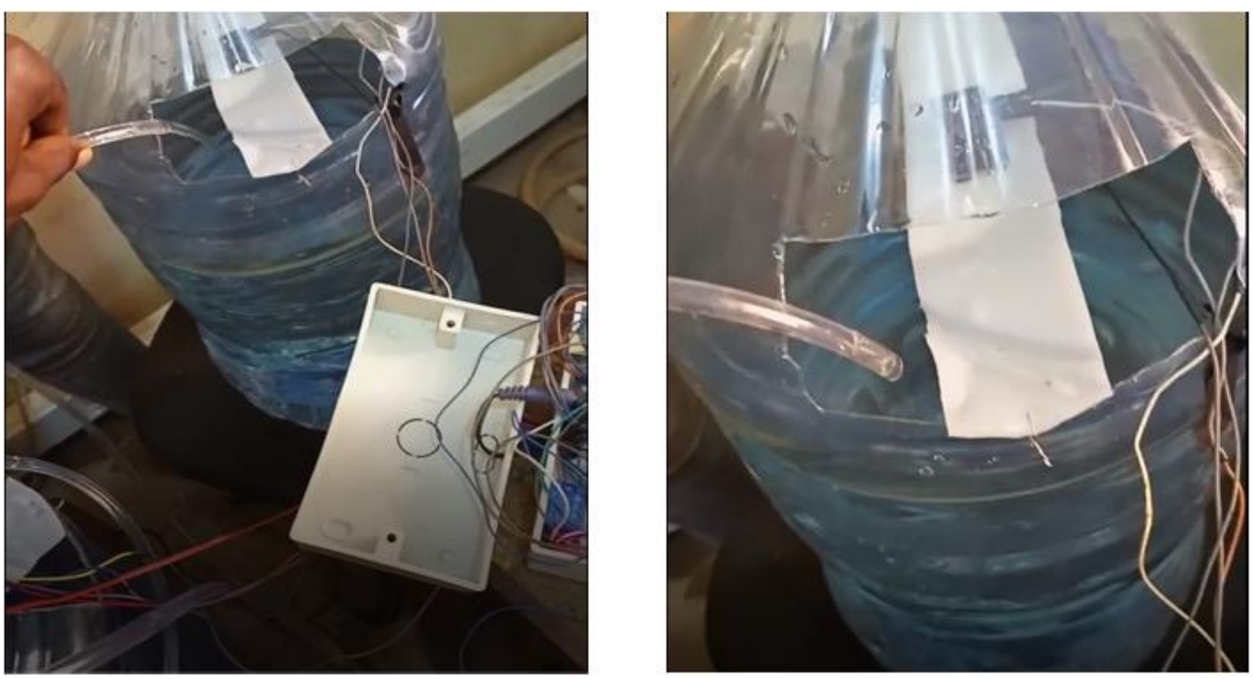

Figure 4.35: Pump operating on left and Stopping operation on the right

Figure 4.36: Pump stopping operation on the left and Solenoid valve connection on the right

