EEE4113F – Design Project

How might we help small business owners to grow their businesses sustainably, in a way that benefits both society and the environment?
Introducing:

SmartH_2OME

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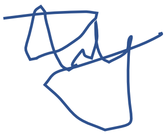

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1. Introduction

This project aims to ask the following question: how might we help small business owners to grow their business sustainably in a way that benefits both society and the environment? More specifically, this project aims to help the owner of a small plumbing business boost their business through water-saving methods that benefit both the customers, the business, and the environment.

The solution to our problem is an in-home water filtration system: a system capable of capturing the effluent water coming from all the different sources in the house and would then filtering and testing this water such that it may be used again in a range of applications, from watering the garden to refilling the cistern of a toilet.
In this way, a great deal of water can be reused and thus save clients expenses on their water bill, while also facilitating sustainability and boosting business for a plumber with their novel and eco-friendly system installation now on the market!

2. Problem Analysis

2.1. D – School Activities

The D-school activities entailed the completion of weekly Mural boards, both as a team and individually for certain tasks, with a meeting with our tutor at the end of each week for feedback. Each week, a new module would be required to be completed, centred around the following.

Challenge Statement throughout:

How might we help small business owners to grow their businesses sustainably, in a way that benefits both society and the environment?
Each week's mural was intended to build up to developing a system that fulfils the challenge statement. And each mural extrapolated in each of the following design thinking steps in turn: Understand, Observe, POV, Ideate, Prototype, Test. Going through how each of these was implemented in turn:

Understand & Observe:

First, before attempting to solve the challenge, we had to individually reflect on the challenge statement; how we related to it and what it made us feel and empathize with, thereafter grouping similar ideas in themes. Furthermore, we had to unpack the challenge statement, reflecting on our understanding of the terms and concepts it encapsulated. We then brainstormed and investigated the different parties who have a stake in the challenge - the stakeholders - going as far as to conduct interviews with real life stakeholders.

POV:

This module involved refining the individual interview answers, choosing the most interesting ones, and exploring what these statements meant, made the stakeholder feel, and how the stakeholder could improve upon the statement in question. A single stakeholder/ user was then voted to focus on, and each statement was fully explored, in an attempt to understand what the stakeholder was experiencing and how their situation could be improved upon, i.e., a POV diagram was generated by each team member.

Ideate & Prototype:

Based on a chosen POV diagram, as a group the team generated numerous 'how to' statements, aimed at tackling the challenge set out. Solutions to these 'how to's' were then brainstormed. From these solutions/ ideas, each team member then individually groups three of the ideas into one 'bucket', with the aim of making a new, more involved solution from the random ideas chosen. The best one is voted upon, and this then becomes the solution to be prototyped, as is done (drawn) by each group member.

Test:

This module aims at ensuring that all team members are fully aligned around the finer details of the idea being prototyped. As such, each team member has to clarify their understanding of the different aspects of the idea/ system. These individual assessments are then merged into one, group one. The system is then put under the rigours of being tested by users - users are asked for their feedback and feelings towards the proposed system. This ensures that all practicalities of the system are fully considered, and that certain aspects can be improved/ changed to suit the potential users' needs.
All in all, the sequential Mural boards allowed us to reach an idea for a sound, feasible solution, as a team.

2.2. Design Choices

Each of the design choices made during the progression of the system design, were made based on either one or many of the following criteria:

- How well the design choice aids us in being able to solve the given problem
- Ease of use by the user
- Minimal interaction necessary by the user
- Cost effectivity of the system as a whole
    a. System construction costs should be kept to a minimum
    b. System maintenance costs should be kept to a minimum
    c. Installation costs should be minimized
- Ease of installation
- Overall maintainability of the system
- Minimizing environmental impact
- Maximizing water saving
- Maximizing water cleanliness

- Ease of subsystem breakdown
- Maximize money saving for the client

The following ***design choices were made in our system:***

a. Separate tanks will be used for capturing and cleaning water coming from the toilets and water coming from other sources in the house.

    - This choice was made to maximize water cleanliness while also minimizing costs by ensuring that large amounts of the given chemical aren't used unnecessarily to clean water that could simply have been cleaned by minimal use of those same chemicals.
    - This was also chosen since minimizing chemical usage would also minimize environmental impact of the system

b. UV filtration system for killing bacteria and other waterborne pathogens

    - This was chosen to minimize chemical usage, which would minimize the overall costs of the system, as well as maximize the water cleanliness

c. Piping from all drains in the house will be run into this system

    - This will ensure the maximum amount of water is saved

d. An app will be developed and will be installed for any user who buys the product

    - This will be able to alert the user if any errors have taken place during the cleaning process and will also be able to inform the user about the general health of the system and will therefore maximize ease of use by the user.
    - This application will also send notifications to us as the manufacturing company in the event of any system error and a team member will immediately be dispatched to the home of the client to solve the error. This will maximize ease by the user while also maximizing maintainability of the system.

e. Filtration and water housing system comes pre-assembled and only the connections to the drain system from the house would have to be made on site

    - This was chosen for a variety of different reasons, namely, ease of installation, feasibility towards a practical approach, higher rate of maintainability, as well as cost effectiveness [minimal construction costs, minimal maintenance costs]

f. Hybrid power supply

    - This hybrid power supply would be able to draw power from both the AC mains power as well as from the solar panels that will be installed along with the installation of the system.
    - This was chosen to Minimize environmental impact of the system as well as to maximize the money saved by the client

g. Chemical refills for the cleaning process

    - The system would be able to alert the manufacturer whenever the level of cleaning chemicals in the system are too low and a team member would be dispatched to refill these chemicals at a small cost to the user.

- This was chosen to maximize ease of use by the user as well as to maximize cost effectivity and water cleanliness

2.3. Merging of Ideas

2.3.1. Water Filtration

The following ideas were put forward for the water filtration:

- The use of Ultraviolet (UV) lighting. This idea involves killing bacteria without the use of harmful chemicals that can be detrimental to other microorganisms later in the water filtration cycle. In addition to this method being environmentally sustainable, UV light is less resource expensive and is cheaper in the long run.
- The use of pH testing strips. This method helps determine the acidity of water and is cost efficient. It is beneficial in that the acidity of the water is tested before the water is used in the garden where it can kill microorganisms.
- Water filtration through reverse osmosis and use of carbon filters. Reverse osmosis is a water purification method that involves using partially permeable membranes to separate ions, unwanted molecules, and larger molecules from drinking water. Carbon filters use activated carbon to remove contaminants and impurities utilizing chemical adsorption.

The team agreed on using the first two methods because whilst UV light can kill bacteria in the water, it is impossible for the acidity of the water using this method and this is where pH testing comes into play. After coming to the agreement that the water was not going to be used for drinking, it was not necessary to use the last method as it would unnecessarily increase the deployment cost.

2.3.2. How to Save Client on Water Bill

The following ideas were put forward to minimize water leakage and water use:
Use of efficiency faucets.
Use of ultrasonic sensors to detect any irregularities in the flow of water in the pipes.
Use of vacuum toilets which are toilets that use suction for the removal of faeces and urine resulting in a minimal requirement of water (0.5 to 1.5 litres).
The team agreed to use the first two methods because in as much as the use of vacuum toilets results in less water being used, deploying the system is pricey, heavily dependent on electric power supply and uses bulky materials therefore the system might not be affordable for many households.

2.4. UML Diagram of Final Design

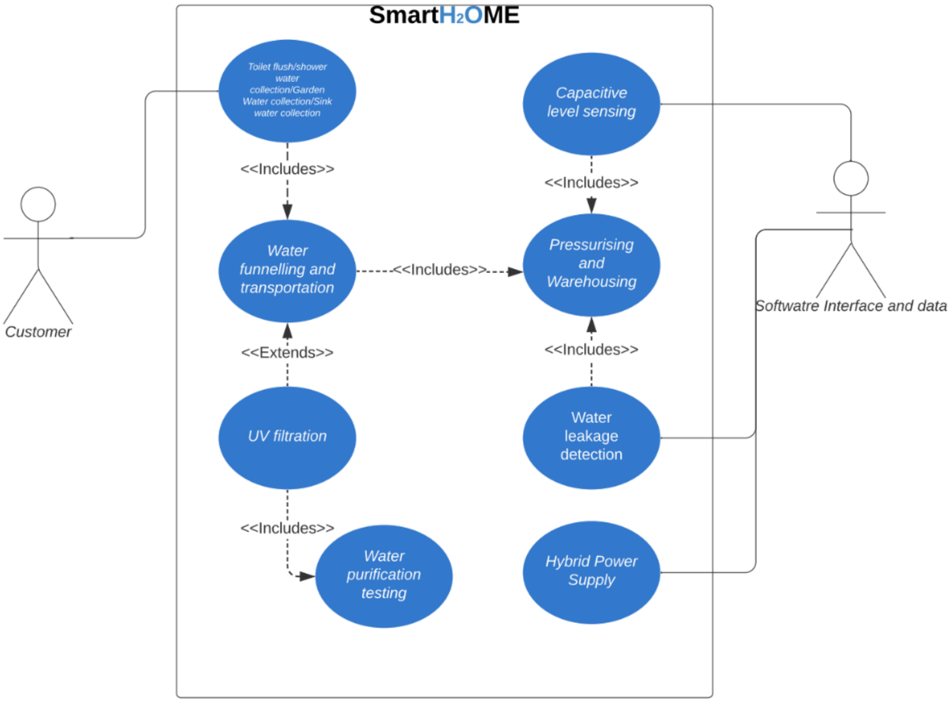


Figure 1: UML Diagram of Final System

2.5. SmartHome V-Diagram

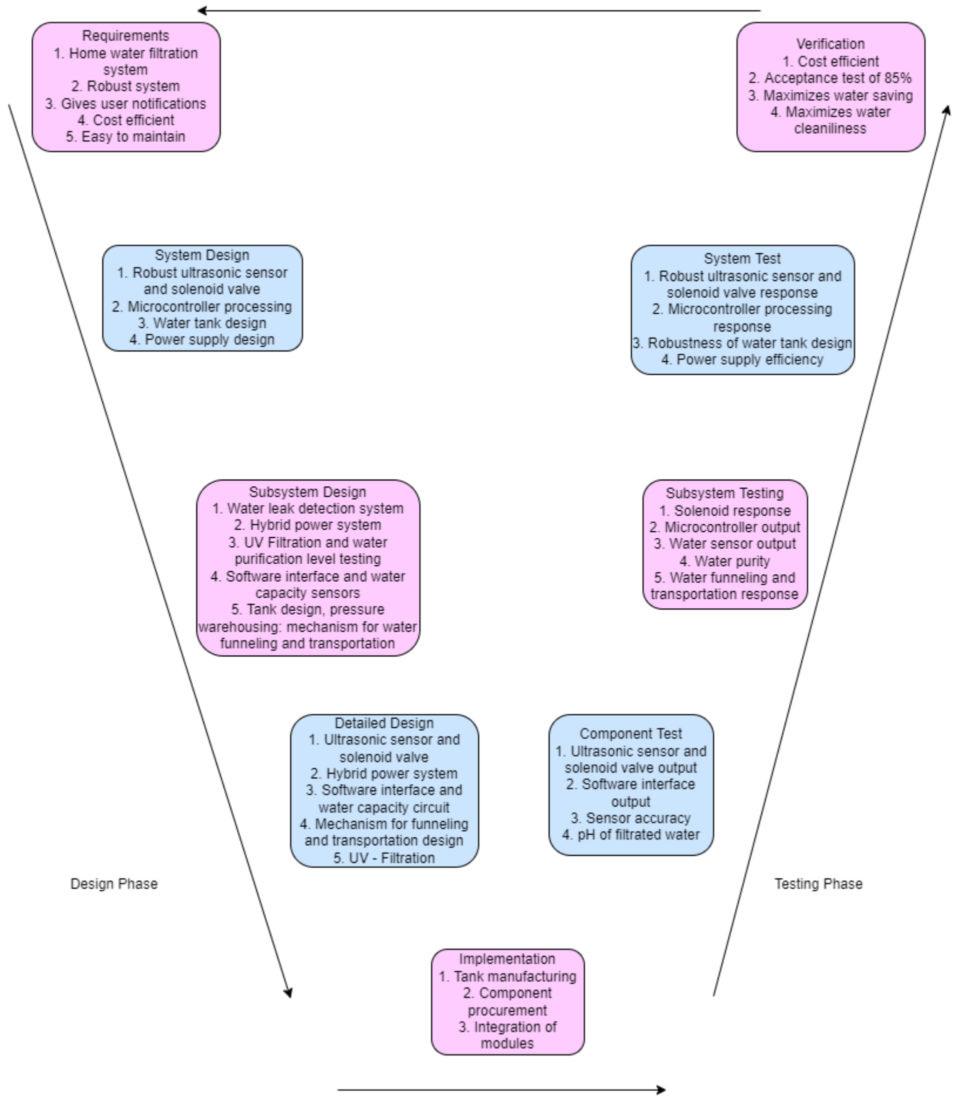


Figure 2: V-Diagram of Overall System

2.6. Description of Modules: Subsystem Chapters

2.6.1. Tank Design, Pressure and Warehousing

This subsystem is responsible for the storage of miscellaneous wastewater before purification by UV lighting and biochemical filtration (which itself is another subsystem) and the subsequent storage of filtered water. The filtered water is redistributed to other areas of the house for reuse via the funnel and transport system of the "individual subsystem itself". This subsystem has various user requirements for the smart home system to function optimally and provide the promised benefits to the user (that is, long-term savings in water charges and reduced water waste).

2.6.2. Water Tank Capacity Monitor Sensors and Software Interface

Capacitive Level Sensor

Manufacture of capacitive sensors for water level detection. The impedance part (reactance) of the capacitor, features a high impedance sensor, especially at low frequencies. Capacitance sensors are also commonly used non-contact devices. The system used two copper plates, height (h), width (b), to create a water level sensor based on the principle of capacitance.

Software Interface

This subsystem is basically an application (a mobile app connected to the system`s sensors and software) that serves the purpose of the app basically communicates with the system to see the capacity of the tank, the speed at which the tank is being filled, and the time remaining before the user can start the water recycling process. of water from being filled if the automated process fails and allow the app to override access.

2.6.3. Water Leak Detection Subsystem

The water supply shortage has increased dramatically over the years because of overpopulation, changes in climate, and dilapidated water facilities, where deteriorated pipes account for most of the water leaks. The biggest challenges are the size of the leaks as well the time taken to detect them. This subsystem presents an implementation of a system that is installed in the hydraulic facilities of a residential home to detect water leakages. The system consists of an ultrasonic water sensor, a microprocessor for data interpretation, a notification sent via Wi – Fi to the user's phone and a solenoid valve that shuts off the main water supply to avoid leakage.

2.6.4. UV Filtration

This subsystem is responsible for cleaning/ filtering the greywater intended to be reused as part of the whole system. The greywater is the household wastewater from washing machines, bathroom sinks, showers, and bathtubs, which is only lightly soiled and poses a minimal health risk.

The greywater flows into the UV filtration chamber, which contains UV lamps that emit UV light with a 254 nanometre wavelength i.e. the Germicidal Frequency. At this frequency, these UV light waves can disrupt the DNA and therefore functioning of microorganisms. This process destroys 99.99% of harmful microorganisms without adding any chemicals to the greywater. Thus, this subsystem for basically purifying the water.

2.6.5. Water Purification Level Testing

This subsystem is a secondary mechanism for monitoring/ ensuring the effective removal of water pollutants. The water quality is detected via sensors, and if the water is too dirty to be reused even after UV filtration, the polluted segment of water is consequently removed from the system, via the sewage pipes, to keep the entire system clean. This failsafe mechanism is relevant because there are many possibilities for inadvertent contamination of reclaimed water beyond the levels at which UV cleaning is useful.

2.6.6. Hybrid Power Supply

This subsystem powers the entire pump and filter system. If the system runs out of power at night due to insufficient charging of the battery by the solar panel, the system has a detector that automatically switches the power to the main power, which can keep the filter and pump system running. If the panel cannot supply enough power during the day, the system will also switch to mains.

3. Module One – Software Interface and Water Capacity Sensors

Module completed by Muziwakhe ZULU(ZLXMUZ001)

3.1. Subsystem Introduction

This subsystem is designed to monitor the amount of water in the storage tank and relay that information to the user and to the rest of the system's processes. Since the user might only want to recycle the water when the tank is at its full capacity to save on to avoid wasting energy and the amount of chemicals used, it seems more cost efficient to process the water in one huge batch at certain intervals. This module is split into two components namely the software interface and the water capacity sensors. These sub-processes work together to relay information all around. After all processes are checked and everything is working perfectly the water is passed onto the next stage if not the information is relayed to the user and the system through the software as to what could have gone wrong and where exactly.

1.1. User Requirements

Req. ID	**Requirement Text**
R**.U.001**	Interactive Software interface
R**.U.002**	Water capacity sensors

Figure 2; user requirements

1.2. Requirement Analysis

3.3.1 Analysis of R.U.001

Here we have two sections of this subsection, firstly we have the firmware. This will provide the ability to control all processes within the system hardware. Control is needed is a sense that although the processes could be mechanically automated, there is need for low level control of the system to aid when there is failure and to communicate with the user through an application-based software interface. The application is the interface which is the interactive part of the subsystem.
it will communicate with the cloud services, which then relays information to the raspberry pi connected to the water pump which communicates with the water sensor in the storage tank

For this system to be fully functional, it should be installed in mobile device, and must have wireless communication features. Since the raspberry-pi can have its own display interface, this could be used to connect to an external monitor, mounted on a wall preferably to an external monitor and the mobile application can be used for controlling processes and monitoring the system on the go, away from home. The interface can have external plugin ports as well to be able to download data from the system for analysis.

Verification:

Connectivity testing

To check functionality of this subsystem well use a raspberry pi which will communicate with our designed mobile to test the display and response rate of the system. We also will move the host device to multiple destinations to see how distance affects the quality of service. We will also subject the test system to different temperatures to see how accurate the values given are and how quick this communicated to our end host. The application written in C code.

3.3.2 Analysis of R.U.002

In this subsystem we are using speed of sound to measure water level. Speed of sound from ultrasonic transducers can be user to predict and measure the water level in real-time and continuous, advance, reliable, accurate using a microcontroller for processing the signal. Because every object can reflect ultrasonic waves, such as wood, glass, stone, paper, and other materials, ultrasonic sensors can be used to detect the surface of an object. Ultrasonic vibrations are easily absorbed by materials like linen, cotton, and wool, making them difficult to detect. Wide surface undulations make it difficult to notice objects because irregular wave reflections result. This method is used to implement an ultrasonic water level sensor. The distance measurement might be correspondingly weakened by the intensity of dispersed ultrasonic wave signals in air. This is owing to the loss of diffusion and absorption from the round surface due to the phenomena of diffraction.

Below is the diagram of the proposed ultrasonic water sensor measurement

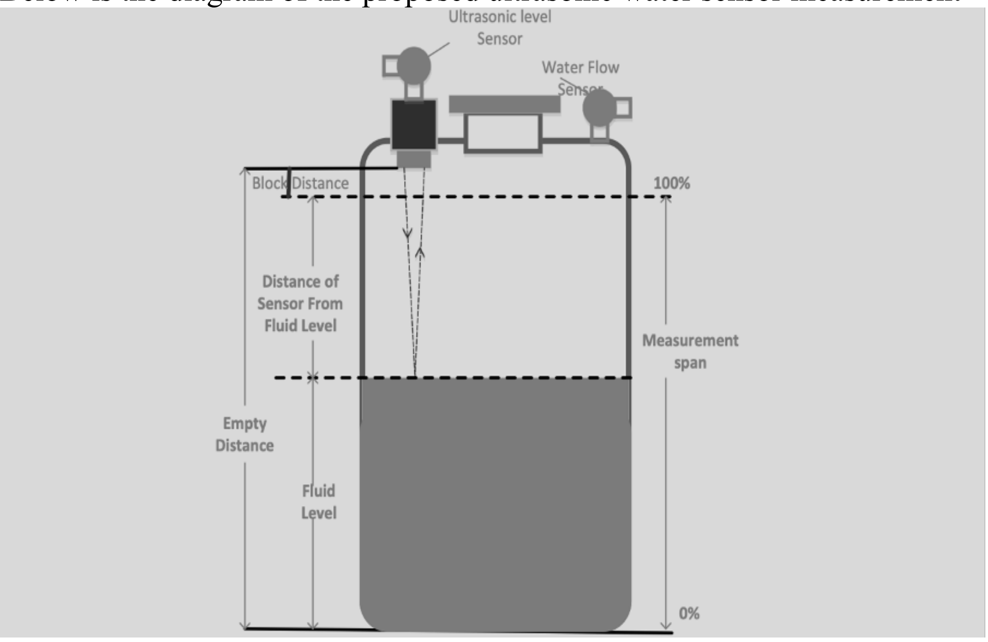


Figure 3; illustrates the overall design of where the water sensor will be located on the storage tank

Level Height Calculations

The distance of object detected from ultrasonic waves can be expressed by equations:

$S = c * t/2$...... (1)

Propagation speed of sound (c) :
c=331.5+ 0.607∗T........(2)
[in meter/second (m/s),]
T = air temperature.

result of measurement distance of water level , calculate volume water in tank by equation :
$V=\pi * 1/2 * D^2 * t$...........................(3)

D = diameter, t = high fluid level
Liquid level sensing is based on the theory of a ratio metric measurement, using three sensors as shown below

3.4. Design Choices

We wave two types of systems: 1) An internal field system which includes a water level sensor and a control system unit, and The external system consisting of mobile application and database real-time server). Sensors initiate and capture data every 100-200 milliseconds (measuring water level and water flow). Pump switches (On/Off) are controlled by measuring the water level, such that when the optimal water level is reached the pump switches on and start processing the water, this is to save power as the pump would be switched off when water level is not at the required level. The water flow sensor can be utilized as a pump status indication (On or Off condition).
Every one second, measurement data is provided via RS485 BUS communication to the System Control Unit. Sensor data is received and stored in internal memory by the Control System unit (data is deleted periodically). Data processing and tank capacity calculations are done by the Control System Unit.

SYSTEM DESIGN OVERVIEW SHOWN BELOW

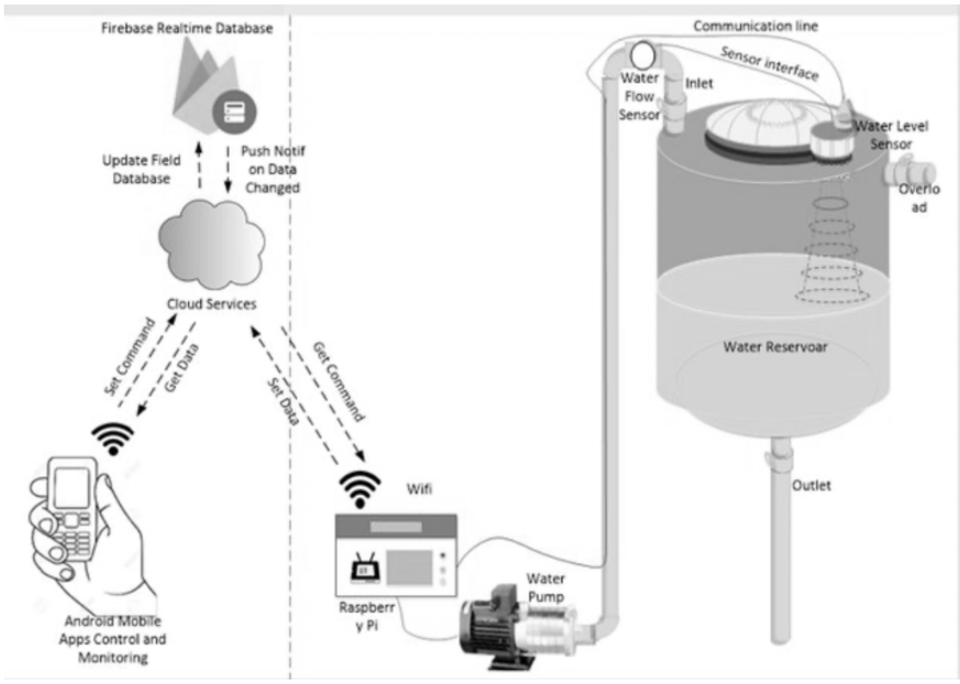


Figure 4; overall subsystem layout depicting the linking of each subsystem component in carrying the subsystem processes

Below the block diagram of the proposed design is shown:

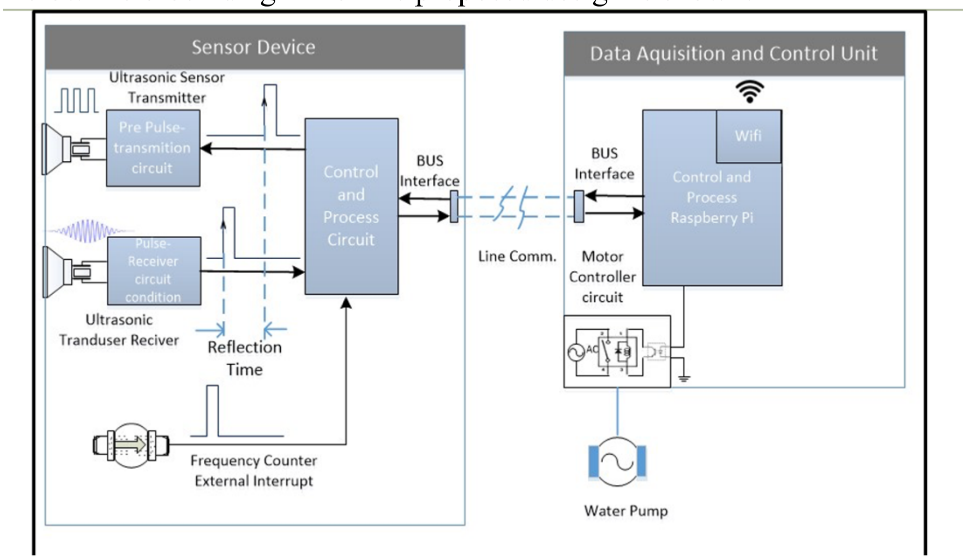


Figure 5; block diagram illustrated the explicit sensor design, internal and external features to support its full operation.

Sensirion's SHT 10 series sensor was utilized to measure temperature. With normal two-wire serial interface connection, only four wires are necessary to connect the sensor to the microcontroller board. Water flow sensor with speed pulse counter based on interrupt external signal. The Raspberry Pi version 3 was utilized for data acquisition and control (Unit Control System).

Server and cloud storage

In designing the system, we saw the need for and importance of backing up data collected in the system and the status it is encase of total power failure. This was done by utilizing a cloud storage system that periodically backs up information from the system. This storage was set to have at least adequate gigabytes of storage. This meant that our system software would support internet connectivity. This would also mean that if failure occurs the information would be automatically sent to the manufacture company and to the user to make troubleshooting way easier and convenient. It contains a database as well that could be used to trouble shoot errors, push appropriate notifications as well.

Instruction manual

It was noted that creating such a sophisticated system would be tedious and difficult to navigate for an average user. An instruction manual for the software interface was designed, it had to be basic, easy to understand and equipped with image interpretation where necessary. The manual is meant to guide the user on which commands to use at certain times, especially in times of system failure or critical emergency. It guides the user from the power up process to, connectivity troubleshooting and how to refill needed chemicals, to also interact with backup power when needed.

Sensor design

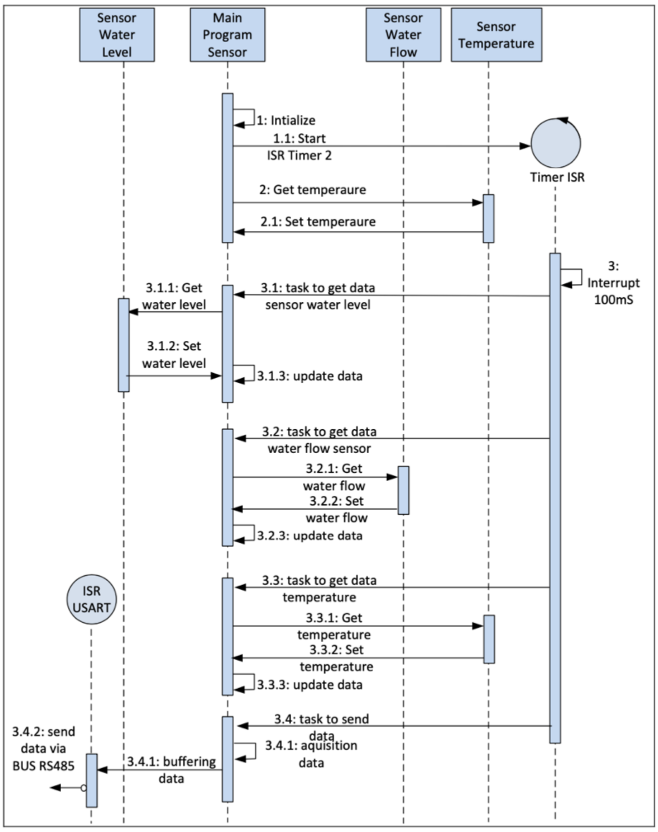


Figure 6; illustrates the flow of commands within the sensor.

Interrupt Service Routine (ISR) generates triggers every 100 mS, the trigger generates counters every second (10 times). Counter time is a ticker, each every sensor has a certain time slot to complete the task. The complete measurement results of the sensors are transmitted to the Control System Unit via RS485 serial communication. Software design with a scheduler system, makes the system predictable.

3.5 V Diagram, Constraints and Limitations

3.5.1 V-Diagram

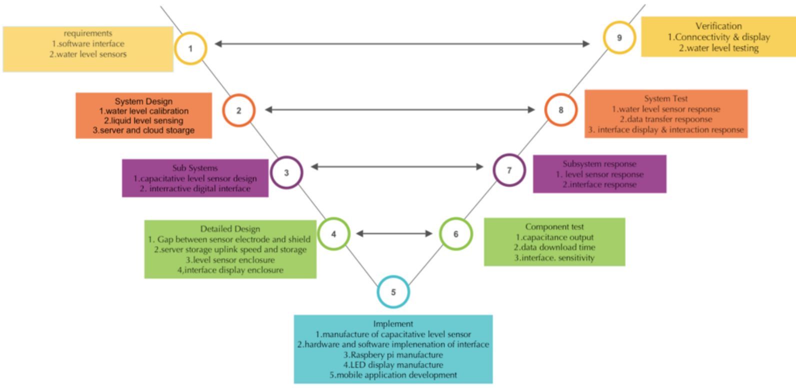


Figure 7; v diagram

3.5.2 Constraints and Limitations

Maintenance

Water level sensor need to be replaced every 2- 3 years, hence it could prove costly having to purchase new components plus installation fees being spent in that repeated period. And the installation is complex.

Data propagation delay.

Ideally the system response of the software interface when communicating with the user, relaying information from the internal system (sensor and firmware) there is going to be somewhat delay in the propagation channels which could prove hazardous incase of a system failure

Security

Given the fact that the subsystem has digital and internet connectivity features the system is exposed to a possibility of cyber-attacks which adds additional costs in installing strong security system and antivirus software which need regular updates and could prove costly in the future

Design specifications:

No	Unit	Specification
1	Main board	Microcontroller ATMega 8A - Memory flash: 8KB, SRAM 2KB, EE-Promp 1024Byte Peripheral Board - Serial RS-485 - Port data Oscillator Clock 7.7328MHz Voltage in DC 5 Volt
2	Sensor HC-SR04	frequency 40 KHZ Trigger and Data Connection
3	Sensor	SHT 10

Table 2; specification attributes of the subsystem sensor components

3.6 STEEPLE ANALYSIS

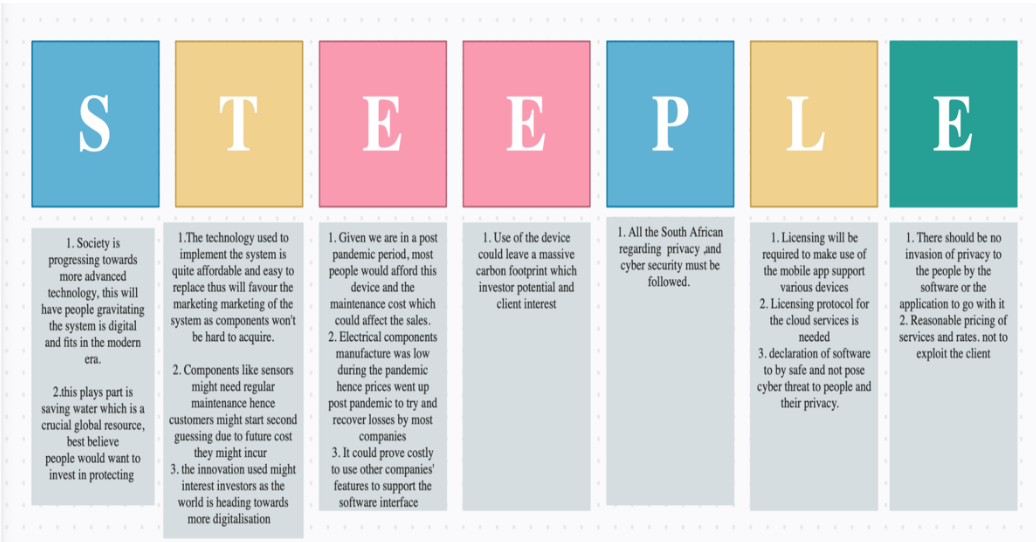


Figure 8; illustrates a chat that explains the STEEPLE analysis of the subsystem

3.7 OTHER DISCUSSIONS AND CONSIDERATIONS

Other than STEEPLE discussion there is some other factors to cover which include:

HEALTH AND SAFETY

The subsystem module must be designed with emphasis of the user's health as priority. Material used in manufacturing must not cause any health hazards towards the user.

3.8 UML DIAGRAM

Class diagram of water level control application

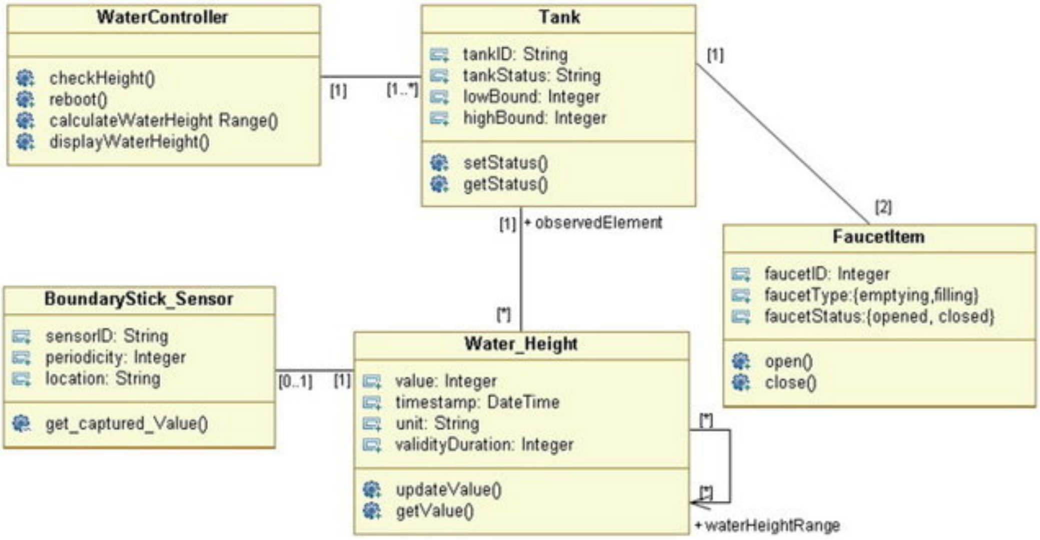


Figure 9; Class UML diagram of the system with addtional features

3.9Sensitivity analysis

Parameters the system is sensitive to include:

- Water level height and pressure
- Raspberry pi uplink speed
- Cloud storage
- Length of communication line
- Material of water tank
- Environment (temperature, humidity)

How to optimise parameters for improved performance

1. control of temperature and humidity is required. International standards suggest that measurements be performed at 20°C or corrected to "true length" at 20°C.
2. Calibrate the sensor to handle any form of shape the water is in, and the size.
3. Connect raspberry to fast speed Wi-Fi for quicker updates and performance
4. Increase capacitor sensor parallel plates surface area and choose better dielectric.
5. Shorten length of communication line and reduce resistance within the line

3.10 SIMULATION

Proposed Simulation using proteus software utilizing an Arduino uno microcontroller

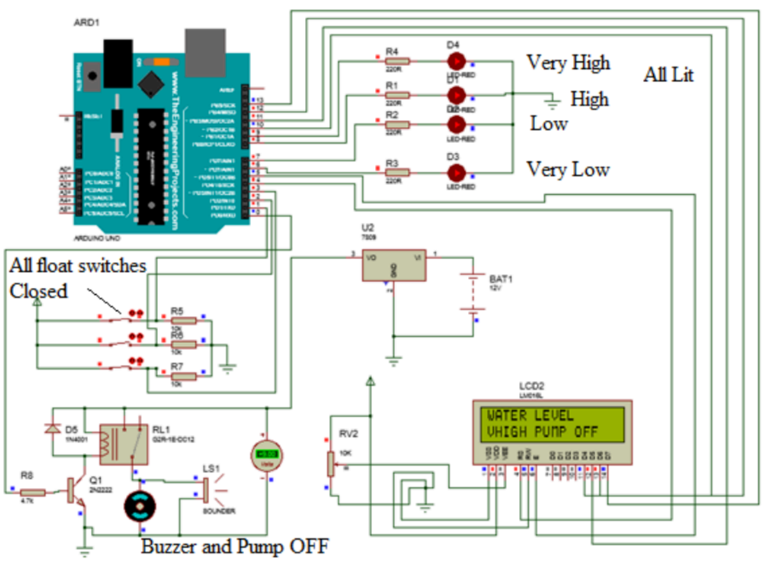


Figure 10; water tanks simulation labelled layout(concept)

SIMULATION RESULTS AND SCHEMATIC

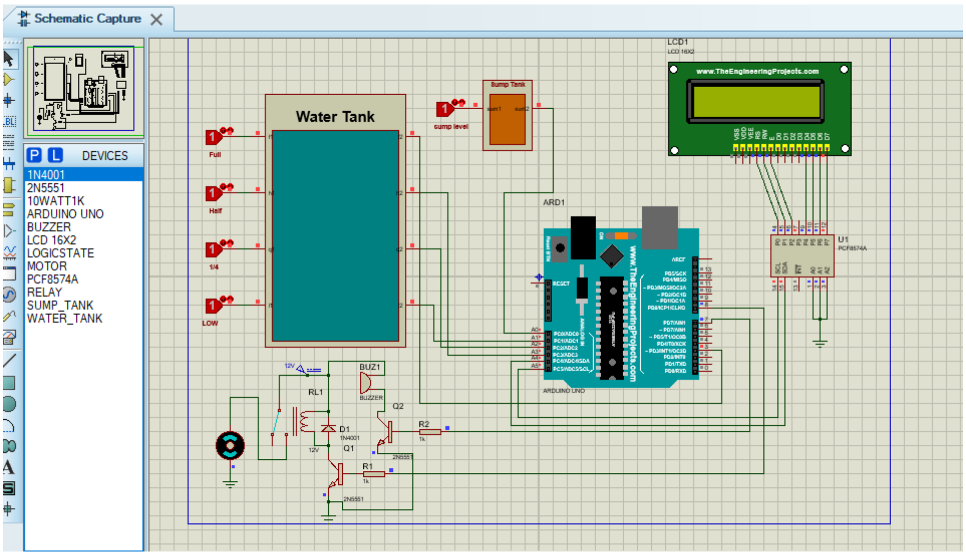


Figure 11; simulation schematic in proteus software

We use voltage to simulated a water tank, utilizes the concept of potentiometer/potential divider.

Water tank has 4 (HIGH/LOW voltages) connected; each represent tank water level when switched on, inital condition are on 1(HIGH) on the water tank.

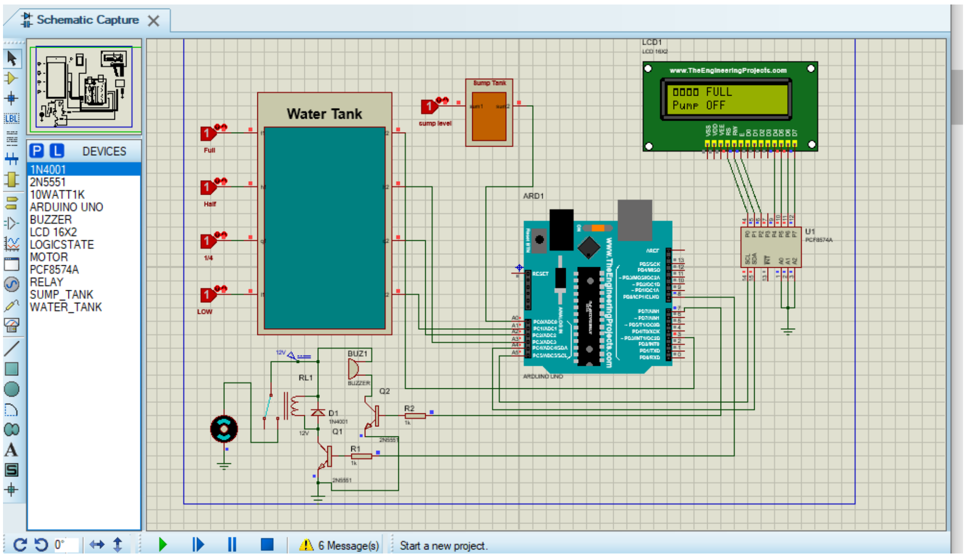


Figure 12; tank full simulation

Tank is full initially, pump is off since water is not needed to follow into the tank at the moment. The LCD display shows the status of the water. Arduino controller implements the sensor.

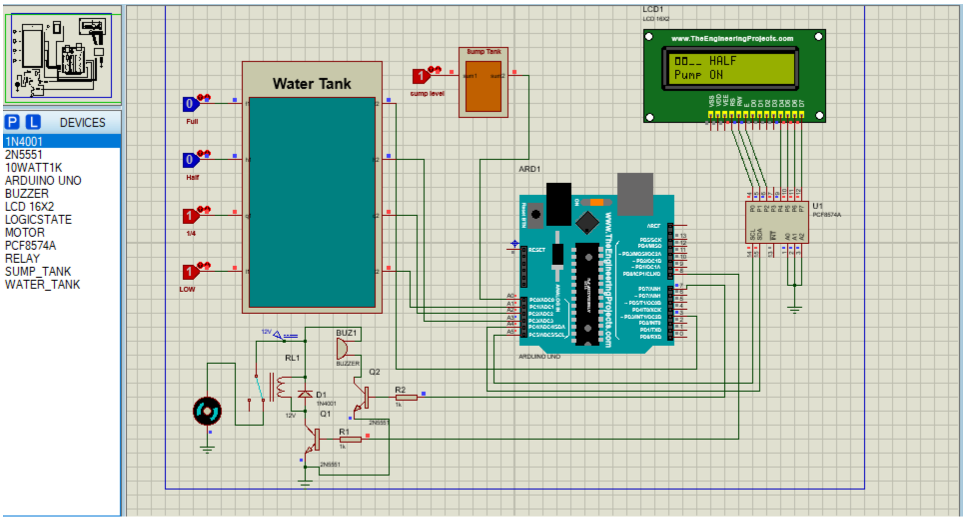


Figure 13; Tank ½ full

When tank is half full (two top voltages on LOW), the pump is swicthed on, flow rate reduces as the tannk approaches full capacity.

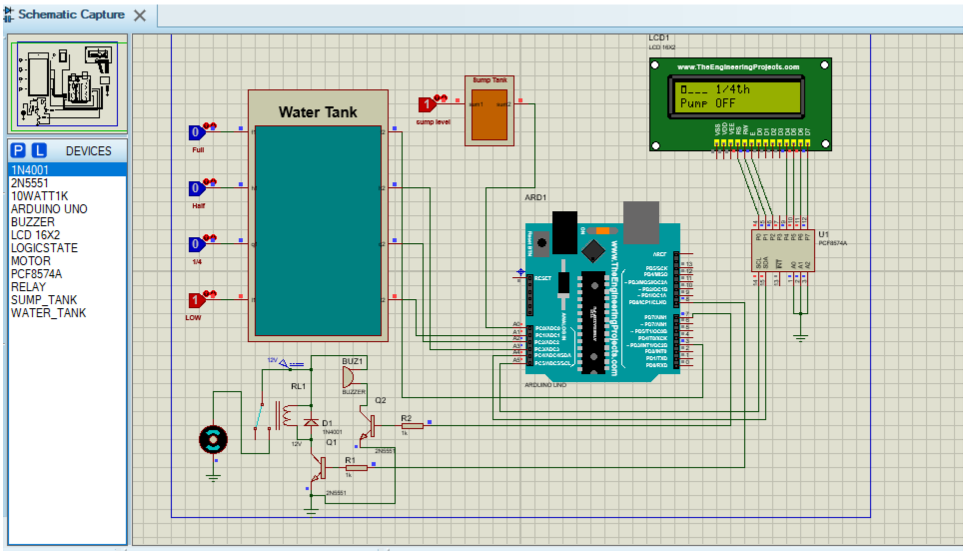


Figure 14; tank on ¼ full,

Pump works at a faster rate to fill up the tank.

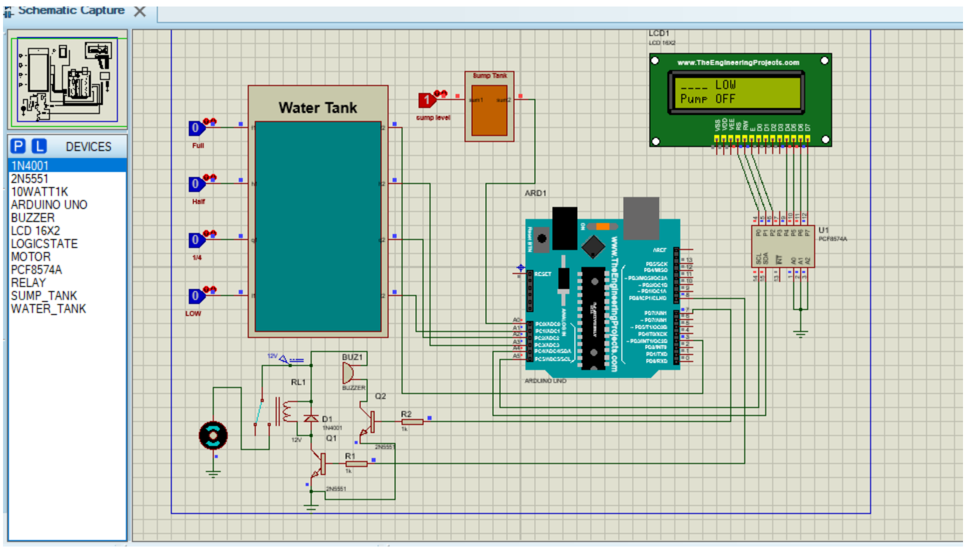


Figure 14; tank on low/empty

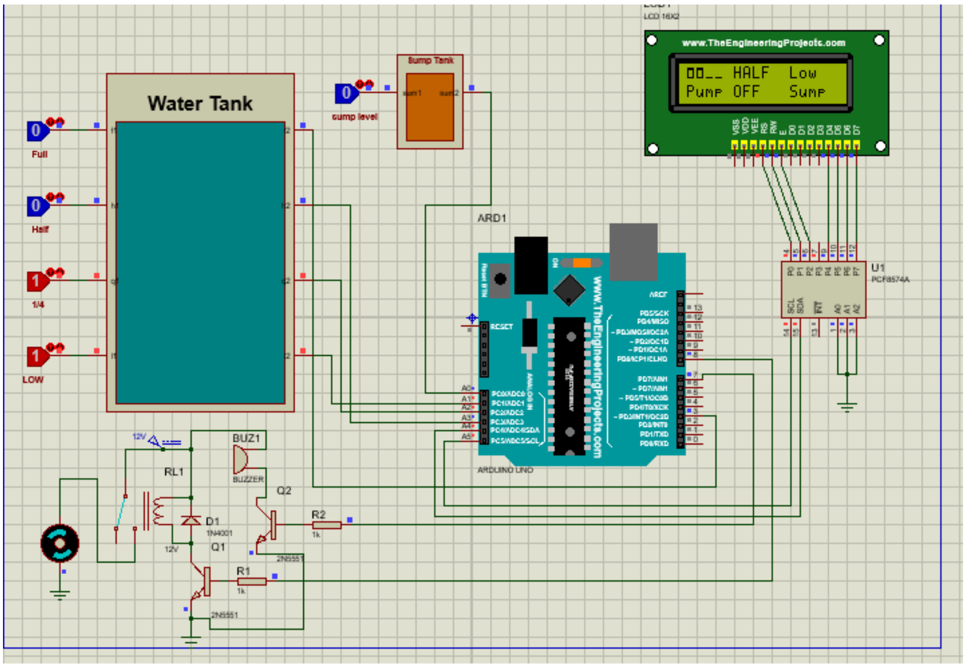


Figure 15; sump(back up tank) on

4. Module Two – (a) UV Filtration and (b) Water Purification Level Testing

Module(s) completed by Noa Anthony (ANTNOA001)

a. UV Filtration

4.1 Subsystem Introduction

This subsystem is responsible for cleaning/ filtering the greywater intended to be reused as part of the whole system. The greywater is the household wastewater from washing machines, bathroom sinks, showers, and bathtubs, which is only lightly soiled and poses a minimal health risk.

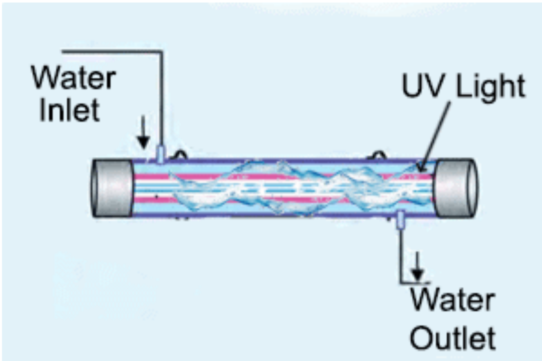


Figure 3 - Simplified UV Filtration System

The greywater flows into the UV filtration chamber, which contains UV lamps that emit UV light with a 254 nanometre wavelength i.e. the Germicidal Frequency. At this frequency, these UV light waves can disrupt the DNA and therefore functioning of microorganisms. This process destroys 99.99% of harmful microorganisms without adding any chemicals to the greywater.

4.1.1. User Requirements

Req. ID	Requirement Text
R.U.001	UV Lamp and chamber housing is required.
R.U.002	UV Filtration section (volume) of water must be segmented from the incoming water supply.
R.U.003	Only biodegradable products may be put down users' drains.

4.1.2. A Requirement Analysis

4.1.2.1. Analysis of R.U.001

"UV Lamp and chamber housing is required."

The UV Filtration system will comprise a device which includes a chamber that encases the entire system. The device will have a glass quartz sleeve that holds the UV lamp that emits the germicidal wavelength of radiation to deactivate living organisms. The quartz glass sleeve is transparent to the UV wavelength, which allows UV light to penetrate the glass and disinfect the water. A quartz sleeve protects the UV lamp (electricity) from the water.

Req. ID	Requirement Text	Derived From
R.T.001	Glass quartz sleeve and UV Lamp can be used.	R.U.001

Verification
The requirement will be verified by validating that microorganisms will successfully be destroyed such that the water will pass the Water Purification test section of the system (i.e. be deemed purified by the system).

4.1.2.2. Analysis of R.U.002

"UV Filtration section (volume) of water must be segmented from the incoming water supply."

Once water flowing through the system reaches and fills the UV Filtration Chamber, the chamber needs to be designed such that water being purified is physically isolated from the water flowing in to and out of the chamber. Two O-rings can be used to seal the chamber.

Req. ID	Requirement Text	Derived From
R.T.002	Two O-rings to seal the system.	R.U.002

Verification
The requirement will be verified by validating that the chamber will successfully be sealed from water flowing into/ out of it while UV Filtration is in process.

4.1.2.3. Analysis of R.U.003

"Only biodegradable products may be put down users' drains."

This requirement reinforces the sustainability element of the project. It ensures the system will function optimally as a whole and guides users to make more eco-friendly choices when it comes to cleaning and grooming products used at home.

Req. ID	Requirement Text	Derived From
R.T.001	The system should have an instruction manual that includes messages on emphasizing the use of biodegradable products.	R.U.001

Verification
The requirement will be verified by validating that biodegradable products will successfully pass through the water purification level testing section of the system (i.e. be deemed purified by the system).

4.2 Design Choices

The section aims to identify the specific components that meet the design requirements as well as compare them to choose the most optimal components for the project. The choice of the optimal solution will be based on various factors such as the cost, technical maturity, ease of testing, reliability, maintenance cost and practicality of implementation. The components evaluated are headed below:

4.2.1 UV Filtration Device

The main components associated with building the UV filtration system are the UV lamp, glass quartz sleeve and two O-rings.

Practically speaking and in the given context of the UV purifier's use, it makes sense to purchase an already-manufactured UV Water Purifier. For a plumber undertaking an extensive project with many different subsystems that need to be installed, as outlined by this report, it makes sense to rather buy the product from a supplier (as plumbers usually do), rather than buy all the separate elements and hire labourers with the relevant expertise to build it. It saves time, device functioning will be more reliable, and will be a similar cost ultimately.