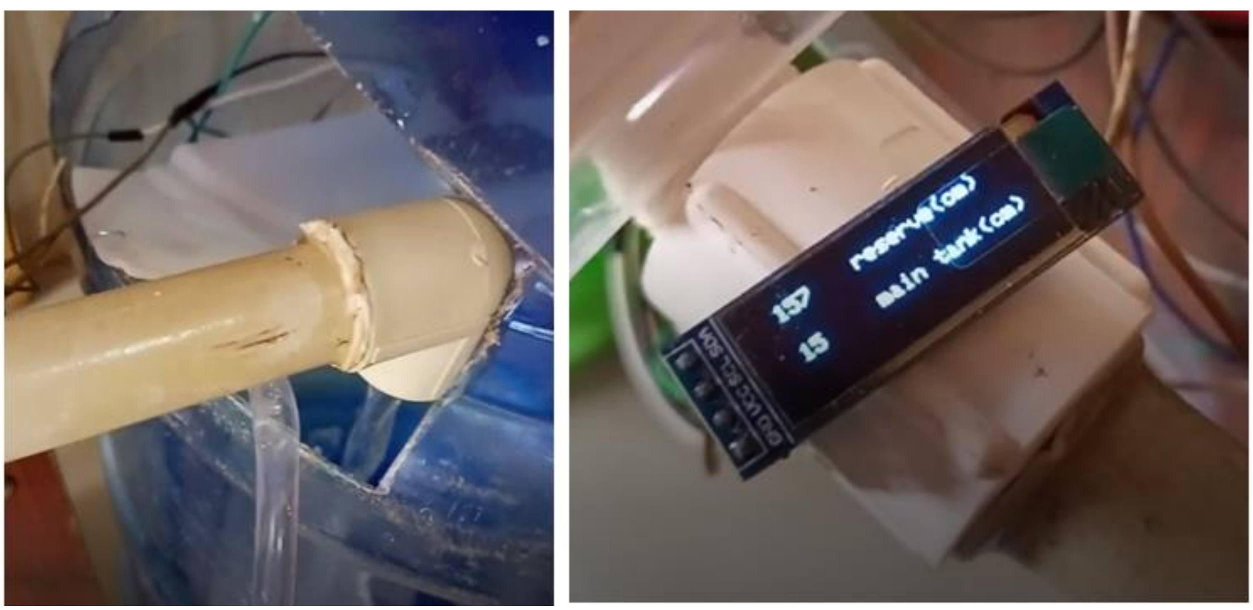

Figure 4.37: Solenoid valve allowing water to flow and the OLED reading at that instant respectively

Figure 4.38: Solenoid valve stopping water to flow and the OLED reading at that instant respectively

CHAPTER 5 : CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The major goal of the project was to design and construct a digital water level controller that automatically controls, monitors and ensures a continuous reserve of water in the storage tank. This was intended to sustainably manage water resources with minimum or no human involvement i.e., reduce time consumption, water wastage, seepage of walls and roofs, and extra power expenditure when the tank overflows. The digital water level control system included a microcontroller (AT Mega 328p) and a circuit (HC-SR04 sensors, pump, solenoid valve, relays, 0.91-inch OLED display, DC power supply, perforated board, and wires) which worked together in monitoring and controlling the water level in a tank. Following are the other objectives for this project which were to;

Determine the system design specifications: These included an Arduino UNO (AT Mega 328p) microcontroller, HC-SR04 sensors, 12V – Wired solenoid valve, 10A – maximum relay load capacity, 0.91-inch OLED display, 12V – DC power supply, 50millisecond – initial time delay, and pump dry run protection.

Developing a conceptual design for the system: Final design concepts generated were; Wired – Ultrasonic water level sensor in underground and overhead tank, Wired solenoid valve on tap supply, and Digital display unit.

Developing a detailed design of the system: Mathematical model of the system was done, CAD model created, and the microcontroller programmed to undertake performance tasks.

Constructing and evaluating a prototype for the system: Prototype was developed successfully. First and Second testing worked out well but with an error of 1cm due to disturbances of water level during water flow into the main tank. Last testing was also successful where the error was greatly reduced by introduction of tuned PID values. For a case when there is no water in the main tank, reservoir and national water supply, the controller kept the pump off and the solenoid valve open no matter whether national water supply was or wasn't available. This was in the name of ensuring continuous reserve of water in the main tank.

All project objectives were successfully attained.

5.2 Recommendations

During prototype testing, it was realized that when water splashes on the ultrasonic sensor, false readings are obtained i.e., the main tank or reservoir reading can jump from 15cm to 1000cm at that instant. Therefore, water should not touch the HC-SR04 sensor for proper functionality.

Improving human – controller interaction i.e., receiving phone messages or Bluetooth phone control via a software regarding the water level controller. Here the user can even set their desired water level in the main tank at which it should start or stop being filled with water.

When there wasn't enough water in both the main tank and reservoir, the controller switched off the pump and it kept the solenoid valve open no matter whether national water supply was or wasn't available. A flow rate sensor can be embraced to close the solenoid valve once there is no detection of flow for national water supply.

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