Furthermore, as the device is integral to the project, the plumber may be able to purchase the devices in bulk at a further discounted price from a supplier.
As such, I will instead be comparing three different models of UV Water Purifiers and decide on the best one to use based on cost, maintenance, and reliability.
Note: the typical household pressure is enough for a UV system to operate.

Three potential products:

a) 6 Watts UV Steriliser
b) Neo-Pure NP5-15 UV Disinfection System
c) Viqua VH150 Whole Home UV Water Disinfection System

	(a) 6W UV Steriliser	(b) Neo-Pure NP5-3	(c) Viqua VH150
Gallons per Minute (GPM)	0.5	3	5
Dimensions (cm)	5 D x 25.5 L	6.4 D x 36.4 L	8.9 D x 33.02 L
Inlet/ Outlet, Pipe Thread (Male/Female)	1/4”	1/2" MPT	3/4" FPT, 1” MPT
Power (W)	6	20	35
Replacement	No	Yes, but	Yes

parts available from same supplier		different brand	
Lamp replacement countdown	No	Yes	Yes

Table 1- Figure of Merit Table

Option (c), The Viqua VH150 Whole Home UV Water Disinfection System is the most suitable product to fulfil the requirements, because:

- It has the greatest flow rate (5 GMP) compared to the other products.
- Its set-up allows for easy lamp replacement (which is required every 1-2 years) as the brand allows for replacement lamps of the same brand to be purchased on their own.
- The device has an audible reminder for lamp replacement and countdown timer with a digital display, which is more helpful to clients, compared to product (a).
- The device is compact and of a practical size for this application.
- Unlike the other two products, this device comes with a guarantee to inactivate chemical resistant parasites like Cryptosporidium, Giardia and E.Coli, as well as viruses.
- This device has the most suitable power specification for the application.

Furthermore, the device has a built-in solenoid valve on its output that ensures water only exits the chamber if UV lamp levels are functioning effectively. The device is also easy to maintain and service, compared to the other two products, as laid out in its instruction manual.

4.2.2 System Instruction Manual

The instruction manual can simply be created in a word Document, for example. The manual can either

(a) be printed and given to clients or it can

(b) be a digitised manual that is emailed to clients once the system has been installed.

Option (b) will be chosen as this will save on printing costs – there will be none, and it ensures customers will never lose the manual.

4.3 V-diagram, Constraints and Limitations

4.3.1 V-diagram

The V-diagram summarizes the main steps to be taken in conjunction with the corresponding deliverables for the subsystem's development. It can be used for this subsystem as the project requirements are clear and the project itself is on a small scale. The V-diagram ensures proactive defect tracking and ensures testing occurs in the early stages of the project. Ultimately, this model enhances the probability of building an error-free UV Filtration system of a good quality.

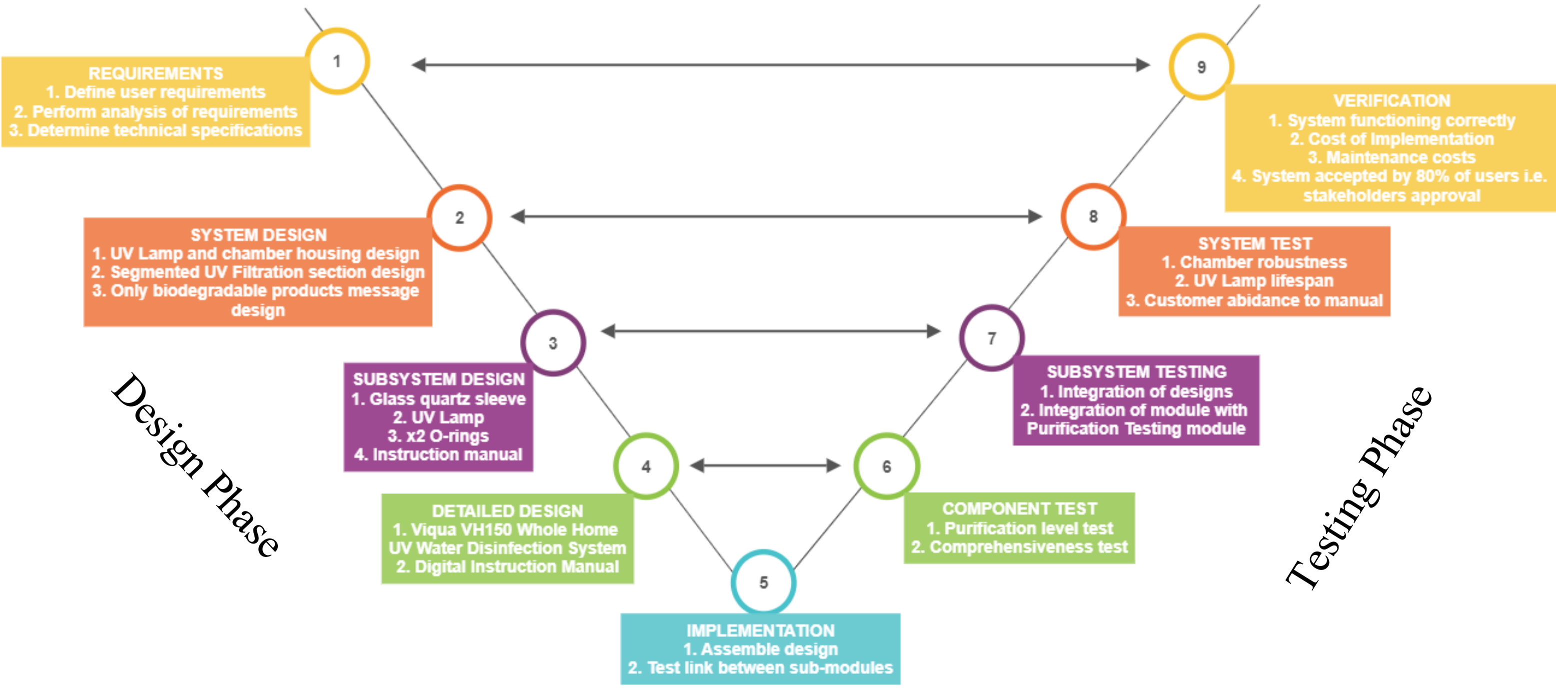


Figure 4 - V-diagram

4.3.2 Constraints and Limitations

Maintenance requirements

UV Lamp replacement is required every 1-2 years which may disincline clients to implement this system. The small business owner might have to offer replacement without the cost of labour for, for example, the first five years from installation, to convince clients to install the system. A working lamp is crucial to the system, which cannot function effectively without it.

Failure to comply with instruction manual

Since the manual is digital, and due to the forgetful nature of people, clients may frequently accidentally use non-biodegradable products on the system, rendering the next few rounds of water processing useless, meaning the water cannot be reused and will have to instead be released to the drain pipes, until the products have been fully 'flushed out'.

Theft/ damage

Theft of pipes, valves etc forming part of this sub-module - that may be situated in the client's garden/ outer wall - are capable of being stolen or damaged, rendering the system ineffective until the parts are replaced. Placement of pipes is limited to the client's property layout and size, and so ultimately in certain contexts, this is an unavoidable potential problem.

4.4 STEEPLE Analysis

The STEEPLE Analysis is an effective and commonly used tool to evaluate different external factors that have the potential to impact the UV Purification sub-system. It is essential to consider some external factors before taking and finalizing decisions.

4.4.1 Social

- Lifestyle Trends: Society is increasingly gravitating towards more sustainable practices in their daily lives. This means there is potential demand for this system as a whole.
- Effect on community: Communities will save water and water bill costs by using this system, meaning more funds will be available to potentially put back into the community. This means there is potential demand for this system as a whole.

4.4.2 Technical

- Lifecycle of technology: The technology used to implement the UV Purification system has a different lifecycle per component, but the shortest lifecycle is that of the UV lamp, which needs to be replaced every 1-2 years, while the Quartz sleeve can be replaced every 24 months or as needed. This could hinder client interest in the system. The chamber, however, has a warranty of up to 10 years.

4.4.3 Environmental

-Resource usage: The resources used in this sub-system are not biodegradable in themselves and are also not made from recycled materials. This could hinder client interest in the system.

-Recycling considerations: The glass of the Quartz sleeve can be recycled, as can the pipes and O-rings when they are no longer suitable to use. This reinforces the sustainability aspect of the system.

-Manufacturing and cost to the environment: The short lifecycle of the UV lamp and Quartz sleeve means there is a continual need to use resources and manufacture these components. This is at the detriment to natural resources.

-Attitudes to environment from government, media and consumers: Water is considered a scarce resource and as such, especially in areas afflicted by droughts, water saving is promoted. This system reinforces this ideal/ attitude.

4.4.4 Economic

-Overall economic situation: In the current Covid 19-recovery context of the economy, the fact that customers may not be financially able to install this system needs to be considered.

-Community issues: In the current Covid 19 context, communities may still be wary of having people in their homes to install the system.

-Water billing trends: Water costs in South Africa have only increased in recent years:

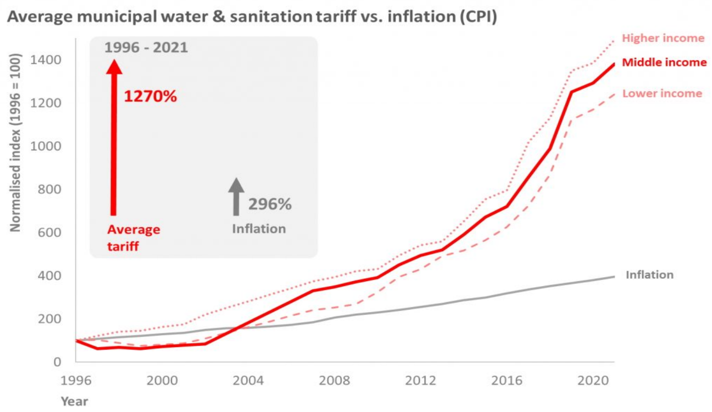


Figure 5 - Water cost trends

This means customers are more likely to install this system to reduce water bill costs and save money in the long term.

4.4.5 Political

-Health and safety legislation in SA: The Constitution of South Africa states that everyone has the right to clean water and basic sanitation. This means the UV Purification system must abide by this and be fully functional, effective and safe.

4.4.6 Legal

-Trading policies and availability of products required for system: In the current Covid 19 context, as well as the Russia-Ukraine conflict, import of goods is more uncertain, meaning it might be necessary to stockpile certain products, specifically the UV Filtration system in this case.

4.4.7 Ethical

-Contribution to society: From an ethical point of view, this system is aligned with good ethics in that it assists in the cleaning and reuse of water - a scarce resource, according to the UN.

-Effect on employees: This system is quite comprehensive and requires a team to install it. This means more people are employed, and employees are able to contribute to sustainable practice.

4.5 Behavioural Activity UML Diagram

The UML Behavioural Diagram depicts the elements of a system that are dependent on time. Furthermore, it conveys the dynamic concepts of the system and how they relate to each other, while in itself being a flexible model. This model effectively communicates the UV Filtration subsystem architecture.

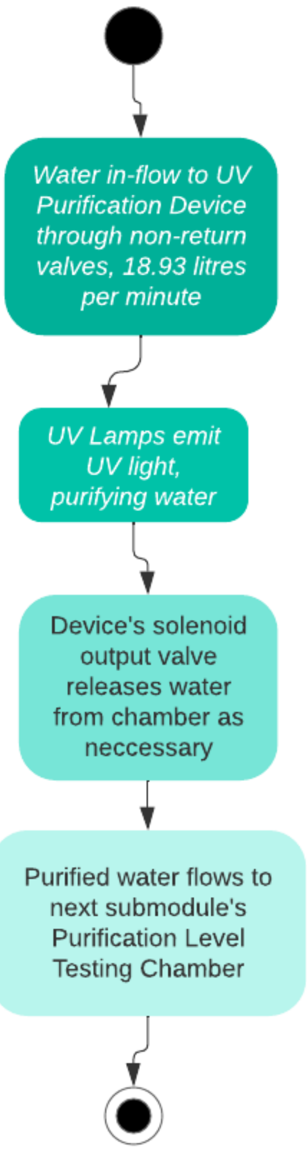


Figure 6 - Activity Diagram

4.6 CAD Drawing/ Prototypes

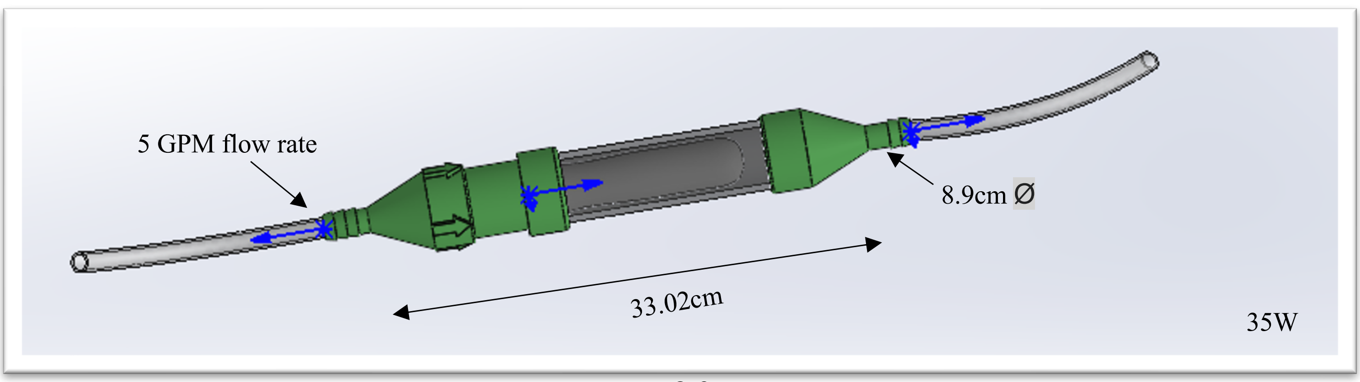


Figure 7 - Water Purification Chamber model

4.7 Sensitivity Analysis

Parameters the system is sensitive to:

1. Lack of lamp replacement.
2. Voltage surges.
3. Temperature/ weather.
4. Water potentially leaking onto the controller by means of a leak at a connection point.
5. During extended periods with no water flow, the water in the chamber can become very hot (+- 60 °C) and potentially lead to scalding.
6. Potential thermal expansion and material degradation due to UV exposure.

Reducing variability/ optimizing each of the abovementioned parameters:

1. Install digital screen which countdowns to lamp replacement requirement, alerting user.
2. A UL1449 certified - or equivalent - transient voltage surge suppressor can be installed.
3. Product to be installed indoors to mitigate this problem.
4. Allow for a ‘drip-loop’ on the lamp, sensor, and power cord to prevent any water from potentially entering the controller.

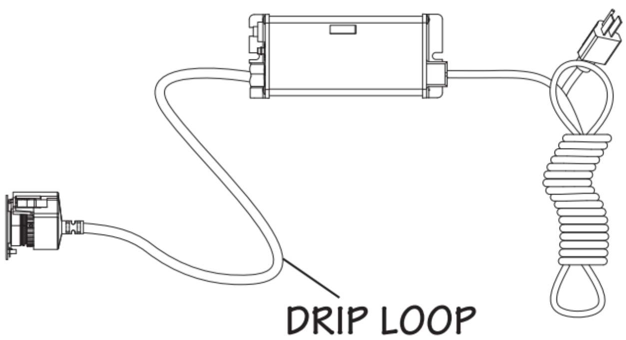


Figure 8 - Drip loop configuration

5. To eliminate this problem, a temperature management valve can be installed at the outlet of the UV system.
6. Installation of metal fittings and at least 25.5cm of copper pipe on the outlet of the UV chamber.

4.8 Discussion on Other Issues

Beyond the STEEPLE Analysis, there are no other issues relevant to this subsystem which warrant discussion. This is because Health and Safety considerations have been discussed under the ‘Political’ context, Socio-economic considerations have been discussed under both the ‘Social’ and ‘Economic’ fields of the STEEPLE Analysis, and Legal and Environmental aspects have also already been covered.

b. Water Purification Level Testing

Module(s) completed by Noa Anthony (ANTNOA001)

4.1. Subsystem Introduction

This subsystem is responsible for testing the pollutant levels of the greywater to be reused, by testing water quality. Water flows into the testing chamber from the UV filtration chamber.

This subsystem is a secondary mechanism to ensure that UV filtration has effectively eliminated the greywater contaminants. In the event that water that is too polluted to be reused, this segment is removed from the system (funnelled back to the sewage water system), to ensure the whole system is not contaminated.

This failsafe is pertinent as there are numerous opportunities for greywater to accidentally be contaminated beyond levels that UV purification is useful. To list a few examples: the use of bleach to clean the user's shower drain, water from the kitchen sink with overly high grease levels, or dirty diapers that were washed in the user's washing machine. In any scenario, the system will detect this and remove the polluted water.

It must be noted that 'water quality' does not refer to a specific parameter; rather, it contains a number of elements to measure the status of water quality, namely, pH, redox potential, conductivity, salinity, and Ammonia Nitrogen ion levels.

4.2.1. User Requirements

Req. ID	Requirement Text
R.U.001	The testing chamber should house all the required water quality sensors in one.
R.U.002	Electronically triggered valve opening and closing is required.
R.U.003	Purification Testing section (volume) of water must be segmented from its outgoing water supply.

4.2 Requirement Analysis

4.3.1 Analysis of R.U.001

"The testing chamber should house all the required water quality sensors in one."
Waterproofed sensors that test for pH, conductivity, salinity, and Ammonia Nitrogen ion levels will be used. The output of these sensors will be read into a Programmable Logic Controller (PLC) or microcontroller (MC), depending on the sensor output communication protocol.

Req. ID	Requirement Text	Derived From
R.T.001	The chamber will have a sensor for pH, conductivity, salinity, and Ammonia Nitrogen ions, connected to a Programmable Logic Controller (PLC)/ microcontroller (MC).	R.U.001

Verification

The requirement will be verified by validating that the sensors work together and output the correct sensor value to the PLC/ MC.

4.3.2 Analysis of R.U.002

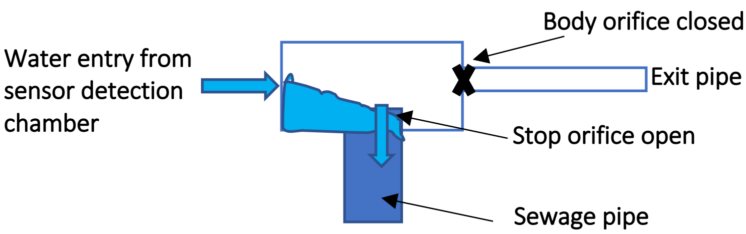
"Electrically triggered valve opening and closing is required."
Please note, the following electronics will be a waterproofed version:

A solenoid valve is an electrically controlled valve. The valve features a solenoid - an electric coil with a movable ferromagnetic plunger core at its centre. In the rest position, the plunger closes off a hole. An electric current through the coil creates a magnetic field. The magnetic field exerts an upwards force on the plunger opening the hole. This basic principle is used to open and close solenoid valves.

3-way normally-open solenoid valves allows for water to exit through one of two ports, depending on whether the solenoid coil is energized or it. This is required as water flowing from the UV Purification Chamber needs to be tested and diverted accordingly, either to the sewage pipes, or to the rest of the system.
More specifically, when the power to the solenoid is off, the plunger is raised which seals off the stop orifice and opens the body orifice allowing flow through the valve from the body orifice port and out the cavity port. When the coil is energized the plunger is down, sealing off the body orifice and opening the stop orifice allowing flow through the valve from the cavity port and out the stop port. In this system, the body orifice will connect to the pipe leading to the rest of the system, while the stop orifice will connect to the pipe leading to the sewage system.

It thus follows:
The output of these sensors will be read into a Programmable Logic Controller (PLC) or microcontroller (MC), depending on the sensor output communication protocol. The PLC/ MC will interpret the relevant signals and output a signal that corresponds to the following:

Only if all sensors read a correct water quality value, the PLC will output a LOW value, and when the water has **not** passed quality control, the PLC will output an electrically HIGH signal. This signal will power the base of a BJT circuited to the solenoid valve (as part of an amplifier circuit with a common emitter configuration), sealing the body orifice and opening the stop orifice, causing impure water to be diverted to the sewage system. Thereafter, when the water is deemed pure and the PLC therefore outputs a LOW signal, the BJT and solenoid valve will power off and the valve to the sewage pipes will close, and the body orifice will open again.
This means the water that 'passes the purification test' will be allowed to pass through to the rest of the system, where it will be stored/ used.
A simplified visual representation of the 3-way solenoid valve is shown:



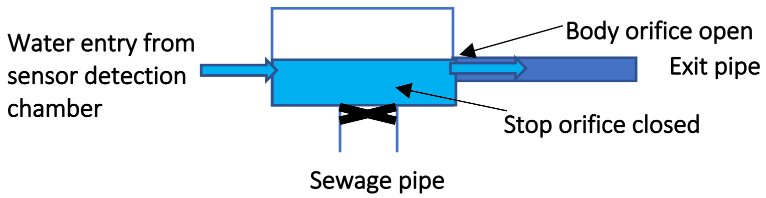


Figure 9 – simplified 3-way Solenoid valve model

Req. ID	Requirement Text	Derived From
R.T.002	3-way normally open Solenoid valve is used.	R.U.002

Verification
The requirement will be verified by validating that the stop orifice to the sewage pipes is only open when the water sensors detect the water to be impure, i.e. not usable as greywater in the home and garden.

4.3.3 Analysis of R.U.003

"Purification Testing section (volume) of water must be segmented from its outgoing water supply."

Once water flowing through the system reaches and fills the Purification Testing Chamber, the chamber needs to be designed such that water will remain in the chamber to be tested and not flow back into the UV testing chamber, as well as ensure that water deemed clean leaves the chamber and does not return. This may be done by using non-return valves at the entrance to and exit of the chamber. This ensures that only a portion of water is tested at a time and determined to be purified/ impurified, as determined by the sensors (and thereafter respectively released out the chamber/ to the sewage [drain] pipes).

Req. ID	Requirement Text	Derived From
R.T.003	Multiple non-return valves are used.	R.U.003

Verification
The requirement will be verified by validating that water flows through the pipes in one direction only.

4.4 Design Choices

The section aims to identify the specific components that meet the design requirements as well as compare them to choose the most optimal components for the project. The choice of the optimal solution will be based on various factors such as the cost, technical maturity, ease of testing, reliability, maintenance cost and practicality of implementation. The components evaluated are headed below:

4.4.1 Chamber

A small water tank is required as a chamber to house the water while the sensors detect the water quality. A plastic tank will be used as plastic is a durable material but also allows for

holes to be cut into it to connect 1) the pipes leading from the UV purification chamber and 2) the solenoid valve (as shown in the section below).
Considering different plastic water tanks, of varying litre capacity and cost, the following tank is chosen: Camp Master 40L Water Tank, as it sufficiently large while not being too expensive.

4.4.2 3-way normally open Solenoid Valve

Use of a 3-way solenoid valve ensures that there are to path options for the water, namely the sewage pipes and the pipes leading to the rest of the system.
Please refer to the explanation of the functioning in *4.3.2: Analysis of R.U.002* for a further understanding as well as a simplified visual representation of the 3-way solenoid valve if needed.

The solenoid valve will have to be purchased from a supplier, namely Alibaba. It thus makes sense to import the device in bulk to save on shipping costs. There is a wide range of products for this device, with little specification provided. Trail-and-error as to the best product to be used may be required. Cost and voltage specifications need to be taken into account.

4.4.3 Sensors

Commercial sensors for pH, conductivity, salinity, and Ammonia Nitrogen ion will be needed. Voltage output and cost needs to be considered. Taking waterproofing costs into account, the sensors will rather be placed externally, on the chamber, with their probes fed into the chamber through holes that are sealed and thus leakage-proof. The outputs of the sensors will therefore also not need to be waterproofed, and will be fed to the solenoid valve (to energize it).

A muliparameter sensor will be used instead of individual sensors for each water quality parameter. This is a practical solution as it means purchasing 'all' the sensors from a single supplier, rather than having to potentially rely on multiple separate suppliers.

Three potential products:

(a) EXO Multiparameter Sensor
(b) Apure KPS-400 Multiparameter Water Quality Sensor
(c) Proteus Multiparameter Water Quality Sensor

	(a) EXO Multiparameter Sensor	(b) Apure KPS-400 Multiparameter Water Quality Sensor	(c) Proteus Multiparameter Water Quality Sensor
Warranty	3 years	Unspecified *	2 years
Communication Protocols	RS-232, Modbus, USB, SDI-12	RS-485 bus, Modbus RTU	R-S232, SDI-12, Modbus RTU
All of required detection parameters (pH etc) present	Yes	Yes	No
Accuracy	Not specified	PH: 1%FS	PH: ±0.1 within 10°C

		ORP:1%FS	of calibration, 0.2°C otherwise ORP: ±20 mV
Measuring range	Not specified	PH: 0~14.00pH ORP: -1999 ~ 1999 mV	PH: 0~14.00pH ORP: -999 ~ 999 mV

Table 2 - Figure of Merit Table

**supplier has been contacted but has not yet provided a warranty period for this product at the time of report submission, but it can presumed to be atleast 1 year.*

Practically, the best option for purchasing these sensors is (b) *Apure's* KPS-400 Multiparameter Water Quality Sensor. This is an integrated sensor design, wherein up to four digital sensors can be connected at the same time.

This was chosen over the other options for the following reasons:

- Its RS485 serial communication is faster than the RS232 of the other products.
- It encompasses all the required pH, conductivity, salinity, and Ammonia Nitrogen ion parameters.
- It has the greatest measuring range and degree of accuracy.

The product is also reliable and easy to use, and is equipped with an automatic cleaning device, which effectively cleans the sensor surface, prevent 'microbial adherence', ensuring higher accuracy and lower maintenance costs. This device is also easy to install in the pipeline and tank, with a 19.05mm pipe thread. The probe and display section can be separated and connected by a cable.

4.4.4 Programmable Logic Controller (PLC) & BJT circuit

BJT circuits can be commercially bought at the low, standardized cost. Voltage and power specifications need to be taken into account, but since BJT circuits can be altered based on Vss, the most cost-effective products are suitable for the application. BJTs can be purchased in bulk along with resistors to build the required common emitter amplifier circuit configuration.

A compact, multifunctional PLC device can be purchased from a supplier. For this purpose, *ASCON Technologic's* Compact PLC NP4 will be used. This is because *Apure's* KPS-400 Multiparameter Water Quality Sensor has a RS-485 bus, Modbus/RTU communication protocol, which the PLC NP4 allows for. Furthermore, this device is chosen for the following reasons:

- The programming is intuitive: it uses open programming logic and has a wide availability of pre-existing functional blocks.
- Flexible: the device allows for the expansion modules to increase the number of available resources.
- Reliable: training support is guaranteed by *ASCON Technologic*, who brand themselves as a 'reliable partner for the realization of new projects'.

4.4.5 Non-return Valves

Comparing the following products:

a) CALEFFI NR 22mm spring loaded non return valve 22mm

b) Sun Command PVC Non Return Valve (50mm)

Option (b) is most suitable for the application as it has a larger diameter compared to option (a) to ensure water pressure is maintained, while still being cost-effective. Furthermore, it is made of PVC which is waterproof and durable.

4.5 V-diagram, Constraints and Limitations

4.5.1 V-diagram

The V-diagram summarizes the main steps to be taken in conjunction with the corresponding deliverables for the subsystem's development. It can be used for this subsystem as the project requirements are clear and the project itself is on a small scale. The V-diagram ensures proactive defect tracking and ensures testing occurs in the early stages of the project. Ultimately, this model enhances the probability of building an error-free Water Purification Level Testing system of a good quality and accuracy.

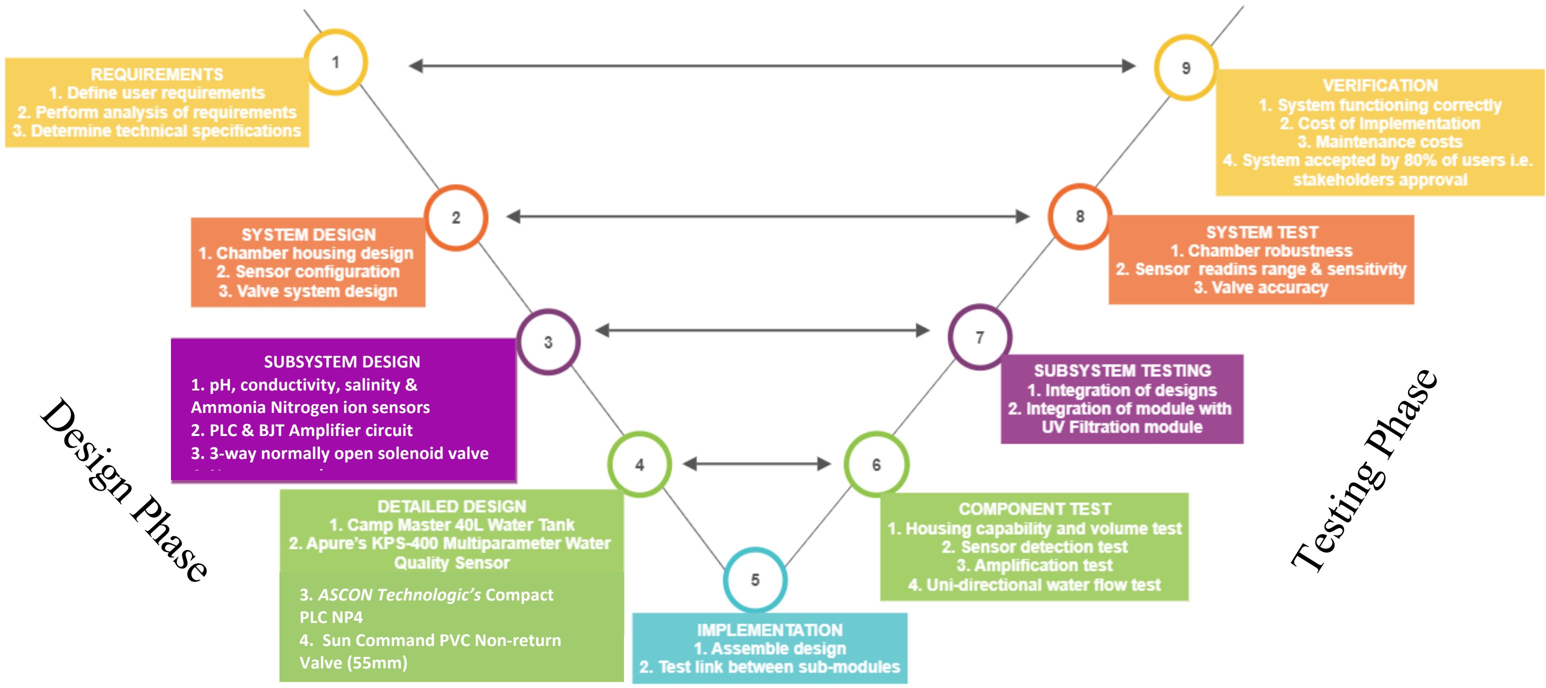


Figure 10 - V-diagram

4.5.2 Constraints and Limitations

Maintenance requirements

PLCs can last up to 20 years, but require regular maintenance to reach this lifespan. This means PLCs need to be kept clean and have a consistent power flow.
While the sensor used is equipped with an automatic cleaning device, corrosion, calibration and cleanliness of the housing of device need to be considered.

Sensor accuracy
Temperature fluctuations and changes in water flow rate may affect sensor accuracy meaning valve control accuracy is reduced and pollutants may exit via the body orifice rather than the stop orifice, meaning the greywater may be harmful to e.g. the garden it waters, over time as the harmful pollutants accumulate.

Power loss (technical disruption)
In the event that there is not sufficient solar power or the solar system is not functional, power loss will affect the functioning of the sensors, PLC and amplifier circuitry. This means the solenoid valve will have no power going to it and will therefore be in the following valve positions: the body orifice will be closed, and the stop orifice will be open, meaning all greywater will automatically exit to the sewage pipes. This means the system will ultimately not perform its intended function of reusing water and will function as a normal plumbing system does.

Theft/ damage
Theft of sensor, tank and valves forming part of this sub-module- that may be situated in the client's garden/ outer wall- are capable of being stolen or damaged, rendering the system ineffective until the parts are replaced. Placement of pipes is limited to the client's property layout and size, and so ultimately in certain contexts, this is an unavoidable potential problem.

4.6 STEEPLE Analysis
The STEEPLE Analysis is an effective and commonly used tool to evaluate different external factors that have the potential to impact the Water Purification Level Testing sub-system. It is essential to consider some external factors before taking and finalizing decisions.

4.4.1 Social
- Lifestyle Trends: Society is increasingly gravitating towards more sustainable practices in their daily lives. This means there is potential demand for this system as a whole.
- Effect on community: Communities will save water and water bill costs by using this system, meaning more funds will be available to potentially put back into the community. This means there is potential demand for this system as a whole.

4.4.2 Technical
- Lifecycle of technology: The water tank is made of PVC and therefore has an indefinite lifespan. The PLC can last up to 20 years, and amplifier circuitry is capable of lasting up to 10 years. Solenoid valves, however, last 1-3 years as they have to work hard. This frequent need for replacement could hinder client interest in the system

4.4.3 Environmental
-Resource usage: The resources used in this sub-system are not biodegradable in themselves and are also not made from recycled materials. This could hinder client interest in the system.

-Recycling considerations: PVC can be recycled up to 8 times, and so the tank can be recycled. This reinforces the sustainability aspect of the system.

-Manufacturing and cost to the environment: The short lifecycle of the solenoid valve means there is a continual need to use resources and manufacture this component. This is at the detriment to natural resources.
-Attitudes to environment from government, media and consumers: Water is considered a scarce resource and as such, especially in areas afflicted by droughts, water saving is promoted. This system as a whole reinforces this ideal/ attitude.

4.4.4 Economic

-Overall economic situation: In the current Covid 19-recovery context of the economy, the fact that customers may not be financially able to install this system needs to be considered.
-Community issues: In the current Covid 19 context, communities may still be wary of having people in their homes to install the system.
-Water billing trends: Water costs in South Africa have only increased in recent years. This means customers are more likely to install this system to reduce water bill costs and save money in the long term.

4.4.5 Political

-Health and safety legislation in SA: The Constitution of South Africa states that everyone has the right to clean water and basic sanitation. This means the Water Purification Level Testing system must abide by this and be fully functional, effective and safe.

4.4.6 Legal

-Trading policies and availability of products required for system: In the current Covid 19 context, as well as the Russia-Ukraine conflict, import and price fluctuations of goods is more uncertain, meaning it might be necessary to stockpile certain products, specifically the solenoid valve and sensor products in this case.

4.4.7 Ethical

-Contribution to society: From an ethical point of view, this system is aligned with good ethics in that it assists in the cleaning and reuse of water - a scarce resource, according to the UN.
-Effect on employees: This system is quite comprehensive and requires a team to install it. This means more people are employed, and employees can contribute to sustainable practice.

4.5 Behavioural Activity UML Diagram

The UML Behavioural Diagram depicts the elements of a system that are dependent on time. Furthermore, it conveys the dynamic concepts of the system and how they relate to each other, while in itself being a flexible model. This model effectively communicates the Water Purification Level Testing subsystem architecture.

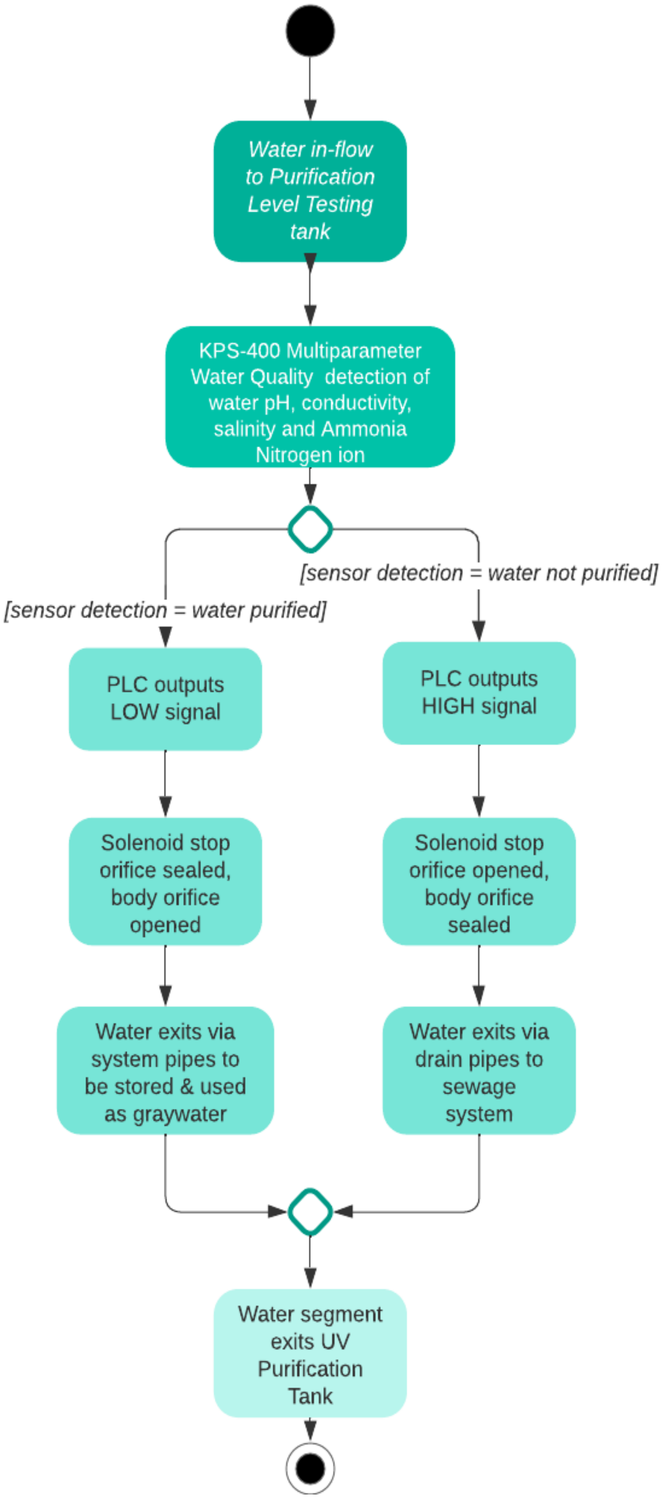


Figure 11 - Activity Diagram

4.6 CAD Drawings/ Prototypes

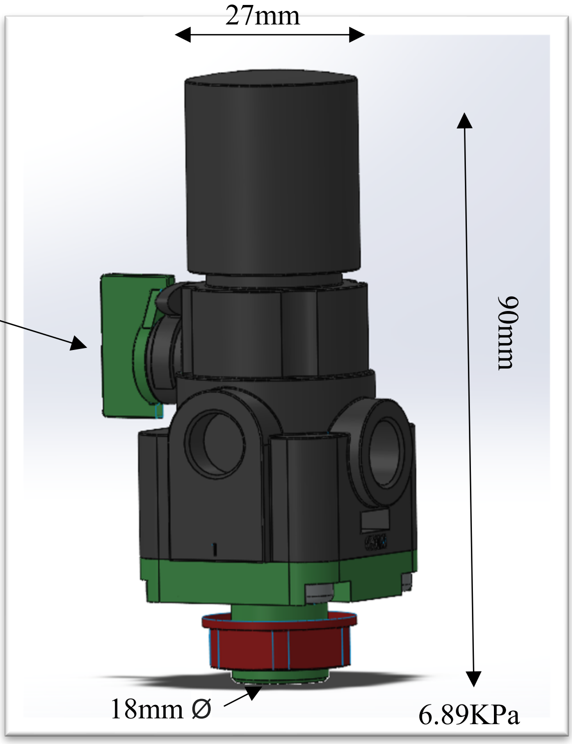


Figure 12 - 3-way Solenoid Valve model

Please refer to Figure 8 for additional model functioning visually represented.

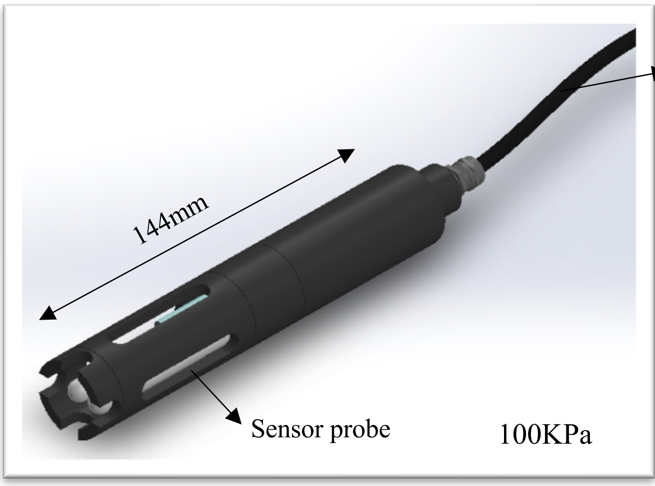


Figure 13 - Water purification sensor model

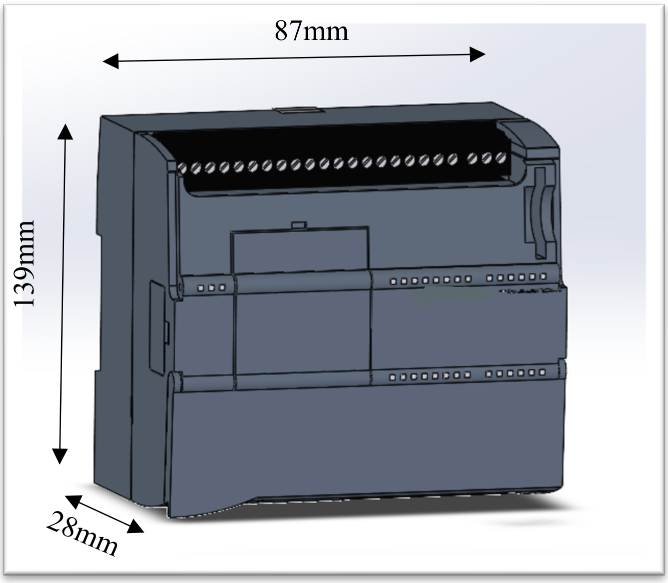


Figure 14 - Programmable Logic Controller Frame model

4.7 Sensitivity Analysis

Parameters the system is sensitive to:

1. Voltage level fluctuations exceeding sensor, amplifier circuit and solenoid tolerances.
2. Voltage sags for the PLC.
3. Temperature/ weather.

Note: Sensor accuracy, resolution and measuring range as outlined by the product specifications are all suitable and need not be considered/ optimized.

Reducing variability/optimizing each of the abovementioned parameters:

1. Install a voltage regulator between the mains supply and the devices or use devices with greater voltage tolerances.
2. Voltage sags can be eliminated with the proper choice of dc bus capacitance.
3. Tank to be installed indoors to mitigate this problem.

4.8 Discussion on Other Issues

Beyond the STEEPLE Analysis, there are no other issues relevant to this subsystem which warrant discussion. This is because Health and Safety considerations have been discussed under the 'Political' context, Socio-economic considerations have been discussed under both the 'Social' and 'Economic' fields of the STEEPLE Analysis, and Legal and Environmental aspects have also already been covered.

5. Module Three – Water Leak Detection System

Module completed by Faith Masasi (MSSFAI001).

5.1. Subsystem Introduction

Water is a crucial resource; it contributes significantly to agriculture, production of electricity, manufacturing as well as keeping humanity healthy. Urban water is usually transmitted using underground pipelines. From time to time, water transmission pipelines lose roughly 30% of water and this number increases to above 50% in old pipelines that have suffered neglect and insufficient maintenance. There are several reasons for loss of water in pipelines which include metering errors, leakage, and theft of pipelines. Leakages contribute approximately 70% of water loss in transmission pipelines. The objective of this subsystem is to minimise water leakages in the home and contribute towards the overall reduction in water loss. This subsystem is designed to monitor if there are any water leakages in the home to ensure that there are no costly water losses.

5.2. User Requirements

The following table specifies the user requirements for the water leak detection system.

Req. ID	Requirement Text
R.**U.001**	The system should be Wi-Fi compatible.
R.U.002	The system should communicate with the user via a software interface.
R.U.003	The system should be programmable so that it meters the amount of water that flows through the pipes, at what flow rate and for what period.
R.U.004	The system should be connected to a power supply with a rechargeable standby battery and must always be on.
R.U.005	The system should immediately stop the flow of water to the home if a leak is detected.

5.3. Requirement Analysis

5.3.1. Analysis of R.U.001

"The system should be Wi – Fi compatible."

The ultrasonic water sensors should have an in-built Wi – Fi module port through which a Wi – Fi module can be connected to establish an internet connection with the home Wi – Fi.

Req. ID	Requirement Text	Derived From
R.T.001	The Wi – Fi module ESP8266 is going to be used	**R.U.001**

Verification
This requirement is going to be verified when the ultrasonic smart water sensors are connected to the home Wi – Fi and see if the connection is successful.

5.3.2. Analysis of R.U.002

"The system should communicate with the user via a software interface"

The ultrasonic water sensors should be Wi – Fi compatible to send the user weekly notifications on the water meter status as well as immediate notifications when there is a leak detected.

Req. ID	Requirement Text	Derived From
R.T.002	Ensure that the ultrasonic water sensors module sends weekly meter notifications and immediately whenever there is a water leak.	**R.U.002**

Verification
This requirement is going to be tested by simulating a water leak and have the ultrasonic water sensors send a water leakage notification.

5.3.3. Analysis of R.U.003

"The system should be programmable so that it meters the amount of water that flows through the pipes, at what flow rate and for what period."

The system should be programmable such that the user is able to give instructions on the amount of water that flows through the pipes, at what flow rate and for what period. This decision is multi criteria and some examples of the criterion features are illustrated in Figure 29: The commands that can be given to the Arduino to execute.

Req. ID	Requirement Text	Derived From
R.T.003	On the software interface click on the button that stops the water and observe the response.	**R.U.003**

Verification
The user is going to change the parameters for the flow rate and specify the time for that given flow rate. The flow rate is going to be measured and see if it corresponds to the set values and to the set period.

5.3.4. Analysis of R.U.004

"The system should be connected to a power supply with a rechargeable standby battery and must always be on."

Ultrasonic water sensors and a solenoid valve are going to be used. This system needs to be supplied with 12Volts DC power supply with a rechargeable standby battery and use less than 3A (at 12V DC).

Req. ID	Requirement Text	Derived From
R.T.004	The ultrasonic water sensor device and the solenoid valve must not draw large currents. Additionally, the devices should be always working.	**R.U.004**

Verification
This requirement is going to be tested by measuring the current using a multi – meter to ensure that the system does not draw large currents.

5.3.5. Analysis of R.U.005

"The system should immediately stop the flow of water to the home if a leak is detected."

Leaks are automatically stopped as soon as flow times violate the Home or Away settings using solenoid valve device. Water is proactively shut off before pipes can freeze, the user is notified immediately through the software interface.

Req. ID	Requirement Text	Derived From
R.T.005	A solenoid valve is going to be used to shut down the water to the house.	**R.U.005**

Verification
A water leak is going to be simulated and then observe if the flow of water is stopped immediately as well as sending a notification to the user.

5.4. Design Choices

This section aims to identify the possible mechanisms that can be used to monitor leaks in the water leakage detection system. Two methods of implementing the water leakage detection system are investigated which are leak detection by sounding and acoustic devices and leak detection using the ultrasonic water sensor. The final design choice of the water leakage detection system is going to be determined by the cost of the components, complexity of the design circuit, resolution, accuracy, precision, testing, and implementation complexity.

5.4.1. Leak detection by sounding and acoustic devices

This design uses sounding and acoustic devices to detect leaks. The listening sticks and ground microphones detect the leakage by the sounds or vibrations of the pressurized water in the pipes. The vibrations are transmitted to a signal processing circuitry that is made up of a sensor with a magnetic base that computes the intensity of sound using sounding and acoustic fundamentals to determine if there is a leak or not as well as its location. Water leak detection design using sounding and acoustics diagram illustrates the design of the system. This system works on the principle that different pipe material, size and aging will produce different leak noise.

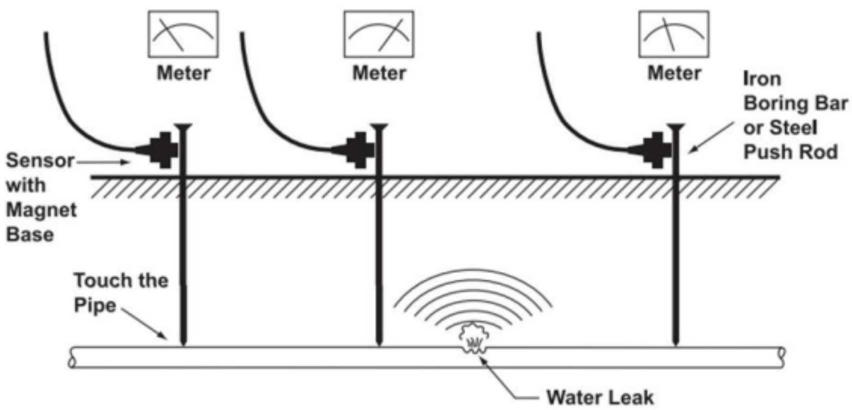


Figure 15: Water leak detection design using sounding and acoustics

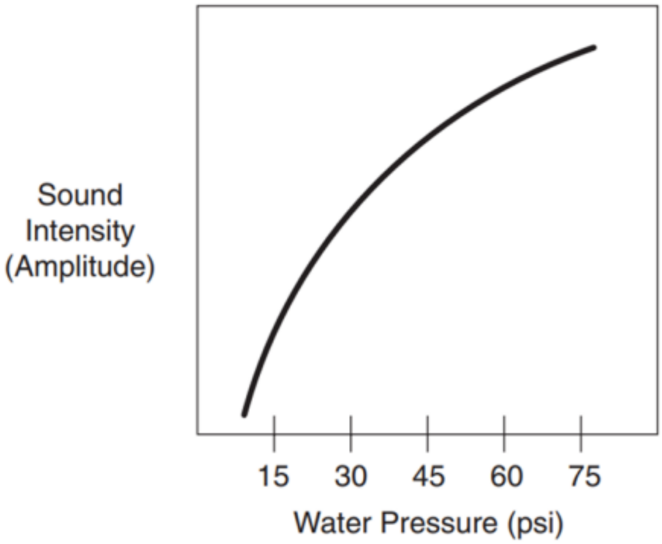


Figure 16: Sound intensity increases with water pressure

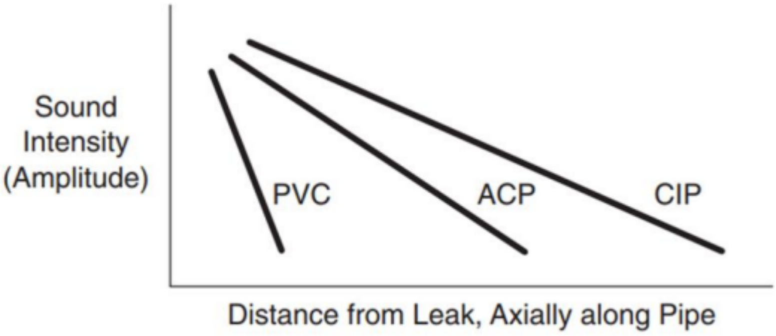


Figure 17: Different materials produce sounds of different intensity

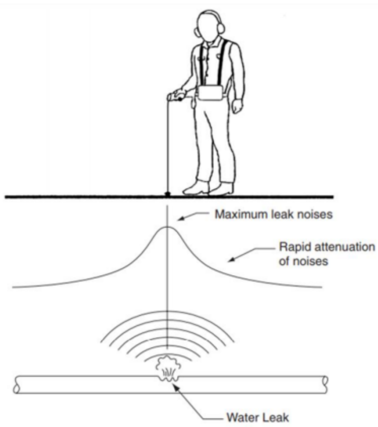


Figure 18: Water leak pinpointing

5.4.2. Leak detection using ultrasonic water sensors

The design is based on the implementation of ultrasonic water sensors that detect any irregularities in the flow of water in the pipes. The ultrasonic sensor sends wave pulses at a specific frequency which hit the surface of the liquid. The waves are then reflected to the ultrasonic sensors. There will be a measuring circuit that calculates the time of flight of the waves and hence give an estimation of the depth of the water as well as any irregularities in the flow of water. This system is advantageous as there are no pressure losses. This information is recorded and communicated via the software interface. The method uses real time leak detection technology. The figure below Water leakage detection design using wireless ultrasonic sensors illustrates the design approach.

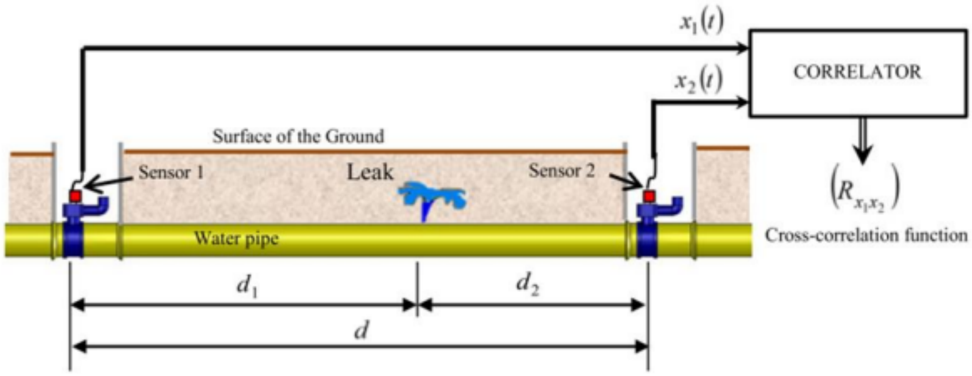


Figure 19: Water leakage detection design using wireless ultrasonic sensors

Figure 20: The two ultrasonic sensors that can be used

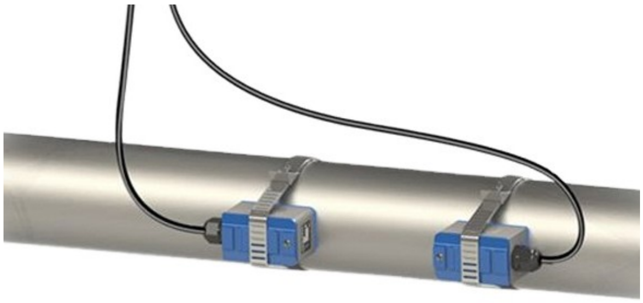


Figure 21: Ultrasonic water leak sensors mounted on the pipes

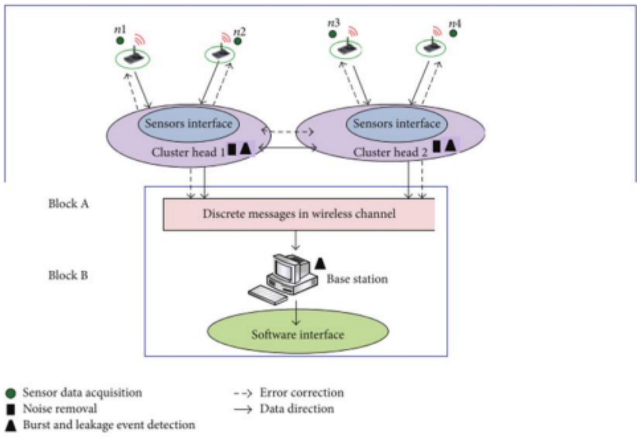


Figure 22: How the ultrasonic sensors communicate with the software interface

5.4.3. Comparison: leak detection by sounding and acoustics versus leak detection using ultrasonic sensors

Both methods can be implemented as they are suited for the specified application. However, there are certain aspects that need to be considered such as cost, technical maturity, ease of manufacturing, ease of testing, reliability, and maintenance costs.

5.4.3.1. Cost Comparison

Leak detection by sounding and acoustics		Leak detection using ultrasonic sensors	
Item	Cost	Item	Cost
Ground microphones	R2 380.00	Arduino microcontroller	R260.00
Magnetic base measuring set	R2 000.00	ESP8266 Wi - Fi module	R70.00
Arduino microcontroller	R260.00	USB cables	R80.00
ESP8266 Wi - Fi module	R70.00	Linear Actuator	R340.00
USB cables	R80.00	Circuitry and wires	R500.00
Linear Actuator	R340.00	Ultrasonic water sensors	R400.00
Circuitry and wires	R500.00		
Total Cost	R5 630.00	Total Cost	R1 650.00

Figure 23: Comparison of cost of components for leak detection by sounding and acoustics versus leak detection using ultrasonic sensors

As illustrated in the table above, in terms of cost, it is advantageous to implement the water leak detection using ultrasonic water sensors as the cost of components is less compared to the cost of the listening sticks used in sounding and acoustic leak detection. The listening sticks/ground microphones are made of chrome and platinum coated steel this makes them unsuitable and expensive.

5.4.3.2. Assessing technical maturity

Assessing the maturity of a particular technology involves determining its readiness for operations across a spectrum of environments as well as determining the fitness of a particular solution to meet the customer's requirements and desired outcomes for operations. One of the clients requirements is that the leak detection system should be standalone and produce results in real time. This makes the ultrasonic water sensors more convenient because the information is real time meaning a leakage is detected immediately when it happens. Additionally, the location of the leakage is determined without having to go to the scene compared to sounding and acoustic leak detection as it requires an experienced leak detection technician as well as only being able to detect leaks at night.

5.4.3.3. Ease of manufacturing

It is harder to manufacture the ground microphones used in sounding and acoustics leak detection due to the sophisticated design and the specialised transducers used. Additionally, the steel listening sticks are plated with chrome and platinum which is expensive to mine. It is better to use the leak detection using ultrasonic water sensors because it is easier to manufacture because the materials used are obtained easily.

5.4.3.4. Ease of testing

It is more difficult to simulate tests using the leak detection by sounding and acoustic devices because it requires an experienced leak detection technician who needs to be hired at a fee. It is more advantageous to perform the leak detection using ultrasonic water sensors because the installation and testing of the system is simple, straightforward and requires no technical experience.

5.4.3.5. Reliability

Results from the ultrasonic water sensors are more reliable than those from the sounding and acoustic detection water leak detection because the results are in real time. Leak detection by sounding and acoustic devices can only be used if there is a suspected water leakage in the pipes. This means that water can be lost for days because of the leak before the user notices any irregularities and this makes the use of sounding and acoustic devices unreliable.

5.4.3.6. Maintenance costs

The leak detection using ultrasonic sensors has a life span of five years and the system needs to be serviced once a year. Whilst the devices used in leak detection by sounding and acoustics needs to be serviced once every month due to the frequent use by different clients. As a result, it is more advantageous use the leak detection using ultrasonic sensors because they have a longer life span with a service plan of once every year.

5.5. Figure of Merit Table

Figures of Merit		
	Leak Detection by Sounding and Acoustics	Leak Detection using Ultrasonic Sensors
Cost	R5 360.00	R1 650.00
Technical maturity	Less convenient because the location of the leakage one needs to be at the scene of the leak and requires and experienced leak detection technician hence leak detection can only be done at night	More convenient because it is standalone and produces results in real time hence leak is immediately stopped without going to the location of leak
Ease of manufacturing	It is more difficult to manufacture ground microphones due to the sophisticated design and specialised transducers used	Easier to manufacture as materials are easily obtainable
Ease of testing	More difficult to test because it requires an experienced leak detection technician who needs to be hired at a fee	Installation and testing of the system is simple, straightforward and requires no technical experience
Reliability	Less reliable because leak detection can only be done after one suspects a leakage	More reliable as results are in real time
Maintenance cost	More expensive because of regular services	Less maintenance cost because the system has a life span of five years and needs to be serviced once a year

Figure 24: Figure or Merit for Water Leak Detection Subsystem

5.6. Solution: leak detection using ultrasonic sensors

Based on the information above, leak detection using ultrasonic sensors is an optimal solution as it can perform the required tasks with great accuracy, and minimal installation and maintenance costs.

5.7. V-diagram, Possible Constraints and Limitation, and Steeple Analysis

5.7.1. V-diagram

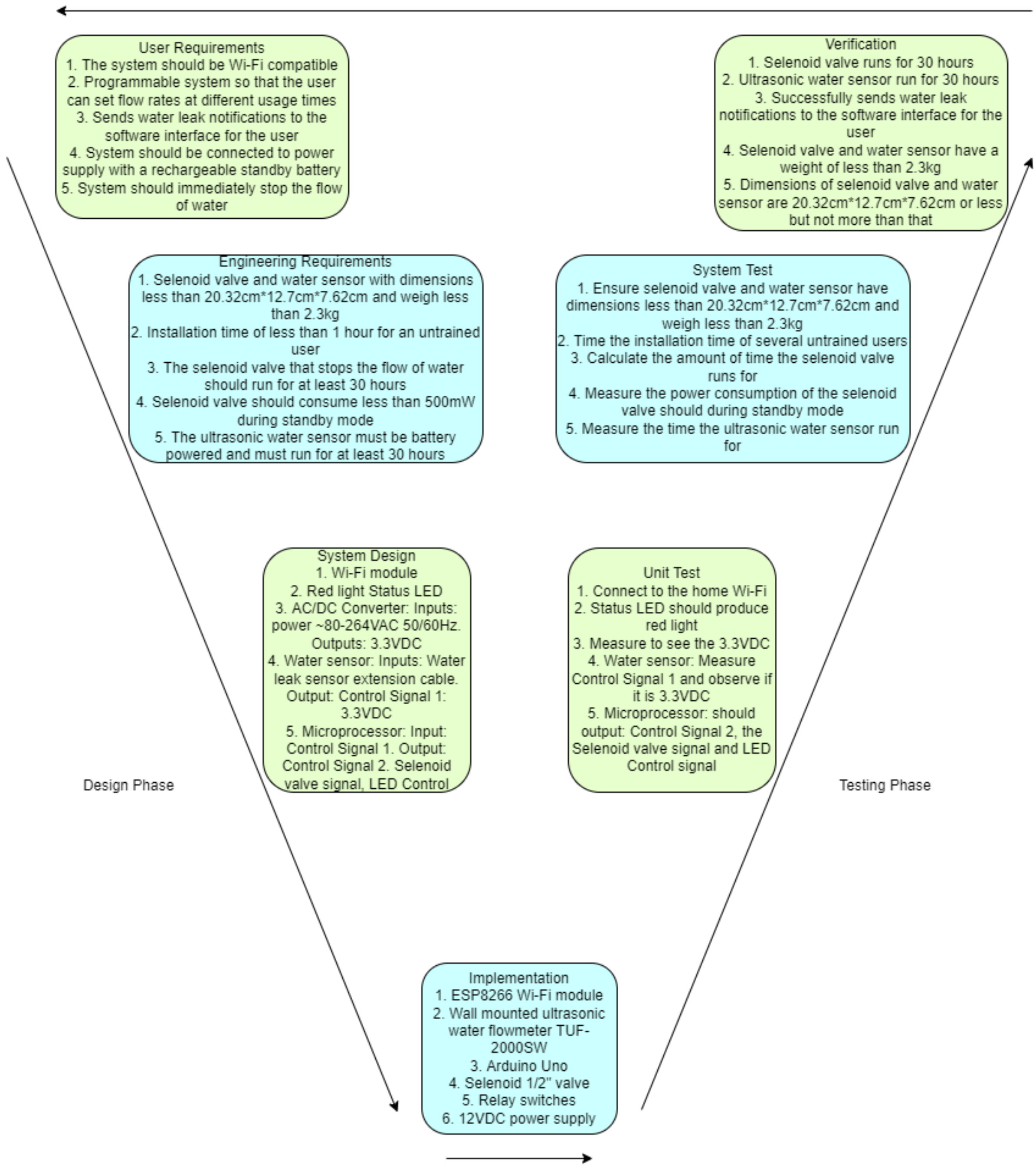


Figure 25: V-diagram for Water Leak Detection Subsystem

5.7.2. Possible Constraints and Limitations

Constraints and limitations must be considered to determine the feasibility of the module as well as to consider any problems that might arise so that they may be rectified before implementation.

5.7.2.1. Regulatory Constraints

The wireless ultrasonic sensors must meet the National Electrical Manufacturers Association (NEMA) standards for manufacturing electrical equipment and medical imaging equipment. The ultrasonic sensors and solenoid should provide protection against human contact with electrically charged, live electrical parts.

5.7.2.2. Power Consumption Constraints

The solenoid valve that shuts off the water supply to the whole house, operates off the electrical mains but has a backup battery as well. The backup battery must last for at least 30 days, and this sets a limit on the power consumption of the wireless ultrasonic sensors.

5.7.2.3. Damage of Electrical Equipment with Water and Wind

The Arduino might get damaged if it gets into contact with water as well as being blown away with strong winds. The Arduino must be housed in a waterproof place with no wind.

5.7.2.4. Theft

The system might be liable to theft. The system should be securely mounted and installed. Access to the system should be controlled and limited to a select number of people.

5.7.3. STEEPLE Analysis

The STEEPLE analysis aims to identify the key issues present in the design of the module and how the issues within it could affect certain factors such as the economy, environment, society and so forth. These macro-economic factors usually incorporate financial, technological, and social situations that potential users may experience with the implementation of the solution to the specified problem. Therefore, the desired solution should be tangible and have a relatively high user acceptance if the product is anticipated to be a success.

5.7.3.1. Economic Impact

It is expected that the proposed solution should be durable as well as being economically efficient. The user benefits from the water leak detection system module in that the with an effective control system, a water leak becomes detected and terminated immediately resulting in less money used for repairs and replacements of plumbing pipes as well towards the water bill. The wireless ultrasonic sensors can be replaced if they alone fail. Additionally, the increased water savings save the energy consumption and outweigh the cost of manufacturing the smart water meter because most of the energy goes towards treating and transporting. water.

5.7.3.2. Ethical Considerations

The water leak detection system upholds the standards of the Institute of Electrical and Electronics Engineers code of ethics. The design of the module is made with the welfare of the public in mind by including warning labels as well as a user guide to prevent incorrect usage that can be hazardous. Additionally, the members working on the design and implementation of the module should not work long hours without their consent, if they must work for long hours, they should be compensated accordingly. Moreover, the employees should have standard working hours as well as competitive salaries. Furthermore, valid contracts should be in place for any procurements of goods.

5.7.3.3. Health and Safety Considerations

The water leak detection system helps clients protect their properties from damage due to water leaks. The water detection system assists in maintaining public health and safety. The water leak detection system is autonomous, and this allows users with physical disabilities and ailments to the arduous work associated with periodically fixing their water reservoirs or losing possessions due to water. However, not all aspects of the water leak detection system are beneficial to people's health. The electronic equipment is processed using harsh chemicals and this is hazardous to the work force if the manufacturing plants do not take precautionary measures. Additionally, the chemicals used can infiltrate the water supplies resulting in sickness on anyone who drinks the water. The solenoid valve is connected to the mains supply, and this can deliver dangerous electric shocks if tampered with.

5.7.3.4. Social and Political Considerations

The water leak detection system creates social problems in that individuals with expendable money can afford the product and this gives them an advantage over those without further solidifying the money and power. The client is a direct beneficiary of a well working water system making him or her the primary stakeholder. The water leak detection system has secondary stakeholders who are the manufacturing workers as well as the plumbers. The plumbers benefit greatly since it creates job opportunities for them. Other stakeholders include investors who can earn a profit, but this can result in issues if investors only want to contribute if they are able to influence specific changes on the product. The implementation of the water leak detection system introduces technological services to the community which could greatly help those with physical disabilities. The local government can decide to buy the water leak detection system for individuals who cannot afford, and this can be beneficial in that there will be a net decrease in the water loss per year.

5.7.3.5. Sustainability and Environmental Considerations

The water leak detection system needs minimal maintenance for the sensors used to monitor the leakages. The system needs to be connected to a power supply for it to perform its functions. A possible improvement to this is to incorporate a solar panel to minimise energy usage and make a greener product. The materials utilized in creating the water leak detection system include electronics made of metals mined out of earth. The mining operations impact ecosystems greatly because of the overall destruction of the surrounding environment. The manufacturing plants use harsh chemicals which are usually disposed in rivers contaminating drinking water as well as destroying water living organisms. The water leak detection system consumes power putting pressure on power generation plants to produce more power. When the product lifetime has elapsed, it must be disposed of by recycling so that it does not decompose and release toxic chemicals. However, the water leak detection system does reduce the customers water usage such that its benefits outweigh the negative impacts stated.

5.8. Design

5.8.1. OPM Diagram of Module

The figure below shows the OPM diagram of the Ultrasonic Water Sensors module.

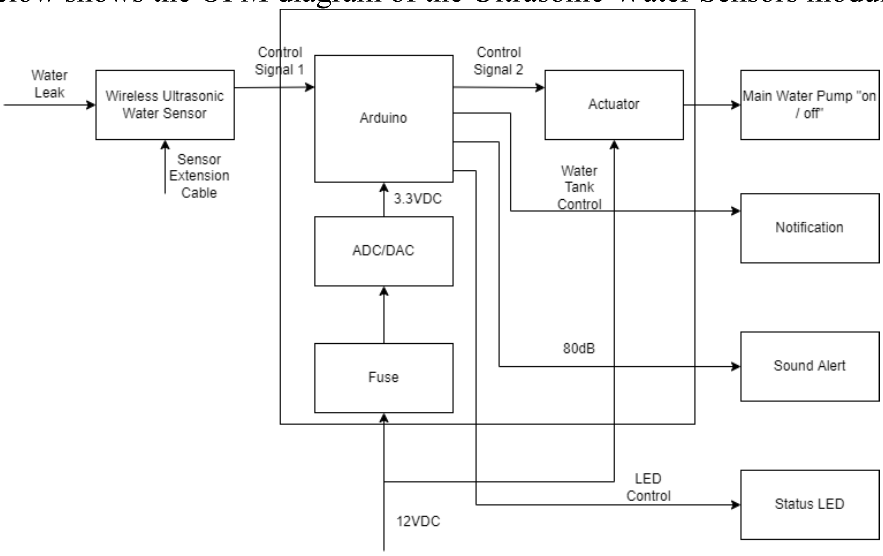


Figure 26: OPM diagram of Wireless Ultrasonic Water Sensors module

5.8.2. Simulation of Complete Subsystem

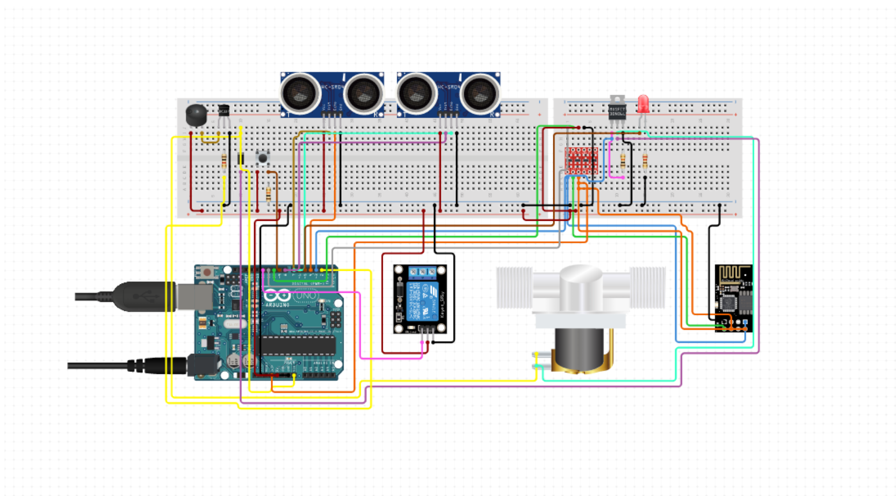


Figure 27: Arduino water sensor with ultrasonic water sensor in circuit.io

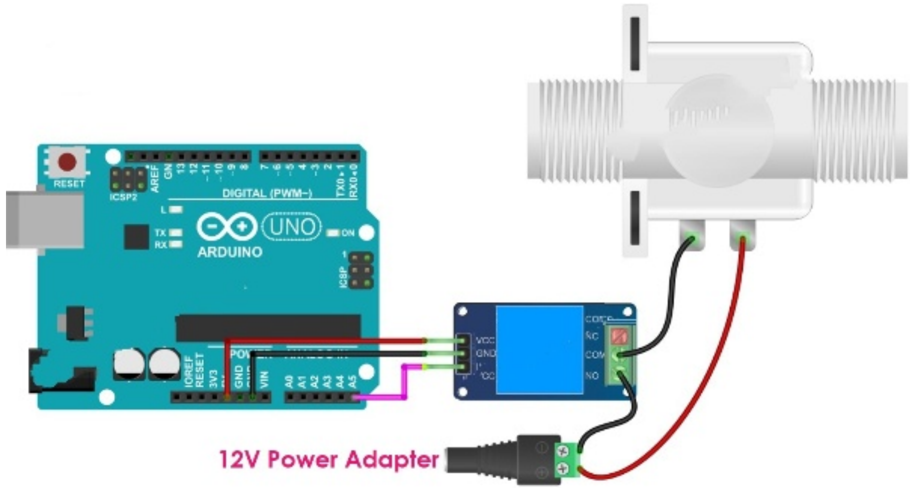


Figure 28: Solenoid valve connected to the Arduino

The ultrasonic water sensors are connected to 5V and GND on the Arduino as illustrated in the diagram above Arduino water sensor with ultrasonic water sensor. The signal pin (S) is connected to an analogue pin A0 on the Arduino, this allows the Arduino to read the analogue voltage. The LED is also connected to pin 13 and the ground.

In the figure above **Error! Reference source not found.** is used to stop the water flow when the water leak detection system detects a leak. It needs to be connected to a 12V DC, a starting current of 0.8A and the current should not exceed 3A. The solenoid valve is connected to a relay switch because the Arduino only outputs a maximum voltage of 5V, but the solenoid valve needs 12V DC. The relay is supplied with 5V from the Arduino, and this activates an electromagnet which pulls a switch that allows for a bigger voltage to flow on the opposite side of the relay.

5.8.2.1. Simulation Code for the Complete Subsystem

```
// Include Libraries
#include "Arduino.h"
#include "Buzzer.h"
#include "ESP8266.h"
#include "NewPing.h"
#include "LED.h"
#include "Button.h"
#include "Relay.h"
#include "SolenoidValve.h"


// Pin Definitions
#define BUZZER_PIN_SIG    2
#define WIFI_PIN_TX       11
#define WIFI_PIN_RX       10
#define HCSR04_1_PIN_TRIG       6
#define HCSR04_1_PIN_ECHO       4
#define HCSR04_2_PIN_TRIG       8
#define HCSR04_2_PIN_ECHO       7
```

```
#define LEDR_PIN_VIN        5
#define PUSHBUTTON_PIN_2        9
#define RELAYMODULE_PIN_SIGNAL      12
#define SOLENOIDVALVE_PIN_COIL1      3

// Global variables and defines
//
===============================================================
=============
// vvvvvvvvvvvvvvvvvvvv ENTER YOUR WI-FI SETTINGS  vvvvvvvvvvvvvvvvvvvv
//
const char *SSID     = "WIFI-SSID"; // Enter your Wi-Fi name
const char *PASSWORD = "PASSWORD" ; // Enter your Wi-Fi password
//
// ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
//
===============================================================
=============
char* const host = "www.google.com";
int hostPort = 80;
// object initialization
Buzzer buzzer(BUZZER_PIN_SIG);
ESP8266 wifi(WIFI_PIN_RX,WIFI_PIN_TX);
NewPing hcsr04_1(HCSR04_1_PIN_TRIG,HCSR04_1_PIN_ECHO);
NewPing hcsr04_2(HCSR04_2_PIN_TRIG,HCSR04_2_PIN_ECHO);
LED ledR(LEDR_PIN_VIN);
Button pushButton(PUSHBUTTON_PIN_2);
Relay relayModule(RELAYMODULE_PIN_SIGNAL);
SolenoidValve solenoidValve(SOLENOIDVALVE_PIN_COIL1);


// define vars for testing menu
const int timeout = 10000;       //define timeout of 10 sec
char menuOption = 0;
long time0;

// Setup the essentials for your circuit to work. It runs first every time your circuit is powered
with electricity.
void setup()
{
   // Setup Serial which is useful for debugging
   // Use the Serial Monitor to view printed messages
   Serial.begin(9600);
   while (!Serial) ; // wait for serial port to connect. Needed for native USB
   Serial.println("start");

   wifi.init(SSID, PASSWORD);
   pushButton.init();
   menuOption = menu();
```

```
}
// Main logic of your circuit. It defines the interaction between the components you selected. After setup, it runs over and over again, in an eternal loop.
void loop()
{


   if(menuOption == '1') {
   // Buzzer - Test Code
   // The buzzer will turn on and off for 500ms (0.5 sec)
   buzzer.on();       // 1. turns on
   delay(500);             // 2. waits 500 milliseconds (0.5 sec). Change the value in the brackets (500) for a longer or shorter delay in milliseconds.
   buzzer.off();      // 3. turns off.
   delay(500);             // 4. waits 500 milliseconds (0.5 sec). Change the value in the brackets (500) for a longer or shorter delay in milliseconds.
   }
   else if(menuOption == '2') {
   // ESP8266-01 - Wifi Module - Test Code
   //Send request for www.google.com at port 80
   wifi.httpGet(host, hostPort);
   // get response buffer. Note that it is set to 250 bytes due to the Arduino low memory
   char* wifiBuf = wifi.getBuffer();
   //Comment out to print the buffer to Serial Monitor
   //for(int i=0; i< MAX_BUFFER_SIZE ; i++)
   //  Serial.print(wifiBuf[i]);
   //search buffer for the date and time and print it to the serial monitor. This is GMT time!
   char *wifiDateIdx = strstr (wifiBuf, "Date");
   for (int i = 0; wifiDateIdx[i] != '\n' ; i++)
   Serial.print(wifiDateIdx[i]);

   }
   else if(menuOption == '3') {
   // Ultrasonic Sensor - HC-SR04 #1 - Test Code
   // Read distance measurment from UltraSonic sensor
   int hcsr04_1Dist = hcsr04_1.ping_cm();
   delay(10);
   Serial.print(F("Distance: ")); Serial.print(hcsr04_1Dist); Serial.println(F("[cm]"));

   }
   else if(menuOption == '4') {
   // Ultrasonic Sensor - HC-SR04 #2 - Test Code
   // Read distance measurment from UltraSonic sensor
   int hcsr04_2Dist = hcsr04_2.ping_cm();
   delay(10);
   Serial.print(F("Distance: ")); Serial.print(hcsr04_2Dist); Serial.println(F("[cm]"));

   }
else if(menuOption == '5') {
   // LED - Basic Red 5mm - Test Code
```

```
  // The LED will turn on and fade till it is off
  for(int i=255 ; i> 0 ; i -= 5)
  {
  ledR.dim(i);                    // 1. Dim Led
  delay(15);                              // 2. waits 5 milliseconds (0.5 sec). Change the value in the
brackets (500) for a longer or shorter delay in milliseconds.
  }
  ledR.off();                     // 3. turns off
  }
  else if(menuOption == '6') {
  // Mini Pushbutton Switch - Test Code
  //Read pushbutton state.
  //if button is pressed function will return HIGH (1). if not function will return LOW (0).
  //for debounce funtionality try also pushButton.onPress(), .onRelease() and .onChange().
  //if debounce is not working properly try changing 'debounceDelay' variable in Button.h
  bool pushButtonVal = pushButton.read();
  Serial.print(F("Val: ")); Serial.println(pushButtonVal);

  }
  else if(menuOption == '7') {
  // Relay Module - Test Code
  // The relay will turn on and off for 500ms (0.5 sec)
  relayModule.on();       // 1. turns on
  delay(500);             // 2. waits 500 milliseconds (0.5 sec). Change the value in the brackets
(500) for a longer or shorter delay in milliseconds.
  relayModule.off();      // 3. turns off.
  delay(500);             // 4. waits 500 milliseconds (0.5 sec). Change the value in the brackets
(500) for a longer or shorter delay in milliseconds.
  }
  else if(menuOption == '8') {
  // 12V Solenoid Valve - 3/4'' - Test Code
  // The solenoid valve will turn on and off for 500ms (0.5 sec)
  solenoidValve.on(); // 1. turns on
  delay(500);       // 2. waits 500 milliseconds (0.5 sec). Change the value in the brackets
(500) for a longer or shorter delay in milliseconds.
  solenoidValve.off();// 3. turns off
  delay(500);       // 4. waits 500 milliseconds (0.5 sec). Change the value in the brackets
(500) for a longer or shorter delay in milliseconds.

  }

  if (millis() - time0 > timeout)
  {
     menuOption = menu();
  }

}
// Menu function for selecting the components to be tested
// Follow serial monitor for instrcutions
char menu()
```

```
{
  Serial.println(F("\nWhich component would you like to test?"));
  Serial.println(F("(1) Buzzer"));
  Serial.println(F("(2) ESP8266-01 - Wifi Module"));
  Serial.println(F("(3) Ultrasonic Sensor - HC-SR04 #1"));
  Serial.println(F("(4) Ultrasonic Sensor - HC-SR04 #2"));
  Serial.println(F("(5) LED - Basic Red 5mm"));
  Serial.println(F("(6) Mini Pushbutton Switch"));
  Serial.println(F("(7) Relay Module"));
  Serial.println(F("(8) 12V Solenoid Valve - 3/4''"));
  Serial.println(F("(menu) send anything else or press on board reset button\n"));
  while (!Serial.available());

  // Read data from serial monitor if received
  while (Serial.available())
  {
    char c = Serial.read();
    if (isAlphaNumeric(c))
    {

      if(c == '1')
                Serial.println(F("Now Testing Buzzer"));
            else if(c == '2')
                Serial.println(F("Now Testing ESP8266-01 - Wifi Module"));
            else if(c == '3')
                Serial.println(F("Now Testing Ultrasonic Sensor - HC-SR04 #1"));
            else if(c == '4')
                Serial.println(F("Now Testing Ultrasonic Sensor - HC-SR04 #2"));
            else if(c == '5')
                Serial.println(F("Now Testing LED - Basic Red 5mm"));
            else if(c == '6')
                Serial.println(F("Now Testing Mini Pushbutton Switch"));
            else if(c == '7')
                Serial.println(F("Now Testing Relay Module"));
            else if(c == '8')
                Serial.println(F("Now Testing 12V Solenoid Valve - 3/4''"));
      else
      {
        Serial.println(F("illegal input!"));
        return 0;
      }
      time0 = millis();
      return c;
    }
  }
}
```

The commented code explains the function of the code. The analogRead reads the sensorPin and outputs a value between 0 to 1023 which represents the voltage from the ultrasonic water sensors. If there is no water leak, the value read is 0 and if there is a water leak, the value read is 600 which is equivalent to 1.5mL of water and this triggers the LED to be on as well as sending a notification to the homeowner that there is a water leak. When there is no water leak the LED is off.

5.8.2.2. Sample Results from Running the Code

The simulations for this section were done in circuit.io.

```
975
Buzzerr Buzzing!
961
Buzzerr Buzzing!
910
Buzzerr Buzzing!
843
Buzzerr Buzzing!
860
Buzzerr Buzzing!
785
Buzzerr Buzzing!
786
Buzzerr Buzzing!
723
Buzzerr Buzzing!
681
Buzzerr Buzzing!
709
Buzzerr Buzzing!
705
Buzzerr Buzzing!
670
Buzzerr Buzzing!
691
Buzzerr Buzzing!
624
Buzzerr Buzzing!
576
599
```

Figure 29: Results from running code

5.8.3. Wi – Fi communication to send the instructions to ultrasonic sensors as well as receive notifications of water leaks

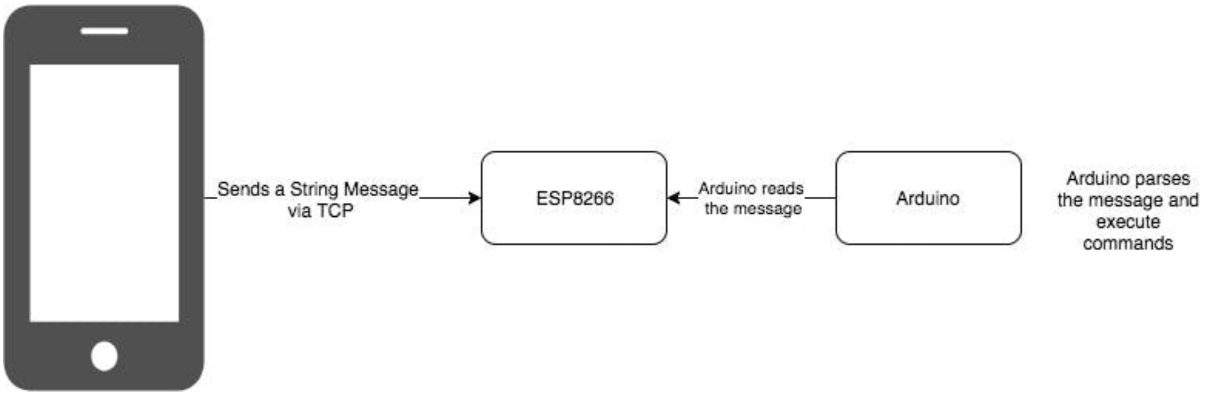


Figure 30: Wi - Fi communication between the user and the ultrasonic water sensors via the Arduino

The user needs to download the TCP client on their phone from the Play Store and this allows the user to connect with the ESP8266 Wi – Fi module. Once the connection has been set up the user can give commands to the Arduino to execute. Additionally, if there is a water leak, the user is notified. The diagram below illustrates some of the commands that can be given to the Arduino to execute.

Commands	Description	Type
AT+RST	restart module	basic
AT+CWMODE	wifi mode	wifi
AT+CWJAP	join AP	wifi
AT+CWLAP	list AP	wif
AT+CWQAP	quit AP	wifi
AT+CIPSTATUS	get status	TCP/IP
AT+CIPSTART	set up TCP or UDP	TCP/IP
AT+CIPSEND	send data	TCP/IP
AT+CIPCLOSE	close TCP or UDP	TCP/IP
AT+CIFSR	get IP	TCP/IP
AT+CIPMUX	set multiple connections	TCP/IP
AT+CIPSERVER	set as server	TCP/IP

Figure 31: The commands that can be given to the Arduino to execute

5.9. Discussion of Other Issues

There is geographic location – based constraint associated with this project. The system should be able to work in different countries for example in the United States that use 110V or Indonesia that use 220V that is the system should not be limited for use only in South Africa.

Additionally, building a non-intrusive solenoid valve system is a challenge. There are non-intrusive systems, however they are more expensive, and this poses a greater implementation difficulty.

Other than the issues stated above, and the issues discussed in the STEEPLE Analysis section, there are no other issues to discuss in connection to this subsystem. Health and Safety considerations, Social and Political considerations and Sustainability and Environmental considerations were extensively discussed in the STEEPLE analysis section.

6. Module Four – Hybrid Power System

Module completed by Raees Razack (RZCRAE002)

6.1. Subsystem Introduction

This subsystem is responsible for creating an uninterrupted power source that will supply the entire filtration and pumping system with power whenever the system is in use.
In South Africa specifically, where the citizens of this country are constantly under the threat of having their power shut off due to loadshedding, it becomes imperative that, for any such system to function optimally an alternate source of power besides mains power must be added to the system to ensure continued operation under any circumstances.

Thus, a hybrid power system such as this one, is necessary. This power system will mainly be run via solar power but will also have the capability to switch over to mains power in the event that the solar power is unable to supply the needed power to the system.

6.2. User Requirements

Req. ID	**Requirement Text**
R.**U.001**	The system must use solar power to keep electricity costs down
R.U.002	The power level of the battery will be continuously updated to the application on the user's cell phone
R.U.003	To ensure that there are no backups in the filter system, the filtration process will not stop once it has started. (This ensures that the system requires as little maintenance as possible)
R.U.004	System should do a power test before commencing with the filtration process

6.3. Requirement Analysis

6.3.1. Analysis of R.U.001

"The system must use solar power to keep electricity costs down"

The solar system will be connected to a high-capacity battery that will be charged from the solar panels whenever there is sunlight shining on the panels. When the catchment tanks in the system are full, the pumping and filtration system will begin drawing power from this high-capacity battery and the filtration process will begin.

Req. ID	**Requirement text**	**Derived from**
R.T.001	The system will be connected to a solar panel and battery configuration	**R.U.001**

Verification:
A mock system with a solar panel, a battery and a load equal to that of the entire filtration system will be built and tested in order to ensure that the power in this battery is capable of operating the entire system. Furthermore, tests will be run with different solar panels to find the perfect combination of panel and battery to ensure as fast a charging time as possible.

6.3.2. Analysis of R.U.002

"The power level of the battery will be continuously updated to the application on the user's cell phone"

The application that will be installed on the phones of the users, will be given continuous updates about the power level of the battery in order to ensure that the user knows that the solar charging system is perfectly functional

Req. ID	Requirement text	Derived from
R.T.002	A section on the application will be coded to always receive automatic updates from the battery	**R.U.002**

Verification

The battery will be charged and discharged using a specialized circuit built for the purpose of testing this function and the battery level indicated on the application will be monitored in order to ensure that updates are being continuously sent from the battery to the app.

6.3.3. Analysis of R.U.003

"To ensure that there are no backups in the filter system, the filtration process will not stop once it has started. (This ensures that the system requires as little maintenance as possible)"

Once the filtration process has begun, the power provided to the filter will not be inturrupted by anything. In the event that the battery level is not enough to complete the entire pump and filtration process of the system, the system will be able to recognise this and automatically switch from the solar battery to mains power to complete the filtration process.

Req. ID	Requirement text	Derived from
R.T.003	The system will be created with a switching circuit capable of switching the power supply from solar to mains power and vice versa.	**R.U.003**

Verification

The battery will be disconnected from the filtration system during its operation and the system must be able to automatically switch to using mains power to complete the rest of the operation

6.3.4. Analysis of R.U.004

"System should do a power test before commencing with the filtration process"

Once the tanks are at the level necessary for the filtration process to begin, the system will do a power test to check if the battery has enough charge to complete the operation. If the battery does not have enough power to complete the process it will check to make sure that there is a mains power connection so that the system can fall back onto it when the battery power runs out. If there is no mains power connection, the system will not commence with the filtration system and a notification will be sent to the phone of the user to notify them of the halt in operation

Req. ID	Requirement text	Derived from
R.T.004	The system will be coded to perform these checks	**R.U.004**

Verification

The system will be sent a signal to indicate that the filtration system should begin and at the same time, both the battery and the mains power should be disconnected. If the system halts and the error message is sent, then it operates as required, if either one of these does not happen then the system will have to be fixed.

6.4. Design Choices

Each component within this subsystem can be broken down based on an analysis between the cost of the product and the necessity of the product for the system's functionality. Many different design options were examined by ultimately only a few met the requirements for the system that we are designing at the moment. Of these options that were suitable to the given operation, the best model for price was used as the design choice for this system.

6.4.1 Rechargeable battery choice

A detailed energy cost analysis of the system has not yet been completed, Others have attempted to create systems such as this one in the past and they have made calculations regarding the total usage of their similar system. Their total power usage has come to around 1.5Kw of electricity per filtration cycle.

Since our system houses a great deal more water than the research that was consulted to gain the above-mentioned power consumption figure, and since we have gone through the process of incorporating UV filtration systems as well as a sensor system that constantly updates to a software system, we can assume that the power usage of this system to be around 3Kw to 3.5Kw of electricity per cycle.

Based on this information, a few different design choices were considered
[All of the options that were considered were solar batteries]

Option A: Hubble Am-2 5.5Kw Lithium Battery, R24 900
Option B: Pylontech Lithium Ion 3.5Kw Usc3000C Battery, R17 500
Option C: 48V 4.8KWH NEN-ENERGY lithium batteries R17 999

Each of these devices would be excellent for the device to meet the needs of this power system. The Hubble and NEN-ENERGY devices are obviously overkill for this sytem, however if we were to include one of these devices in our system, then we would be able to syphen off some of the residual power in these batteries [over the necessary 3.5Kw] to power the home of the user, which would further reduce the homeowners electricity charges.

Comparison of device discharge capabilities

- The Hubble device has a life cycle of 3000 cycles with a depth of discharge of 100% for these 3000 cycles, after this is has a depth of discharge of 50% for another 3000 cycles.

- The pylontech device has a life cycle of 6000 cycles with a 95% depth of discharge for all 6000 cycles.

- The NEN-ENERGY device has a life cycle of 5000 cycles with a depth of discharge of 80% for all 5000 cycles

Based on the above depth of discharge figures, the Hubble Am-2 battery, would not be suite to this application for a long-term solution as it would no be able to output the necessary power after 3000 cycles. This leaves the pylontech and NEN-ENERGY device as the remaining two options.

Based on the price to power ratio of the two remaining devices, it is obvious that the NEN-ENERGY device would be the best possible choice for the system as it outputs a constant 48V with a power storage of 4.8KWH, which is 1.3KWH more than the Pylontech device, for only R500 more. An image of this device can be seen below

[1]

Figure 32: Nenenergy Li-ion solar battery

6.4.2 Solar panel Choices

An average solar panel produces anywhere between 1.5 and 1.9 Kw of electricity per day based on the amount of sun that is receives during the day. In places like South Africa where we have even more sunlight per day then most other countries, it stands to reason that the average power created by the solar panel per day could rise to between 2 to 2.5 Kw per day. Given that we have a battery of 4.8 Kw that needs to be charged up, possibly on the daily, it means that we would need to install no less then 2 of these solar panels along with the system, in order to ensure that the system remains fully powered for the entire life of its operation. For this system the following solar panel was chosen the following solar panels were considered:
[Each of these devices were chosen as options due to the voltage of the panel matching the voltage of the battery, which would allow for steady transfer of power from panel to battery]

Option A: 460w 48v MONO JA SILVER FRAME SOLAR PANELS, R3 650
Option B: 400w 48v Mono Solar Panels, R2 450
Option C: 495W 48V MONO SPLIT CELL SOLAR PANELS, R2 850

Either of the above-mentioned devices would work for the purpose of charging up our battery in a timely manner, so the choice was made simply based on the price on the panel and its guarantee on the device and its efficiency.

The 495W 48V Split cell Solar panel for R2850, would be the best design choice, due to the fact that it is not too expensive, has a ten-year warranty along with manufacturers guarantee of over 90% output voltage for the entire 10year warranty.

1

An image of these devices can be seen below:

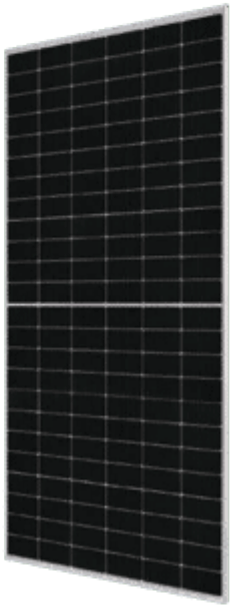


Figure 33: 48v split cell solar panel

If two or even three of these devices are installed along the filtration system, then it will be able to maintain its operation for many years, without ever needing to be serviced.

6.4.3 Voltage regulation from solar panel to battery

The voltage flowing out of the solar panel has been noted to be at 48V, while the battery charger maintains input voltage 48V. In order to regulate the voltage and keep it at a constant of 48v a voltage regulator circuit will be needed. This regulator must be able to take in 48v and always keep the output at 48v, for these purposes a 48v-to-48v DC voltage regulator circuit will be designed and implemented.

6.4.4 Voltage regulation from Battery to Pumps

The pump that will be used in this filtration system will be the Simer ¾ HP Water Pressure Booster Pump. This pump device has a input voltage of 115v and as such a boost converter from the 48v output voltage of the battery to the 115v of the pump is required. This system will be fully designed and implemented.

6.4.5 Voltage regulation from Battery to sensors

The sensors being used in the system require an input voltage of 12v Dc. Therefore, a Buck converter to convert the 48v from the battery to the 12v Dc voltage required will be fully designed, constructed and implemented.

6.5 V-diagram, Possible Constraints and Limitations, and Steeple Analysis

6.5.1 V diagram

The following V-diagram will describe the process of the hybrid power supply development from the user requirements all the way to the verification of a completed sub-module

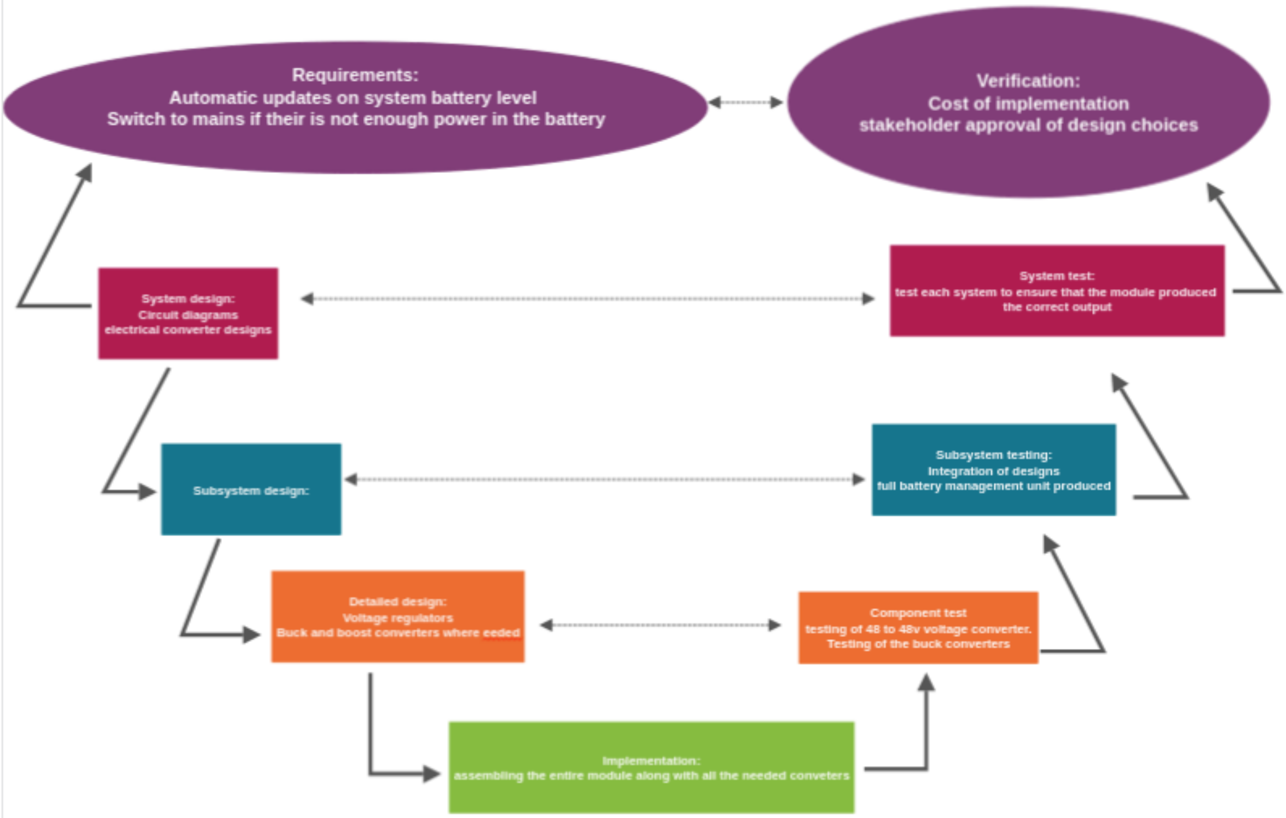


Figure 34: V-diagram of power supply module

6.5.2 Constraints and limitations

6.5.2.1 Power loss

Each converter or regulator circuit brings with it, the possibility of power loss. These circuits all come with a calculated efficiency rating, efficiency being the ratio of the input power to the output power. Since each circuit has this power loss, and since the power must cycle through a few of these regulators or converters before actually reaching the point where it is being used, the overall efficiency of the power delivery might be quite low.

6.5.2.2 Battery malfunctions

The Hubble battery is the lifeblood of this entire system. Without it, the system would switch solely to using power from the power grid and thus would end up using way more power and therefor be far more expensive than the user wishes for the system to be. Failure in the battery could be due to many different factors including, but not limited to, a failure in the regulator which ensures that the battery has a constant 48v flowing into it.

6.5.2.3 battery could end up being too small

The battery has a limited charge and as stated earlier a full analysis of the power needs for this system has yet to be determined, therefore there is a very real possibility that this battery could end up being too small and thus the system would always have to use power from the grid in order to complete its filtration process thereby skyrocketing the user’s electricity prices.

6.5.3 Steeple analysis

6.5.3.1 Social
The world is beginning to realise that our current way of life is completely unsustainable. Thus, people are trying to find more and more ways to try and save the environment. The number one way to help the environment and produce a more sustainable lifestyle, is by ensuring that we don't us as much of our limited natural resources. This means that a product such as this one would be in high demand at some point in the near future.

6.5.3.2 Technological
As the world evolves, everyone is always looking to have that hip new product. Something that they have never seen before, or even something that they have seen a thousand times being used in a new way that no one has ever thought about. This product satisfies that need. Not only is it a fully automates system, but it is also a system that uses cutting edge software and hardware components to be able to clean this water to the absolute best it can be.

6.5.3.3 Economic
The main part of the power supply system would be the solar panels as well as the HUBBLE battery. Both parts are not manufactured here in South Africa and would need to be imported into the country. Since they are being imported, it makes sense that the import and export price to our city from wherever it originated, would also be going higher and higher.

Furthermore, the world has just gone through the wringer with the covid pandemic. Due to this virus causing basically all our lives to come to a halt, many people do not have the cash to purchase this system. But once the cost analysis is done, then we would be able to answer the question of how much this system would cost and thus would be able market the system to the proper clientele.

6.5.3.4 Environmental
This system uses solar power at its main source of energy and only uses the grid power on rare occurrences where the solar power system is unable to carry the full load of the operation of the system. The switch to the grid power is merely a backup safety procedure and is something that will almost never be used; thus, the system can be said to be solely dependent of solar power.

Based on this, we can say that renewable energy is being used in order to produce reusable water and thus this system would have a negative carbon footprint. Essentially the system would have no negative environmental impact and only positive impacts on the environment.

6.5.3.5 Legal
The legal parameters for this device would be based on copyright claims against the design. In order to fully avoid these, we would have to come up with an original design and then we would patent it before anyone else can. Furthermore, any other legalities would be moot if the owner of the property has given permission for the system to be installed

6.5 Design

6.5.1 UML Diagram of Module

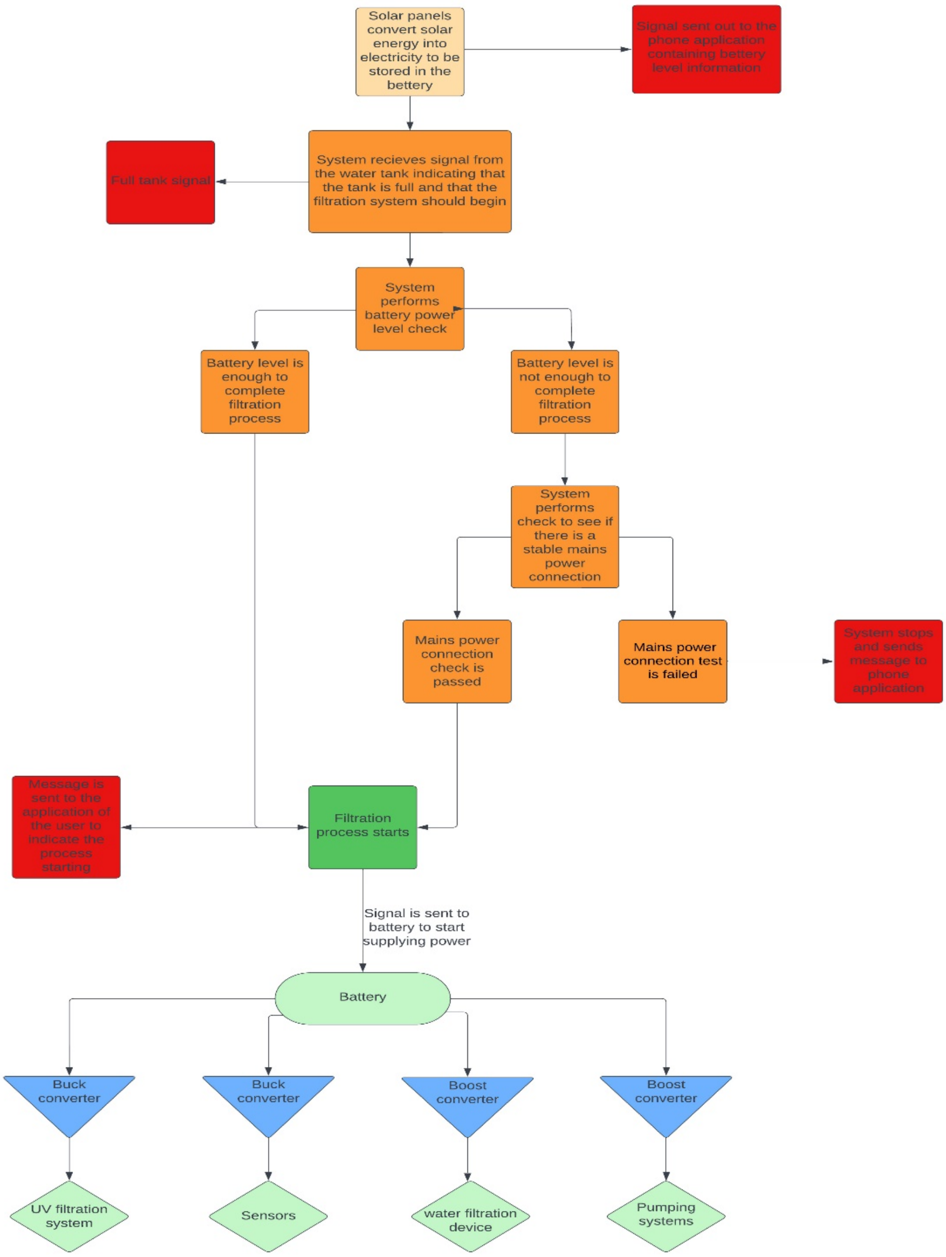


Figure 35: UML diagram for power supply module

6.5.2 CAD diagrams of system components

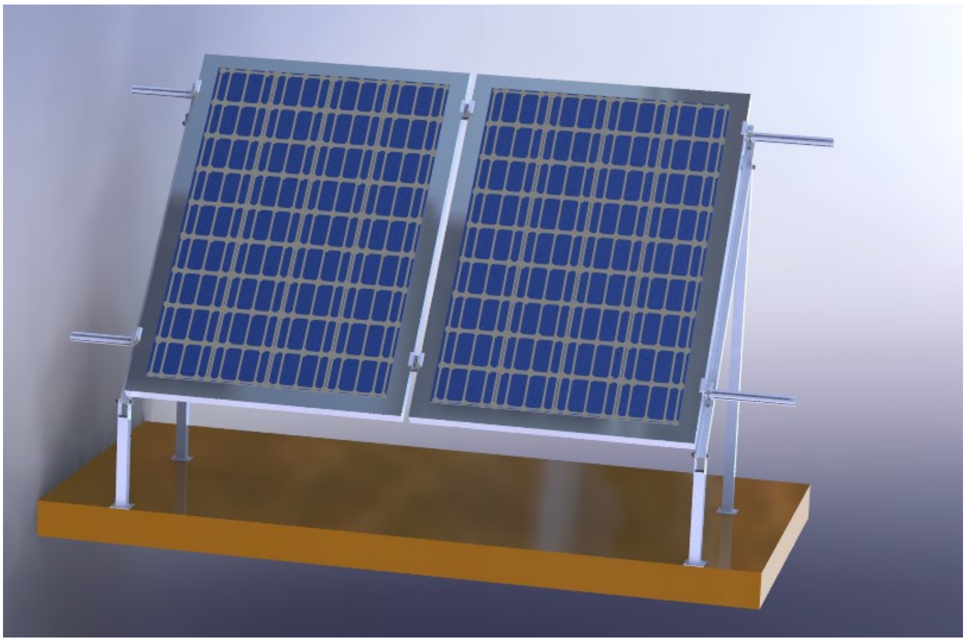


Figure 36: CAD diagram for solar panel

Figure 37: CAD diagram for solar battery

6.6 Sensitivity Analysis

Parameters in the system are sensitive to:

- Erroneous signals coming from devices

- Weather
- Surges in the battery

Reducing variability of each of the above-mentioned parameters

- Signal checks can be performed. The system can perform a check to see if the signal that was received was sent at the correct time. This ensures that the system does not turn on unnecessarily, which would waste the power in the battery and could possibly damage the machine
- The weather issue can't really be mitigated. If there is not enough sunlight to charge the battery, then the system will be forced to use mains power
- Surges protectors can be installed which would mitigate this issue

6.7) Simulation of converter modules

6.7.1) Buck converter from 48V to 12V for sensor power supply

The following buck converter was designed for this application:

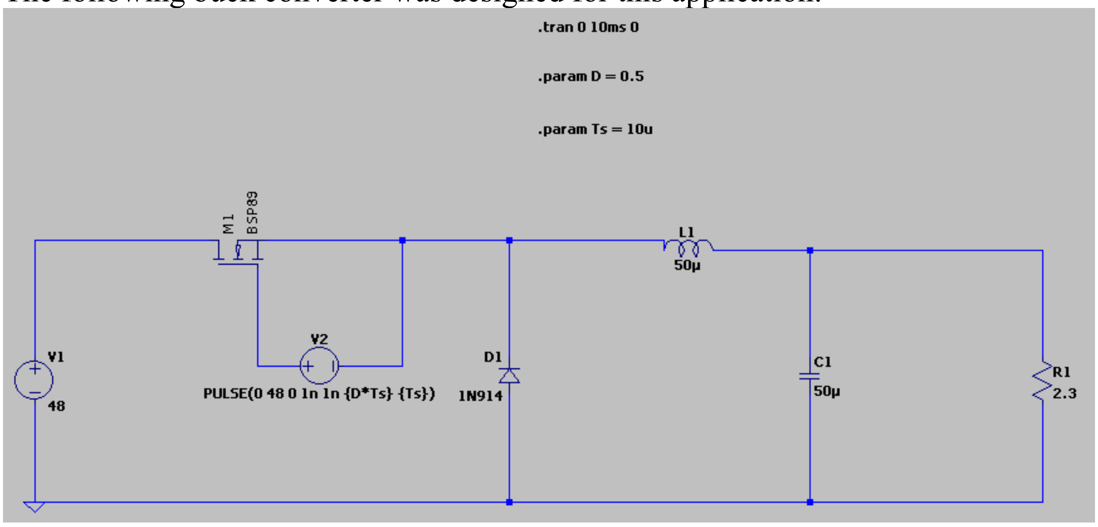


Figure 38: Buck converter module

The input to this module is a 48V Dc voltage, which would be supplied from our battery, and the simulated output of our buck converter is as follows:

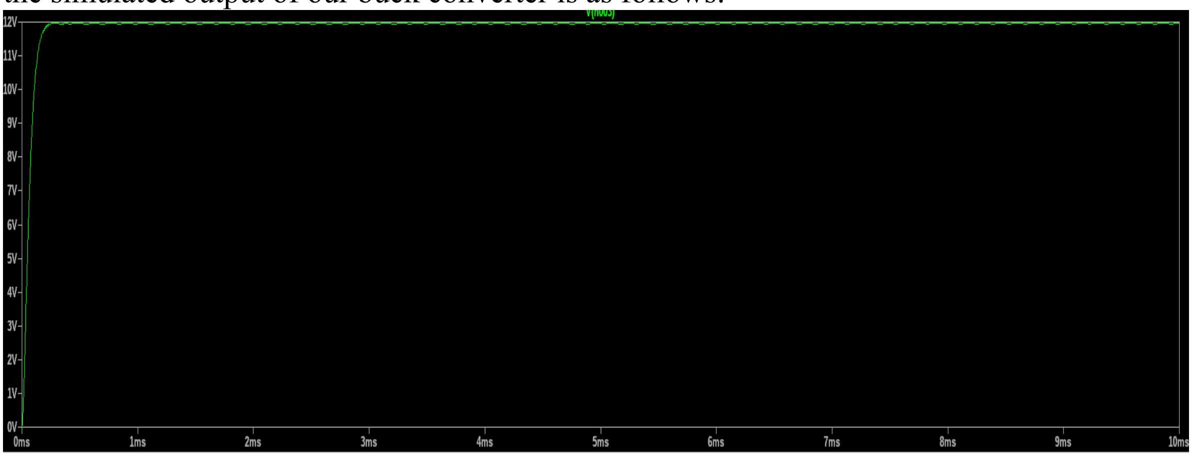


Figure 39: Buck converter output

From the above figure, we can see that this buck converter, converts the 48v supply into a perfect 12v signal for use by the sensors.

6.7.2) Boost converter module for voltage regulation to 115v pumps

To regulate the convert the 48V supply voltage to the 115V requires by the pump, the following boost converter was constructed.

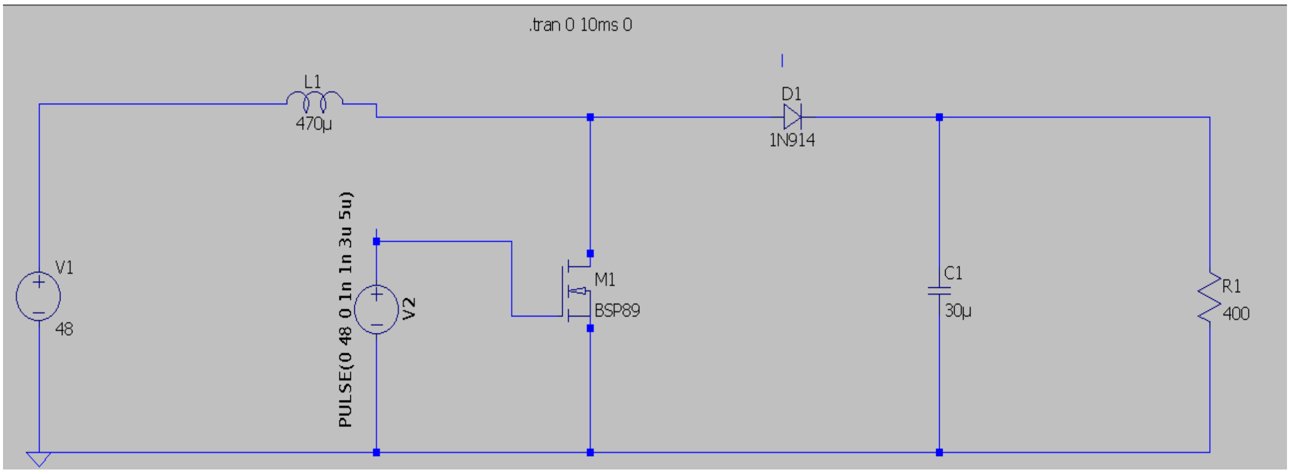


Figure 39: Boost converter circuit diagram

Simulating the above circuit produces the following output

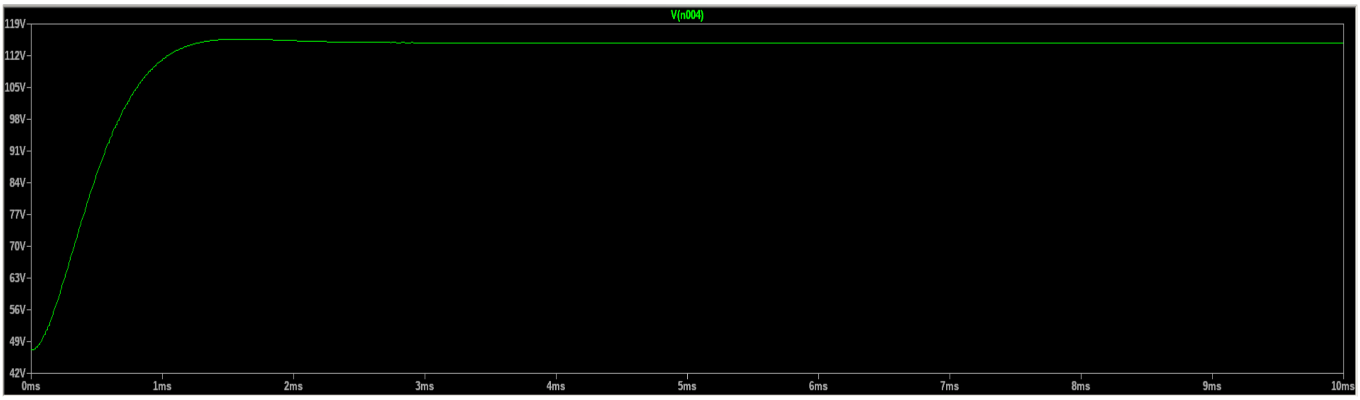


Figure 40: Boost converter circuit output

From the above figure we can see that the boost converter adequately converts the 48v battery voltage into a 115v voltage to be used by the pump system

6.8) Other issues to consider

6.8.1) Socio economic

The converters described above, were created using simple circuit components and as such these converters would not be too expensive to produce, however some of the components used in this power system are quite costly and could have a negative impact on the demand for the product.

For example, the battery and solar panel system would come to around R30000, which would be a major expense for anyone who chooses to purchase a system like this, but it should be noted, that the excess power stored in the battery could be syphoned off into the homes of the users and would therefor decrease their overall electricity spending while also decreasing their water bill (as this is the purpose of the product)

6.8.2) Health and safety of the device

This device deals will very large current and voltage systems and could obviously be very dangerous if handled incorrectly. Since our product deals with large amounts of water, this creates an even greater danger and thus extreme care must be taken in the installation of the product to ensure that no leakages can make their way into the power system which could short the entire system out. Similar levels of caution should be taken by anyone who deals with the power supply system as a single mistake could cost someone their lives.

6.8.3) Possible future development

Since the system houses a solar power supply unit and a battery large enough to hold more power than neccesary for the filtration system, possible future development could include implementation of a system that is able to swtich the solar panel power output to the house after the battery is fully changed so that the house can then be powered by the same system.
There are no other issues to consider regarding the power supply of the device

7. Module Five – Tank Design, Pressure, Warehousing; Mechanism for Water Funnelling and Transportation

Module completed by Michael Altshuler (ALTMIC003)

7.1. Subsystem Introduction

This module is broken down into two main components. That being the tanks that house the water in its different states based on where it is in the cycle of filtration, and the mechanism for funnelling and transportation of the grey and filtered ('clean') water. This subsystem can therefore be viewed as two separate subsystems on their own.

The tank design, pressure and warehousing 'sub-subsystem' will be responsible for the storage of greywater before purification with the use of UV lighting and biochemical filtration (separate subsystem on its own), and the subsequent storage of filtered water. The filtered water will then be redistributed to other areas of the home for reuse via the funnelling and transportation system (separate subsystem on its own). There are various user requirements for this subsystem to ensure the SmartHome system operates optimally and provides the user with the promised benefits (I.e long-term saving on water bill and less waste of water).

The second aspect to this larger subsystem is the Mechanism for water funnelling and transportation. The reason being that this 'sub-subsystem' is part of the larger subsystem is that it forms an integral part in ensuring the tank operates optimally. This mechanism is responsible for the distribution of water throughout the entire system. Furthermore, the water funnelling system houses the control mechanism which controls the water levels within both tanks with the use of sensors (a subsystem on its own). There are various user requirements to ensure the most cost effective and efficient system that further has longevity in terms of its maintenance.

7.2. User Requirements

Req. ID	**Requirement Text**
R.**U.001**	The two primary purposes of a storage tank system are to provide for volume and pressure.
R.U.002	The storage tank should allow the use of constant flow in the distribution system.
R.U.003	The tank holding greywater should have a larger volume than that of the filtered tank.
R.U.004	All water distributing systems must have means of pressurizing the system.
R.U.005	The piping must be flexible.

7.3. Requirements Analysis

7.3.1. Analysis of R.U.001

"The two primary purposes of a storage tank system are to provide for volume and pressure." This system needs to provide sufficient storage volume to ensure the user is getting the most out of the SmartHome system as a whole, and saves a sufficient amount of water for reuse to make the initial and maintenance costs for the product worthwhile in the long run.

Req. ID	Requirement text	Derived from
R.T.001	The volume and pressure will be constantly measured and monitored.	**R.U.001**

Verification:
The volume and pressure of both tanks will be measured and subsequently monitored by built-in pressure meters. The pressure of the tank will therefore change based on the volume and pressure at the time in order to maintain stable levels.

7.3.2. Analysis of R.U.002

"The storage tank should allow the use of constant flow in the distribution system."
The pumps that fill the tanks need to be operated by controls which start and stop them as the water levels in the storage tanks rise and fall. This is the main factor that will ensure there is no overflow. This requirement works in conjunction with both the volume and pressure monitoring component of the subsystem and the funnelling and transportation of the water.

Req. ID	Requirement text	Derived from
R.T.002	Control mechanisms to operate the flow of water into the tanks.	**R.U.002**

Verification:
This requirement can be verified by testing the control mechanism's function before the installation of the tanks in the client's home. Varying volumes of water will be pumped at different rates in order to test these control mechanisms, and the pressure and volume within the tank will subsequently be measured to ensure all requirements operate optimally in conjunction with one another.

7.3.3. Analysis of R.U.003

"The tank holding greywater should have a larger volume than that of the filtered tank."
The reason for this is to make sure greywater can always be captured even if the filtered tank is full and cannot store any cleaner water.

Req. ID	Requirement text	Derived from
R.T.003	Design a greywater tank with a larger volume than the filtered tank.	**R.U.003**

Verification:
In order to verify this requirement, the greywater tank needs to be designed and manufactured with a volume greater than that of the filtered water tank. This requirement will not take much effort to verify.

7.3.4. Analysis of R.U.004

"All water distributing systems must have means of pressurizing the system."
To do this, both water storage tanks must be elevated to develop the necessary feet to head to force water through the system. Alternatively, a hydropneumatic tank can be used. The only problem with a hydropneumatic tank is the fact that it poses some risk to the house owner and

anyone else living near the tank. The reason for these dangers is that the hydropneumatic tank is highly flammable and may be prone to malfunction.

Req. ID	Requirement text	Derived from
R.T.004	Elevate both tanks above the rest of the system or implement a hydropneumatic tank.	**R.U.004**

Verification:
This requirement can be verified by testing the pressurization of the system as a whole by placing the tanks at different heights above the system and measuring which height provides the optimal output and operation of the system. Alternatively, if a hydropneumatic tank is used it must be tested for its safety and can further be tested by running the tank for a period of time to ensure it runs correctly.

7.3.5. Analysis of R.U.005

"The piping must be flexible."
PEX piping is the best option for this as it's made of plastic and used in many water distribution systems in buildings. Although, it's slightly higher initial cost, it requires minimal maintenance, and has a fast installation process.

Req. ID	Requirement text	Derived from
R.T.005	Elevate both tanks above the rest of the system or implement a hydropneumatic tank.	**R.U.005**

Verification:
Stress tests can be performed on the PEX piping to ensure its durability, as well as tests whereby water is run through the piping at different pressures to ensure it is not damaged at higher-than-normal pressures.

7.4. Design Choices

Due to this subsystem being further broken down into two sub-subsystems, the design choices for the Tank design, pressure and warehousing and the Mechanism for water funnelling and transportation will be looked at and analytically analysed as two separate entities. The following proposed designs for this subsystem have been chosen based on optimal performance of the entire system, and further takes practicality and safety and longevity of the equipment into account. Furthermore, this section aims to identify the specific components that meet the design requirements as well as compare them to choose the most optimal components for the project.

7.4.1. Tank Design, Pressure and Warehousing

There are various user requirements that must be met when considering the design of this sub-subsystem. As stated, above this part of the subsystem is responsible for the storage if greywater before purification and the storage of the filtered water after purification. The water is subsequently redistributed to other areas of the home or building in which the system is implemented via the mechanism for water funnelling and transportation. In order to implement such a subsystem effectively, design choices must be made taking all user requirements into account to not only ensure the safe operation of the system, but also the effective functioning of the system as a whole.

Septic Tank:

In order to implement such a subsystem, it is imperative to have an understanding of how a household deals with greywater coming from all drains of the home. All drains in a home converge to a single pipe that leads to a septic tank buried outside. A septic tank is an underground chamber made of concrete, fibre glass or plastic through which domestic wastewater flows for basic sewage treatment. Solids and organics are reduced in a digestion process that takes place within the septic tank, but the treatment efficiency is only moderate. When wastewater hits the septic tank, it begins to separate. The heaviest matter in the waste (called sludge) sinks to the bottom, while the top of the tank contains fats, oils and proteins. However, the middle of the tank contains the water of interest to this system. The middle water is a comparatively clear liquid layer called effluent or greywater, which in the case of this system is the water that will be later filtered.

A septic tank needs to be considered in the design of this subsystem as the wastewater coming from the selected drains of the home needs to be stored in a septic tank before the filtration process can commence on the unfiltered water. It must be noted that the client will choose which drains are sourced to this septic tank and not the pre-existing septic tank which is not part of the water filtration system.

The septic tank used in the design of this system will have subtle differences to conventional septic tanks used in households. A conventional septic tank makes use of a French drain which serves the purpose of slowly releasing water into the surrounding environment. In the case of the septic tank used in this system, the middle layer of water will be pumped via the Mechanism for funnelling and transportation of water into the filtration subsystem where the water will be further treated. Due to the nature of septic tanks and the waste they hold, these tanks need to be designed and built to be placed at least seven metres from the home (ideally in the garden) to deem the property "habitable". Alternatively, an above ground septic tank can be used if required by the client. Taking all of this into account, pumps are essential in transporting the water to and from the septic tank.

An important aspect to consider when designing this system is the size of the septic tank installed. The size of the septic tank needed will depend on local government regulations, suitability of the ground geology, and the expected volume of wastewater based on the size of the home and the number of drains the client chooses to link to the system. Septic tanks range in price depending on the volume that they hold. In general, septic tanks range from approximately R3000 (1000L tank) to R30 000 (8000L tank) and will be chosen based on the volume of water the client plans on filtering for reuse. These tanks are designed and built by pre-existing companies, meaning the safety and effectiveness of the tank is taken care of and the manufacturing process and underground/above-ground installation is not a concern of this system. The only concern is the fact that the Mechanism for funnelling and transportation of water needs to be attached adequately.

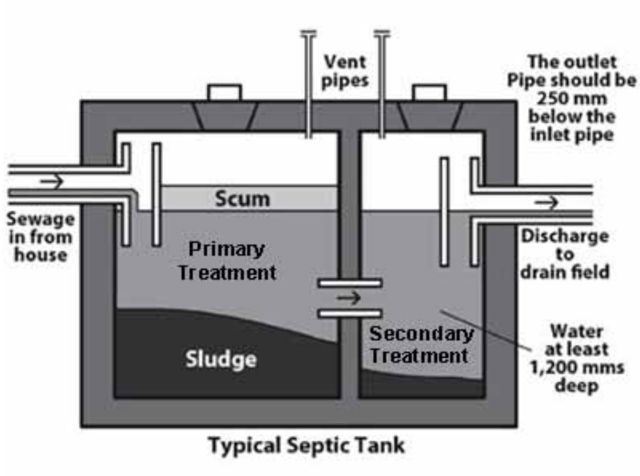


Figure 8: Typical Septic Tank

As can be seen by the design of this typical septic tank where the discharge (effluent/greywater) is fed into a drain field, this system will however drain this effluent water via the Mechanism for funnelling and transportation of water to the filtration subsystem.

Filtered Water Storage Tank:
This storage tank serves the purpose of storing the already filtered water, ready for res-use in the household. Unlike the septic tank described above, this filtered tank does not need to be stored beneath ground. Doing so would be a huge expense and would not be worth it in the long run. Thus, this tank can be kept next to the house outside, or stored in the roof of the house if space permits it to. One of the user requirements was that the filtered tank should be elevated to account for pressure and transportation of the water to the rest of the house, however this can be taken care by using specialised pumps to pump the water to its respective places. These pumps will be described in detail when discussing the Mechanism for the funnelling and transportation of water.
It was found that JOJO tanks offer not only the best tanks in terms of quality, but also in terms of price to storage volume ratio. It is essential that a water tank of the correct volume is chosen according to the client's requirements. Just as the septic tank, the size of this tank will depend on the volume of water the client wishes to filter for re-use.
A hydropneumatics tank was considered for this aspect of the design, however it is extremely costly and harder to maintain. Not only does it come with these downfalls, but it also poses major health risks as it is prone to fires, and easier means of maintaining the correct pressure in the tank can be used (with the use of the correct pumps) without a hydropneumatics tank.

Figure 9: JoJo Water Storage Tank placed outside home depicted with adequate piping.

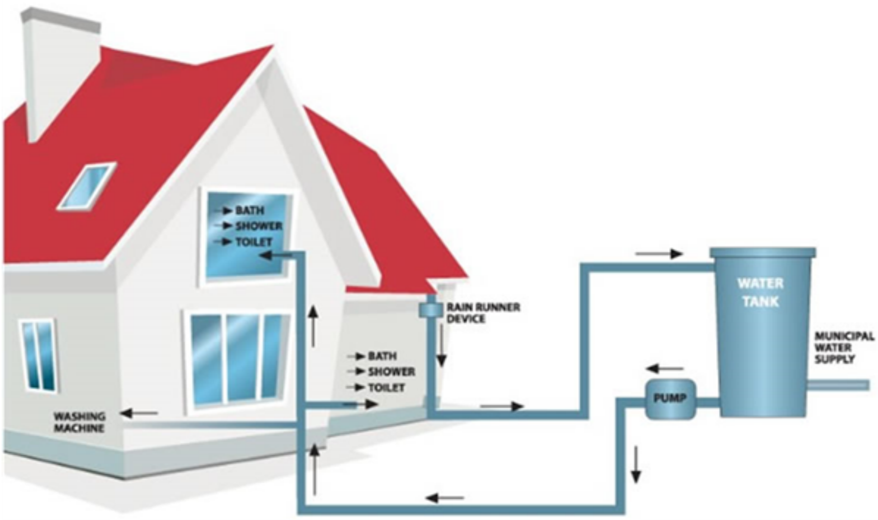


Figure 10: Filtered water tank configuration.

As can be seen by the above figure (*figure 10),* it is shown how the filtered water storage tank would be configured to the rest of the house. This also includes a rain water source, which would also be collected and circulated back into the household. The diagram further shows how the system will be configured with the Mechanisms for funnelling and water transportation, and also shows where the pump will be required to ensure the free flow of water throughout the system.

7.4.2. Mechanism for Water Funnelling and Transportation:

This sub-subsystem is responsible for the movement of water throughout the system. This part of the subsystem consists of PEX piping (the means of transport for the water) and pumps that take control of the pressure throughout the system, and forces the different states of water to their respective housing units.

PEX Piping:
PEX piping was chosen due to its low cost and easy installation. Not only is it a viable option for this system in this respect, but it's also extremely durable and pliable. Other types of piping were considered, however PEX piping seemed to be an overwhelming favourite to use within households.

The use of PEX piping meets all the user requirements for this part of the subsystem.

In order to be sure that PEX piping is the best product to use for this application, a comparison between itself and other common piping types needs to be done. The most common alternative to PEX piping are PVC (Polyvinyl chloride) pipes. PVC pipes are well known for their light weight, ease of use and simple installation process. These two types of piping can be compared according to their durability, life expectancy, flow rate, installation, freezing, uses and price and is depicted in the table below:

	PEX	**PVC**
Durability	Flexible and durable for interior use, does not corrode when not in sunlight	Rigid and sturdy, even in direct sunlight, does not corrode and resistant to damage from roots
Life Expectancy	25 to 50 years	50 to 70 years or more
Flow Rate	May restrict flow	Does not restrict flow
Installation	Very easy to install, extremely flexible	Easy to install, and more connection types
Freezing	Resistant to bursting	More likely to burst when frozen
Uses	Hot or cold, and okay for drinking water	Only cold water, and good for drinking water
Price	$2 per linear foot	$1 per linear foot

Table1: Table depicting comparison between PEX piping and PVC pipes

PEX is especially common for home remodels because of its flexibility and ease of use. PEX pipes are acceptable for both hot and cold water usage – essential for this subsystem – and are safe for drinking water or potable water after filtering.

Pressure Booster Pumps:
The pressure pumps are the controls responsible for maintaining the correct pressure within the water tanks and for the subsequent movement of water throughout the system. The pump contains an electrical switch which turns the pump off when the system pressure reaches a pre-set point. This means that the pressure of the system is fully automated and does not need to be maintained and looked at by the client.

Water pressure booster pumps are essential for this system to operate, so that water can be transported to parts of the home at a higher elevation than the tanks itself. Furthermore, it is essential in getting the water from the septic tank to the filtration subsystem and then to the filtered water storage tank.

Typically, the pressure should be boosted by around 20 – 50 psi for optimal operation of the system and to prevent any leakage. There are various pressure booster pumps that are adequate in providing the correct automated pressure for the system. The first one being the Kolerflo 120-Watt which boosts the pressure by exactly 20psi. This pump is also budget friendly. The only downfall of this pump is that the maximum pressure it can enforce is 20psi, which could lead to problems.

The second pump looked at was the Simer ¾ HP Water Pressure Booster Pump. This pump is strong enough to boost an entire home's water pressure, and reach a pump pressure of 40 psi. Not only does this pump have a better pump pressure than that of the Kolerflo 120-Watt, but it also has a variable pump pressure control which allows for easy automation of the process. The only pitfall is that this pump is slightly more costly ($420), however it's ability to pump and features offered are essential and won't lead to the same potential problems the Kolerflo 120-Watt may present. Thus, the Simer ¾ HP Water Pressure Booster Pump is the design choice made for this system.

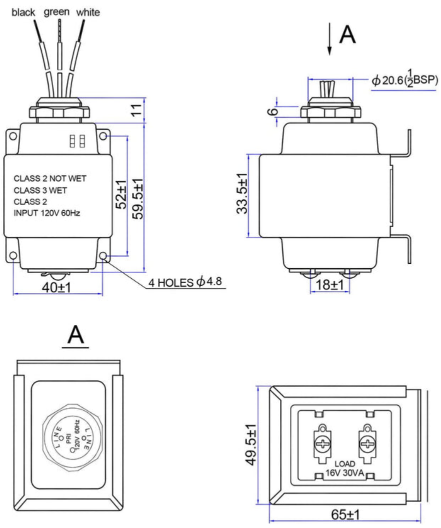


Figure 11: Simer ¾ HP Water Pressure Booster Pump dimension diagram.

Simer Pumps Booster Ace-In-A-Hole System 3/4 HP 115 V # 4075SS-01. This 3/4 HP 115 volt, single phase, booster offers a maximum additional pressure of up to 40 PSI and up to 24 GPM. Assembled, ready to install; includes 6' 115-volt power cord, 1" Female NPT intake and 1" Male NPT discharge pipes. **The 4075SS-01 is Simer's replacement for the obsolete 3075SS-01.**

4075SS-01 Pump Capacity In Gallons Per Minute With 1" Water Meter								
Model	HP	**Discharge Pressure Boost (PSI)**						**Shut-off**
		10	**15**	**20**	**25**	**30**	**35**	
		Gallons Per Minute (GPM)						
4075SS-01	3/4	22	19	17	13.5	10.5	5	40 PSI

Specifications

Applications: Domestic water supply. Pressure boosting from well city. Automatic water transfer. **Type of pump:**Single stage centrifugal **Pump construction:** 304 Stainless steel and corrosion-resistant materials. **Inlet & outlet:** 1" female NPT X 1" male NPT **Cut-in pressure:** 30 PSI factory setting **Maximum operating pressure:** 100 PSI (Suction pressure plus discharge pressure cannot exceed 100 PSI) **Tank size:** none **Suction lift:** none **Maximum inlet pressure:** 40 PSI (Must install a pressure reducing valve on the suction side of the pump if the inlet pressure is more than 40 PSI) **Electrical:** 115 volts, 1 phase, -7.2 Amps, 60 Hz, 3/4 HP,thermally protected, TEFC motor. Includes 6' electrical cord with plug **Maximum water temperature:** 150 degrees Fahrenheit **Carton Dimensions:** 17" high, 17" long, 9.5" wide. **Weight:** 26 lbs

- DO NOT EXCEED A TOTAL SYSTEM PRESSURE OF 100 PSI. THE TOTAL SYSTEM PRESSURE WILL BE THE INCOMMING CITY PRESSURE PLUS THE MAXIMUM OUTPUT PRESSURE FROM THE DATA ABOVE. THE MAXIMUM ALLOWABLE CITY PRESSURE FOR THIS UNIT IS 50 PSI
- USE A PRESSURE REGULATING VALVE IN THE SUCTION AND/OR DISCHARGE LINES AS REQUIRED
- BEFORE INSTALLING THE SYSTEM, BE SURE THAT YOUR CITY FLOW METER CAN HANDLE THE MAXIMUM FLOW REQUIREMENT
  - 5/8" METER SIZE = 12 GPM MAXIMUM FLOW RATE
  - 3/4" METER SIZE = 30 GPM MAXIMUM FLOW RATE
  - 1.0" METER SIZE = 40 GPM MAXIMUM FLOW RATE
  - 1.5" METER SIZE = 65 GPM MAXIMUM FLOW RATE

Figure 12: Simer ¾ HP Water Booster Pump Specifications.

7.5. V-Diagram, Constraints and Bottlenecks

7.5.1. V-Diagram:

The following diagram displays the design-build-test process for this subsystem as a whole. The left side of the V-diagram shows the design stage when realizing this subsystem, the bottom part of the diagram represents the build stage (implementation), and the right side of the diagram represents the test stage.

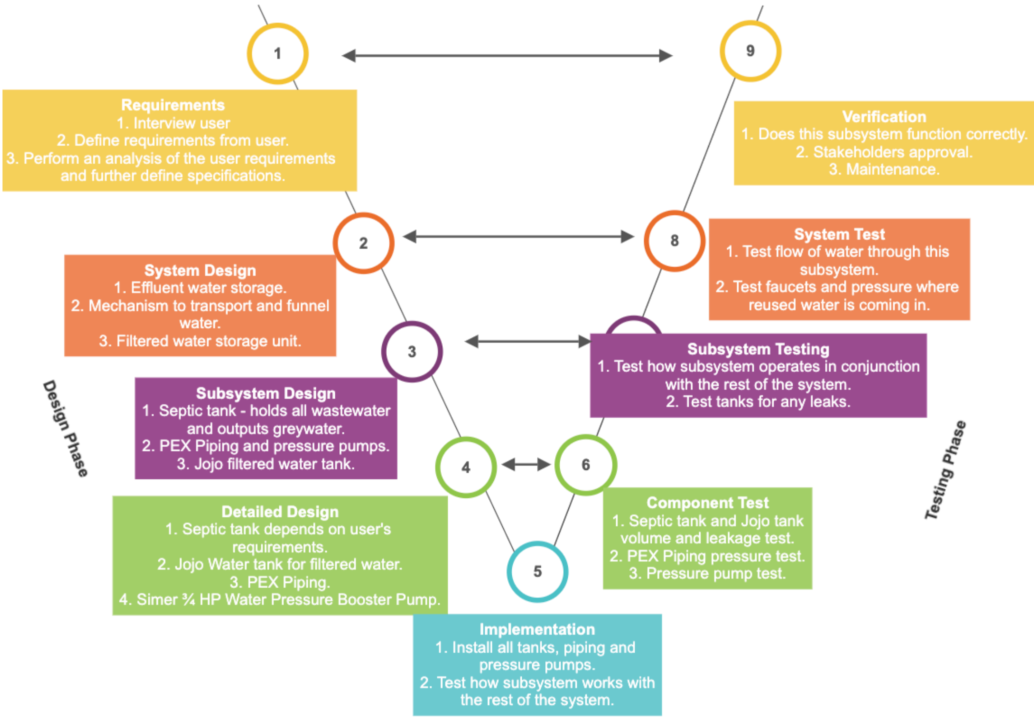


Figure 13: V-Model for Module 5

7.5.2. Constraints and Limitations:

Septic Tank Maintenance

The use of septic tanks come with a variety of constraints that need to be considered when implementing a system that uses them. The overriding constraint is that there are various factors that result in the septic tank needing periodic maintenance in order to maintain safety standards. The septic tank develops a large amount of sludge (the lower layer of solid material that builds up over time), which needs to be periodically removed in order for the septic tank to perform its purpose safely and effectively. This does of course add an additional cost to the client as they would need to pay for maintenance of the system over time.

Filtered Water Storage Tank Maintenance

As for the septic tank, the filtered water tank will need periodic maintenance as well. The periodicity of the maintenance needed for this tank may not be as frequent as for the septic tank, however in order to maintain safe practicing standards, this maintenance is required. The maintenance of this tank will include a cleaning to remove any algae or bacteria build up that may occur overtime, and would result in the contamination of the filtered water. Furthermore, the filtered water may be sitting still for extended periods of time, making it fertile breeding ground for mosquitos. Therefore, it must be ensured that there are mosquito preventative measures put in place such as nets and proper sealing of the tank. Another constraint to consider is the fact that the filtered water storage tank or JoJo Tank will take space in the client's home or outside area. This system can only be installed if the client has adequate space for all parts of this subsystem.

Pressure Pump Failure

Pressure Pump failure can be caused by various issues, and could be catastrophic for the system as a whole if this had to occur. These issues include, but are not limited to: 1) Pressure – restrictions in the pump's suction can result in cavitation of the pump. 2) Cavitation – when liquid pressure falls below vapor pressure, and pump internals are damaged, disrupting flow and leading to seal failure. 3) Leakage – leaks caused by mechanical failures can cause unforgiving problems for the whole system. 4) Installation – Improper installation can lead to shaft misalignment and subsequent excessive vibration which can cause pump damage.

Regulatory Constraints

Due to the nature of septic tanks and the waste they hold, there are various regulations that need to be abided by to ensure safety of the home owner and those residing near the premises on which the septic tank is held. The septic tank needs to be at least seven metres from any house defined as "habitable property". Furthermore, South African legislation states that a household has to have a septic tank of a minimum size of 900 m^2 and must have adequate water supply at all times. Any septic tank with a smaller volume would not be approved by housing regulations and planning permission would not be granted.

Theft/Damage

This subsystem may not be so prone to theft as all aspects of the system are designed and installed in such a way that removing/stealing any part of this subsystem would be extremely difficult. However, damage can occur if proper maintenance of the system is not done. As discussed above, the septic and filtered water tanks need to be maintained and cleaned to stop any sediment build up and to clean out the sludge build up that occurs in the septic tank. Furthermore, mechanical failures and other issues listed above can result in damage of the pressure pump, which could subsequently result in damage of the PEX Piping used to transport and funnel the water to its respective destinations.

7.6. STEEPLE Analysis

STEEPLE analysis aids in the team gaining a deeper understanding of the system and imagine new opportunities that could help the system improve.

7.6.1. Social

This system as a whole provides a social benefit as it reduces water waste. This subsystem in particular is a prime example of this as it is the system that stores the effluent water to be filtered, and then subsequently stores the filtered water to be redistributed to the rest of the household. This has a greater positive impact on the community as a whole, as it doesn't only save water for everyone if many households adopt this system, but it also has a positive environmental impact. Based on interviews conducted early on in the design process it can be said that the community will support this idea. Furthermore, this system requires installation and manufacturing which is are key factors in job creation.

7.6.2. Technical

Septic tanks only need to be replaced every 20 to 30 years, while Jojo tanks only need to be replaced up to 20 years after installation if proper maintenance takes place throughout it's life cycle. Furthermore, the lifespan of the Simer ¾ HP Water Booster Pump is sufficient to make this system cost worthwhile, and further has a product warranty based on the supplier from which this pump is sourced. These are promising lifespans as it reinforces the sustainability of this system as a whole.

7.6.3. Economic

As discussed above, this subsystem and system as a whole is being designed with affordability in mind. However, there are certain costs that cannot be avoided. These being the cost of installation of the septic tank, water funnelling and pressure pump, and the filtered water storage tank. This does mean that clients will have to have some form of financial stability to install the system, however the aim of the system isn't only to reduce water wastage, but also save money on one's water bill in the long run. The client also has to be aware of maintenance fees that are necessary of the upkeep of the system. However, these maintenance fees will be included in a cost analysis of the system and still show that the user will be saving on their water bill.

7.6.4. Environmental

The aim of this system is to be sustainable and environmentally friendly. While not all components of this subsystem can be manufactured in a sustainable way, the purpose they have is to reduce water wastage – a sustainable outcome within itself. The septic tank and pressure pump has to be manufactured in a way that results in the best operating subsystem, and cannot be done so using recycled materials. However, the Jojo tanks are made from recycled plastic – a factor taken into consideration when choosing the filtered water tank to use. Moreover, PEX Piping can be reprocessed for other purposes once it needs to be replaced, but the actual material can't be recycled and re-used for tubing.

7.6.5. Political

Members of political parties may want to associate themselves with this project because of the positive community sentiment around it and the fact that it will take pressure of government water plants if a big enough customer base is made.

7.6.6. Legal

Installation of this system will require permission from the municipality, and septic tank regulations will have to be followed.

7.6.7. Ethical

This system only aims to have a positive impact on all those who decide to use it. This positive impact not only encompasses the idea of saving money, but extends to being sustainable and good for the environment. The use of recycled materials in its design is further testament to the systems sustainability. This project also doesn’t associate with any particular group of people. The final product is for anyone to use.

7.7. Behavioural Activity UML Diagram

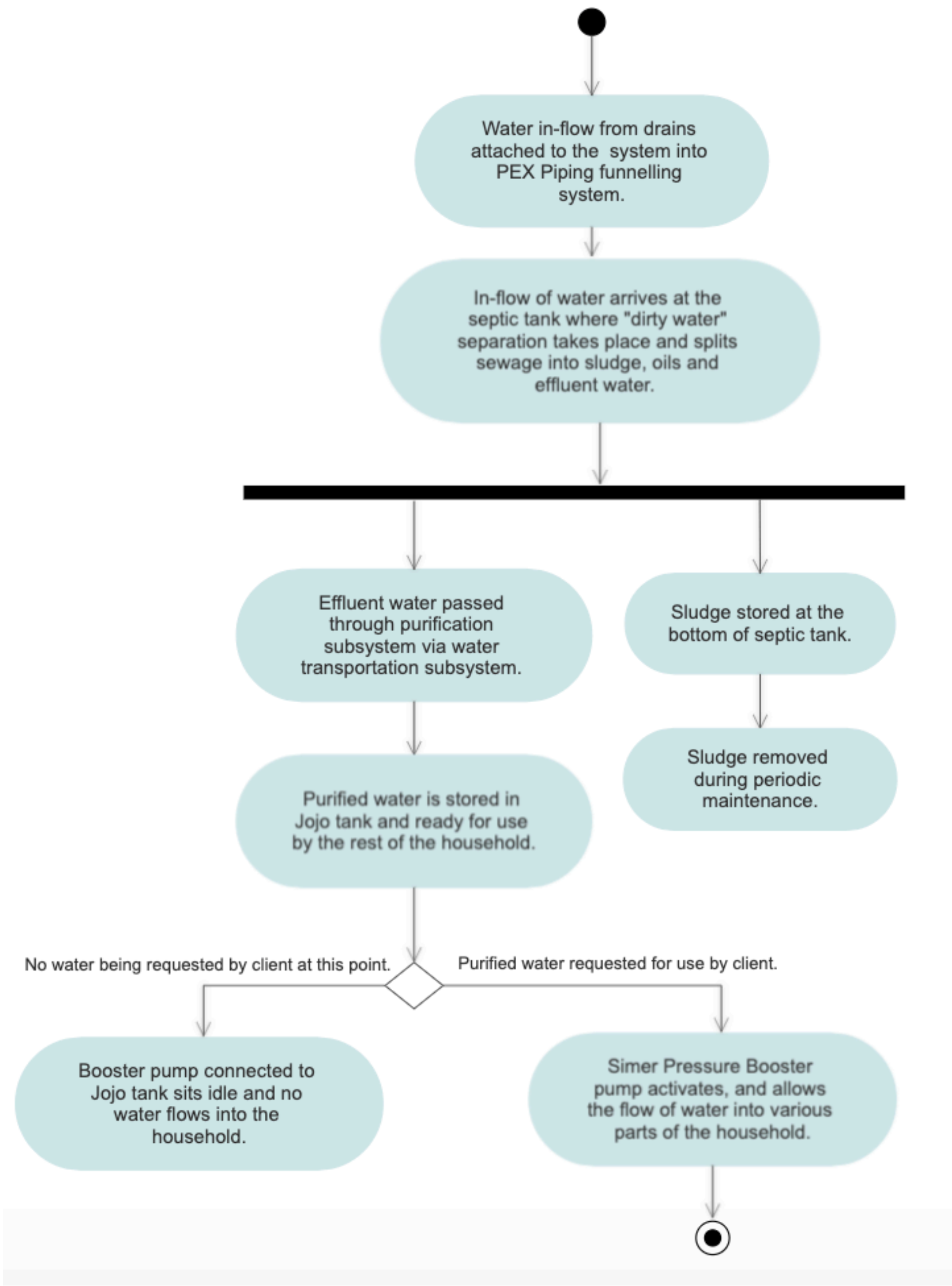


Figure 14: Behavioural Activity UML Diagram for this subsystem.

Note: all funnelling of water throughout the system is done by the Simer Pressure Booster pump.

7.8. CAD Drawings

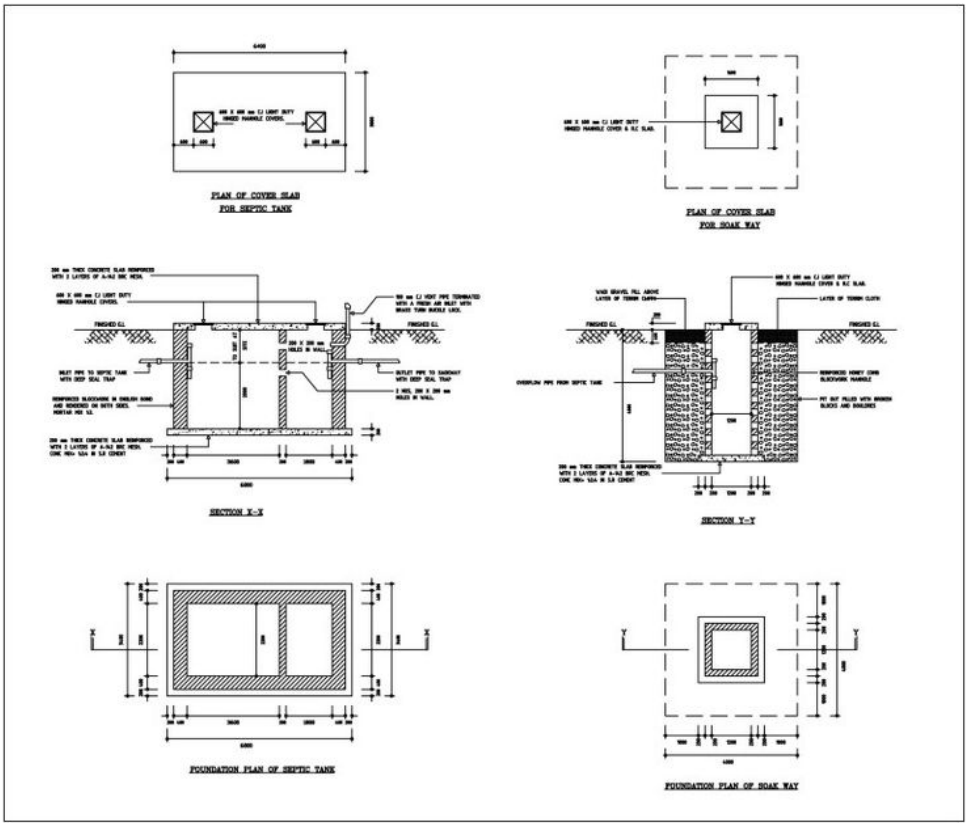


Figure 15: CAD drawing depicting septic tank design and dimensions.

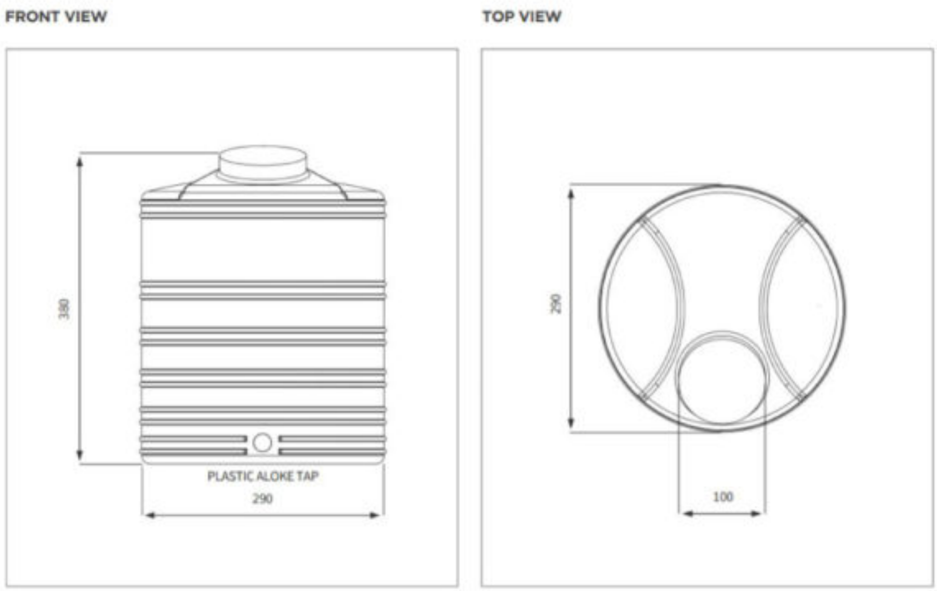


Figure 16: CAD drawing depicting Jojo tank size and dimensions.

Figure 17: CAD drawing depicting PEX Pipe and different mechanisms for connection.

METER AND SERVICE PIPE (inches)	DISTRIBUTION PIPE (inches)	MAXIMUM DEVELOPMENT LENGTH (feet) Table E201.1									
Pressure Range 50 to 60 psi		40	60	80	100	150	200	250	300	400	500
3/4	1/2[a]	3	3	2.5	2	1.5	1	1	1	0.5	0.5
3/4	3/4	9.5	9.5	9.5	8.5	6.5	5	4.5	4	3	2.5
3/4	1	32	32	32	32	25	18.5	14.5	12	9.5	8
1	1	32	32	32	32	30	22	16.5	13	10	8
3/4	1 1/4	32	32	32	32	32	32	32	32	29	24
1	1 1/4	80	80	80	80	80	68	57	48	35	28
1 1/2	1 1/4	80	80	80	80	80	75	63	53	39	29
1	1 1/2	87	87	87	87	87	87	87	87	82	70
1 1/2	1 1/2	151	151	151	151	151	151	139	120	94	79
2	1 1/2	151	151	151	151	151	151	146	126	97	81
1	2	87	87	87	87	87	87	87	87	87	87
1 1/2	2	275	275	275	275	275	275	275	275	247	213
2	2	365	365	365	365	365	365	365	329	272	232
2	2 1/2	533	533	533	533	533	533	533	533	533	486

Figure 17: Dimension sizes for PEX Pipes based on pressure of water flowing through.

It should be noted that the dimensions of all components in this subsystem are based on the user requirements and size of household the system will be installed in.

7.9. Sensitivity Analysis

The use of simulation tools such as CAD were used to model the size and dimensions of the components necessary for this subsystem. Modern computational tools are deemed accurate and reliable, and are therefore necessary in the verification of a system such as this one. There are various limitations to simulating a system using software, but it provides one with a good idea on how the system will operate before installation, implementation and testing.

Sensitivity analysis is useful in determining the amount of variation a system has in response to specific ranges of input. A sensitivity analysis is necessary and can be performed for each component of this subsystem.

Septic Tank:
The septic tank needs to undergo a sensitivity analysis by introducing different amounts of wastewater (sewage water) at different instances to see the duration of time it takes for the tank to decompose varying volumes of wastewater into its three core components: sludge, effluent water and oils. Based on this analysis, it can be seen how long it will take for an effluent water build up based on varying volumes of wastewater which will then be funnelled into the purification subsystem of this design.

Jojo tank (purified water storage unit):
The sensitivity analysis for this component is simpler than that of the septic tank, as one only needs to make sure that the tank is capable of maintaining itself with a full volume of water. Furthermore, one needs to make sure that this component can deliver water to the booster pump and funnelling system when water levels are extremely low.

PEX Piping:
The sensitivity analysis for this component can be done using software available to determine how the PEX pipes cope with different volumes of water passing through it at different rates (pressure of water passing through). Furthermore, a more practical analysis can be done on this component by connecting it to the Simer Booster Pump, and test how it copes with the pressure of water the booster pump is able to output.

Simer ¾ HP Water Pressure Booster Pump:
This component already has CAD drawings designed by its manufacturer which are useful in performing a sensitivity analysis. Furthermore, software such as Solidworks can be used to import these CAD files whereby a simulation test can be run for various volumes of water needing to be pumped by the booster pump. Moreover, it is necessary that a practical sensitivity analysis is conducted on this component, as it is essential that its real-life/practical capabilities can be assessed. One would install the pump in a test environment in which varying volumes of water would have to be pumped at pressures the booster pump is configured to deal with. It is important to drive the pump to its maximum output and test how it handles it and for the duration that it does without failing.

7.10. Other Issues

There are various other issues that need to be considered when designing and implementing this subsystem. These issues are namely socio-economic and health and safety of the devices and components used in this subsystem.

The design, implementation and finally the installation of this subsystem has to take the South African regulations for sewage and the transport of sewage through a residential housing water and waste system into account. The regulation in particular that needs to be taken into account is the SANS 10400-Part P, Drainage, Plumbing, Sanitation and Water Disposal.

The parts of this subsystem that need to take these regulations into account are mainly the transport of waste from the house to the septic tank, the septic tank itself, and the transport of clean water back to the home. The waste water cannot leak from any parts of the system and he filtered water needs to be kept clean when sitting idle in the Jojo water tank, and when being moved in the PEX Piping.

Lastly, the regulations surrounding the design and manufacturing of the pressure booster pumps used in this subsystem don't need to be taken into account as this is the job of the manufacturer of the pump itself. The manufacturer will have to state that all regulations are met when providing the purchased pumps.

There are various socio-economic considerations that need to be made. Although the system aims to save a household on their water bill in the long run, just by the cost of this subsystem on its own, the initial installation fee and cost of the system will be a fair sum of money – an amount that not every household in South Africa could afford. Therefore, while there is still a large market for this product in South Africa, it will be a mission statement for this team to install such systems in lower income areas with profits made from the primary system sales.

8. Conclusion

The system described in this report is an excellent solution to the problem statement. Implementation of this system would benefit society by reducing the cost of water and electricity for the user while also benefitting the environment by reducing the total water usage for the aforementioned society.

Maintenance for this system would produce a very small cost for the user as the system has been designed in such a way that it would self-regulate everything within it and would therefore maintain its quality for many years. The main expenditure for the owner after the installation of the system would be the chemical refills for the filtration system. However, this is part of the future business plan as we would be providing these environmentally friendly chemicals for a much cheaper price then could be found anywhere else.

The idea of an application to go along with the system was a great addition to the device as it ensures that the user is constantly being updated as to the functionality of the system.

Future development of the system could be found in the system's self-regulatory design structure. Since the filtration system works autonomously by using sensors to determine different characteristics of the water both before and after the filtration system, it makes sense that upscaling such a system for industrial use would require nothing more than increasing the size of the different system components and increasing the power being delivered to the device. With large enough scaling, this system could even be used to filter and clean the water for entire cities.

The system has been designed in such a way so that it meets all the users could ever need and more while also incorporating a sustainable and economical method of doing so, and therefore this collaborative project has been considered a great success.

A1 Appendix

Proof of collaboration and communication: