The Development of a Cheap and Effective Water Level Measurement Device

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This report follows the development of a water level measurement device. It is structured into three distinct 'chapters', each covering a significant portion of the technological process. It has been written over a ~9 month period in 2018.

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Brief Development

Sam Kolston - 13ELE

1.0 - Introduction

I live with my family in a rural area in the North Shore of Auckland. The area and our home is a beautiful part of the country and facilitate a fulfilling way of life. Although we have lifestyle advantages such as easier access to the natural environment and quiet, we experience issues that can challenge our way of living. I have decided to explore the environment of rural living for my technological prototype. Rural living is common in New Zealand due to our low population density, and is defined by the homeowner's relative isolation to public utilities such as sewage, processed water, telecommunications, electricity, and so on. This isolation poses many problems that can cause difficulty for people living in such circumstances.

1.1 - Elements and Issues in a Rural Living Environment

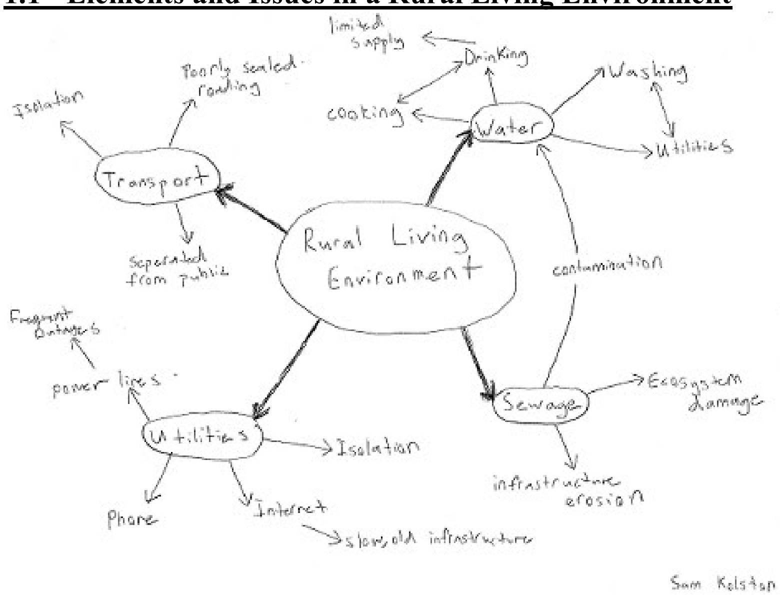


Figure 1: Mind map of the rural living environment

Sewage: Poor waste management can lead to horrendous health consequences. This can be the result of waste contaminated water supplies or other improper disposal of waste. A leak or error in the filtration process could lead to extreme ecosystem damage or contamination of drinking supplies. The filtration process begins with human waste and consumed water (such as shower water) entering a holding tank, where bacteria breakdown most of the contents. It is then discharged into bush or other vegetation, where bacteria again process it. By the time it leaves the property boundary of the rural resident it should be completely drinkable. Sewage disposal will lead to massive interference in any developments that may occur in these rural areas, as it makes a large section of land unusable for construction. As New Zealand's population increases many rural areas will likely be developed, so a form of sewage control that requires less land usage would be highly beneficial. This may also reduce the contemporary issue of waterway damage, especially caused by farming waste. Emptying the holding tank of sewage is also a costly and physically intensive necessity which could seriously benefit from technological automation.

Water: On average, the New Zealand rural household consumes 580L of water per day. Most rural residents use filtered rain water for drinking and otherwise, so in dryer climates running out of water is always an issue. The gutters of a house normally collect rain, which is transported by pipe to a main storage tank. Erosion and other degradation of pipes and tanks that carry drinking water can also lead to health issues, especially if foreign contaminants such as leaves and dirt are introduced after the filtration process. Irrigation issues can also arise when watering a large section, especially considering many rural residents own livestock or practice farming in some other way, something that consumes lots of clean water. A reduction in water usage from rural residents or otherwise could result in massive positive environmental and economical impacts. This could be especially beneficial to rural residents who own some form of farming operation, as water usage can be one of the largest costs in the running of a farming business. While contemporarily New Zealand has an abundance of water, mostly due to its low population, the increase in immigration and population natural increase will result in an unprecedented demand for water which needs to be accurately collected, measured, and distributed for consumption.

Telecoms: Access to the "outside world" through telecommunications can be a rarity in the rural environment, mostly due to lack of financial viability to companies that develop this infrastructure. This can include mobile network coverage, internet connection, and wired phone connection. The vast majority of rural internet connections in New Zealand, if connected to the internet at all, use DSL or ADSL line to do so (digital subscriber line and asymmetrical digital subscriber line respectively). This means that data is transferred through copper wire, mostly suspended alongside telephone lines. If a power line was to be damaged, say in a storm if a tree falls on top of it, all access to the outside world will be lost unless mobile network or satellite coverage is present. In an emergency, this can cause serious issues as minor injuries could lead to permanent damage or death if no help can be obtained. Lack of internet connection can make things like working remotely difficult, or if you own a farm, managing clients and other business-related activities. An optimization of current remote networking abilities would be beneficial to rural New Zealand residents, and therefore New Zealand as a society, for these reasons.

Power: Lack of power in the modern day could have extreme consequences, especially in a brutal environment. If air conditioning or food preservation (such as a fridge or freezer) is not available due to a power outage, living conditions can worsen to the point of death. In rural environments, power is either connected to a normal grid through power lines or the homeowner is self sufficient, mostly using solar energy or wind to obtain their own power (this is extremely rare). Only 32% of consumed energy in New Zealand is done so by standard households, a miniscule fraction of which are rural. Rural locations are often in unsafe environments, places which have low temperatures, snowfall, high heats and so on. These extreme conditions may mean that air conditioning and food preservation, as mentioned previously, could be vital for survival, so any power outage could be deadly. If someone works remotely, lack of power for computers, for example, could result in significant financial loss. For these reasons, constant power is essential, and so power outages should be avoided at all costs. Many outages occur due to technical issues caused by the power company, from no fault of the homeowner. In these occurrences, generators are used, often powered by petroleum, solar power, or a backup battery. A way to decrease fuel consumption for generators would be incredibly useful for not only the rural homeowner, but any organization that uses a backup generator – hospitals, businesses etc.

Transport: Transport within a rural environment can be difficult, mainly due to the danger of the natural environment that most are in the vicinity of. Travelling to and from a home is essential for survival – gathering supplies and so on. A rural resident will usually rely on their own car, since public transport will be non – existent (or else it is probably not a true rural location). The car will need to be stored safely (away from weathering), maintained to an effective working order, have a supply of fuel, and the road must be maintained. A device that can detect defects in a car, or in the road itself, would be beneficial. A CCTV camera, for an example, that is placed in key structural points of a personal road would be very useful and could save lives. A sealed storage unit for fuel is likely already used in extremely harsh environments where a point to refuel is very far away. A device that could accurately measure the amount of fuel either in the car or in a storage tank would be very useful.

1.2 - Stakeholder Introduction and Consultation

Main Client - Stephen Gardiner

Mr. Gardiner is a programming and computer science teacher at Rangitoto College. He lives in a rural environment, making him a suitable representative of the context I have chosen to experiment with. I have chosen Mr Gardiner as my main client as his technological expertise as well as real-world living environment will provide unique insight into the production of my product. Mr Gardiner will help me decide on major product features, designs, and will be able to assist me in the potential programming of my outcome. I have decided on a stakeholder at this point so that I can narrow down the aspect of the rural living environment to further explore and theorise possible improvements and innovations.

After analyzing my mind map and initial expansion into each aspect of the rural living environment, I had a discussion with Mr Gardiner on which he believes could make the most benefit out of technological advancement. To do this, I have asked him to give me information on any issues he encounters within these aspects, and how much of an important/priority these aspects are for himself.

Sewage: *Sewage is not much of an issue for me. We have a basic septic tank system that gets emptied every couple of years has never had an issue. Our one doesn't require monitoring or any other type of regular maintenance. Two of our neighbours across the road have newer smart sewage systems (is there another name for them?) and seem to have regular issues with them*

Water: *We are on tank water. We only have 1 tank and although it's reasonably large we worry about running out of water during the summer months. It is also a time when we have increased demand for water as we tend to have family come and stay with us over summer. We try to be frugal and conscientious with our use of water over the summer but find it very difficult to monitor our water level and how effective our water saving habits are. After some brief rain we have no idea how much of the tank has been filled up unless it is pouring out of the top. We can hit it on the side to establish the level, but it doesn't seem to be very accurate and as our tank is half buried it is very difficult to tell how much is actually left in the tank, or how much is left based on our usage. We try our best to avoid paying for a tanker to deliver water (it's normally free from the sky!).*

Telecoms: *I'm really into technology so like to have good telecommunications. VDSL is the fastest internet available to us and is sufficient (no-one has ever complained that their internet is too fast).*

Power: *Power is the most important. Without power we have no water (the pump needs electricity to run), no internet, no lights, no heating, etc. We are conscientious users of power, using Flick as our provider who charge according to the wholesale rates (taking a small margin). By changing habits slightly and using a higher proportion of power at off-peak times we are able to save quite a bit on power (e.g. running the dishwasher later at night or early in the morning when power is cheaper, rather than during peak times). I have the current and forecast power price as one of the listed items on my home automation app which is attached to my light switch. Fortunately, our power has been very reliable with cuts normally being only a few seconds long. The exception would be the most recent storm where we lost power for a few days, as did a huge amount of other Aucklanders, but for the last couple of years prior to that it has been very reliable. The cost of a generator or house battery does not outweigh the minimal downtime we have had for power.*

Transport: *We have no public transport available so are reliant on private cars. A disadvantage of rural living is the long commute to work, especially once you hit traffic in the city.*

It's difficult to say order of importance between those. Something like sewage is amazingly important, but fortunately rarely has issues. The importance in my situation is probably something like: power, water, sewage, transport, telecoms. Power is needed for the rest to run (except transport - I have a petrol car). The reason I have ranked water higher than sewage is because if we didn't have water, a sewage problem would be irrelevant as there wouldn't be anything going in to the system, i.e. having water and no sewage is better than having no water with working sewage – you at least have access to something in the first case. As for transport and telecommunications I can (probably) survive without internet, but if I don't have transport then I can't get groceries, or get to work in order to get money to pay for all the other things.

After talking over and analyzing this incredible feedback, I have decided to expand on water and the logistics around storing and consuming/using it. This can include transportation, storage, consumption and waste. I have chosen this as Mr Gardiner has already outlined a frustration in the measuring of the water, something that I believe I will be able to explore and possibly propose a solution to.

1.3 - Element of a Rural Living Environment: Water and its Usage

As shown on the mindmap, water is consumed in many ways by the rural resident. These can be cleaning, drinking, cooking and utilities such as dishwashers. All of these require the same clean, filtered water source suitable for human consumption.

As mentioned previously, the vast majority of rural houses, such as my main clients, use filtered rain water for consumption, collected from gutters on their roofs and stored in a tank (usually around 20,000L). When water is needed, say, someone turns on a tap, the water in the tanks travels through a filter and then straight into the houses plumbing, eventually reaching the tap. There are several concerns with this process, including water running out, pipes bursting, and the contamination of water.

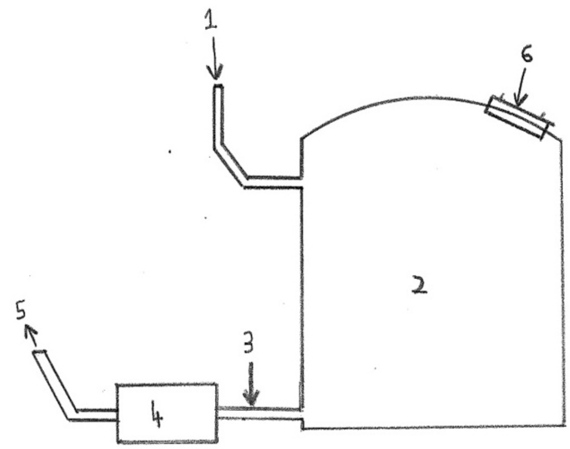


Figure 2: Simple diagram of a standard rural water system and tank

1. Water input	2. Water tank
3. Water output	4. Filter
5. Filtered water output	5. Hatch

Simply put, water is inputted (1) as undrinkable rain water from a gutter, stored (2), outputted as undrinkable with no changes (3), filtered (4), and then outputted as drinkable water (5). Rainwater is almost always drinkable in itself, but when run through gutters and over roofs, it may pick up sediment and other contaminants that make it no longer safe for human consumption, which is why the filter is necessary. The level of water remaining in the tank can be checked by a human through the hatch (6).

Figure 3: Photo of a standard rural water tank setup

Figure 3 is a photo of two water tanks. They are connected with a small PVC pipe, the same type of pipe that connects the guttering system to the water tank, and then the water tank to the filter. The water tanks are somewhat subterranean, with the top of the tanks placed slightly above ground level, allowing for easy access. This also helps keep the water cool. If a leak occurs in the parts of the water tank below ground, however, it could take days to realise as it would not be visible by the naked eye. Currently, the only practical way to detect a leak is by physically standing on top of the water tank and seeing how much water is left, judging based on the amount of water being consumed by the resident.

Figure 4: opening of the hatch on the top of a watch tank. The water in the tank is full

Figure 4 serves as an example of the difficulty involved with determining how much water is left in a tank. The concrete shell that comprises the water tank is thin, thus having limited structural integrity and not being very safe to stand on. From figure 4, you can see that the water in the example tank is very full, and so water level should not be a concern. If the water is running low, for example, at 20% capacity, you can see that it would be difficult to tell how much water is left, as the only source of light is that coming through the hatch, likely from the sun. Exposing sunlight to water can introduce ecological contaminants and damage the quality of the water, so the act of removing the hatch should be reduced as much as possible. This introduces an opportunity for a method of testing how much water is left in the tank without opening the hatch. Another opportunity in the context of the water tank is a method for easily finding cracks and other leaks in the system.

Figure 5: entrance pipe for water into the tank. This pipe connects directly to a guttering system on the edge of a roof

The connection point between the water tank and the gutter is a vital part of delivering drinkable water in a rural living environment. In the example tank, as figure 5 shows, this connection is sealed with silicon sealant (a common form of sealer in New Zealand, as it is cheap, widely available and water proof). This can be a problem, however, if parts of the sealant break off due to weathering, contaminating the water supply or damaging the local environment. Environmental sustainability is, more often than not, a primary concern of a rural resident, as many choose to live rurally due to their perspective of the beauty of the natural environment. This means that environmental sustainability is likely a primary concern of my own when producing any technological device involving the rural living environment.

Figure 6 is an example of a clogged gutter. The main issue with a clogged gutter is the material causing the clog (most likely organic material from nearby plant life, but could also be the remains of insects/small animals that have died on the roof and been pushed into the gutter) reducing water flow or blocking off water supply completely. Because of the blockage of the release pipes, the gutters may fill with water as opposed to releasing it into the tank, which may result in collapsing gutters due to a far higher weight from the water. Another issue is the organic material releasing sediment or toxins of some sort contaminating the water supply, as well as reducing/blocking off the water supply. Erosion of the gutter material (normally PVC) could also contaminate the water, regardless of whether a blockage is present or not.

Figure 6: example of a gutter in a rural living environment

The dangers of water contamination are not to be ignored, especially when said water is used for consumption. Research by USDA has shown that sediment is one of the major causes of waterway pollution. The health effects from drinking contaminated water can lead to severe illness or even death. Private water supplies can be contaminated with bacteria, nitrates and even pesticides. In NZ, these contaminates are especially prevalent in rural living environments close to farms (herbicides, pesticides) and national parks that use 1080 poison, for example, for pest eradication.

This analysis of the guttering system of a rural living environment has introduced the opportunity of a guard of some kind to prevent foreign materials, such as organic matter, from entering the system. This could result in a complete lack of blockages, saving the rural resident time and therefore money unblocking gutters in order to receive a constant supply of water. Another opportunity is the development of a device that detects contaminates in a water system, which could save the lives of many rural residents if the pump system fails or does not possess adequate filtration ability.

While this research into my stakeholder's water tank system is invaluable to further development of a product personal to them, the product will eventually be targeted towards a higher user base. Further water tank systems will need to be analyzed in order to uncover further issues and allow for technological advancement of all rural living environments.

According to Promax Engineered Plastics, the most popular type of water tank in NZ is the rotationally moulded plastic water tank. These tanks must be constructed out of materials of consumable food-grade standard and of potable-water standard (potable meaning safe to drink). The majority of these plastic water tanks are made of a plastic material called Polyethylene. As it is a plastic, Polyethylene will not rust or corrode as metals will, and the resulting tanks from this material are extremely light weight. They can also be recycled at the end of their service life.

I contacted Promax, planning to discuss potential issues in the rural living environment specific to the Polyethylene water tank. This discussion was abrupt, as my contact simply stated that *"Most issues around water in a [rural living environment] are independent of the type of tank. Poly tanks are generally regarded as superior, for reasons like cost, transportation etc, but they both achieve the same thing, and I reckon that most issues will come from the pump, the water itself or the drainage system".* This information is useful, as now I know that aside from the various intricacies of the physical characteristics of the material, the type of water tank makes little difference in the water usage system of the rural living environment. This means that if I make a product for the water tank, it will likely be effortless to apply to any of the major types of water tanks in NZ.

1.4 - Opportunity

I believe that the aspect of the rural resident's water system that could most benefit from technological advancement and innovation is the water tank, specifically involving estimating/measuring how much water is left in their tank. The ability to be certain on how much water is left in their water tank is invaluable to the resident of a rural living environment, as their life and wellbeing depends on it. The issue is that the traditional method of precariously and dangerously standing on top of the water tank and estimating by eye is archaic and in desperate need of a positive change. The efficient measurement of water could be used in a wide range of environments other than just rural living, as water is stored for consumption in every human environment and civilization.

From my experience in living in a rural environment, I believe that there is an abundant need for a cheap, accurate, and most importantly, non-physical way to determine how much is left in a tank at any time that the user needs. This need has both social and environmental repercussions, as without the water that this device may save, plant life and human life will be negatively affected. For this reason, environmental sustainability and recyclability will be of utmost concern when designing, developing and implementing this device.

1.5 - Existing Solutions

There are several different technologies and consumer available solutions to this issue, used by companies, governments and rural homeowners alike. Analysis of such solutions will allow me to determine if there are opportunities to improve and develop a solution, as well as find attributes that may be beneficial if my alternative solution is needed. Below is a list of available devices that can be used to detect and measure water levels that I have researched. I have only analyzed solutions that can be purchased today by an average consumer, not technologies that are currently being researched and have not reached market.

Probe-Based Water Level Meter

References are made to figure 7 (below)

The probe-based water level meter is a perfect example of a device in desperate need of technological advancement. The probe (2) is lowered into the liquid container, such as the water tank of the rural house, and when the tip of said probe (1) reaches water an LED or buzzer will activate, letting the user know when it has reached the top of the water. The user will then read the measurement (5) on the wire (4) that the probe is lowered down with. This measurement will give the amount of free space in the tank, so the user can calculate how much water is remaining using the total height of the tank. The probe itself is normally up to 15cm in length, made of plastic and/or aluminium, with a weight of some kind added. Rubber sheathing is present to connect the "bottom" of the probe to the wire (3). The measurement tape is stored on a reel (7) which can be picked up and moved around with ease thanks to the handle mounted on top (8). The LED or other attention-grabbing component is normally mounted on the reel (6).

Some probe based water level meters are similar in appearance, but instead the probe will be submerged in the water and reach the bottom of the tank. Resistance is measured across bare copper wires, which can detect the presence of water. While this copper wire is perfectly safe while submerged in the water of the tank, exposure to oxygen will cause it to rust. As the water level fluctuates based on level of consumption and amount of rain, the copper will be exposed to oxygen inside the tank. This can be incredibly hazardous as the corrosion of the copper will leak into the water, contaminating it. The United States Department of Health says that *"The human body has a natural mechanism for maintaining the proper level of copper in it. However, children under one year old have not yet developed this mechanism and, as a result, are more vulnerable to the effects of copper".* This means that while the risk of copper contamination in water supplies for adults is low, the opposite is true for children, so this method is incredibly hazardous.

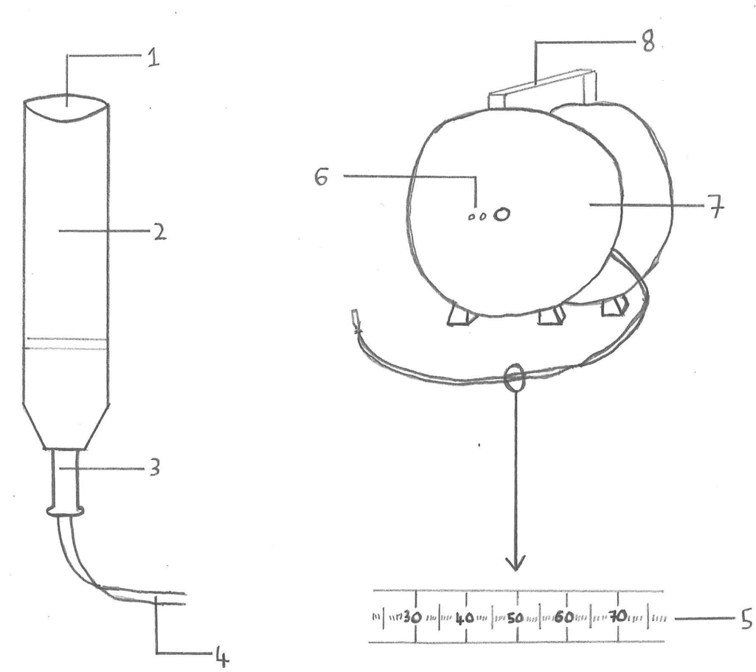


Figure 7: Diagram of a standard probe level meter

The main advantage that the probe-based water level meter has over other existing technologies is the sheer length it can measure, with some retailers and manufacturers claiming up to 1500m. This does not, however, outweigh the plethora of disadvantages it carries with it. Firstly, the device assumes that the user already has available the interior height of their water tank without any liquid, which is highly unlikely unless it were given by the manufacturer. The device also still requires physical labour to utilize; something that I believe should be reduced at all costs on such a weak structure, often placed in precarious locations and heights, as explained in section 1.3. Lastly, depending on the size, a probe water level meter can cost upwards of $75, what I believe is an extortionate price for such a primitive piece of technology. The main advantage of this device, its ability to measure vast heights of water, is irrelevant for the use case of the rural living environment regardless, as domestic water tanks are never larger than 10m in height.

From analyzing the probe based water level meter, I have determined that an important factor in water measurement for the consumer is simplicity. I believe this because this water measurement technique utilizes lacklustre technology for an absurd price, and yet is incredibly common and widely adopted due to its simplicity. Any person can tell how to measure the water with its clear ruler-type markings and weighted probe, and because of this, the probe is an incredibly common device used internationally.

Float Switch

References are made to figure 8 (below)

Another outdated technology, the float switch is another way of detecting water, and when set up correctly, can also test for depth of water. The most common float switch is the Kubler float switch (A). The design is centres around a conductive ball (4), normally made of plastic with a copper sheathing that can float up to meet a contact point (3) along a rod (5). When the ball meets the contact point a connection is made and a circuit is completed, activating an LED or buzzer. On the top of the device is a nut for mounting (2) and a waterproof box for electrical components/circuitry (1), as well as leads for connection to the warning system e.g. LED. Alone, the float switch can merely detect the presence of water, and thus only the level of water in one particular location. While this is better than no detection, it leaves something to be desired as the user can only tell when a certain point of water is reached, say 50%, and can not accurately measure a trend of water usage. When combined, however, float switches can be used to determine water usage trends, by using several in conjunction, placed in spaced intervals throughout the height of water tank, but this is still fairly inaccurate and is a hassle to assemble.

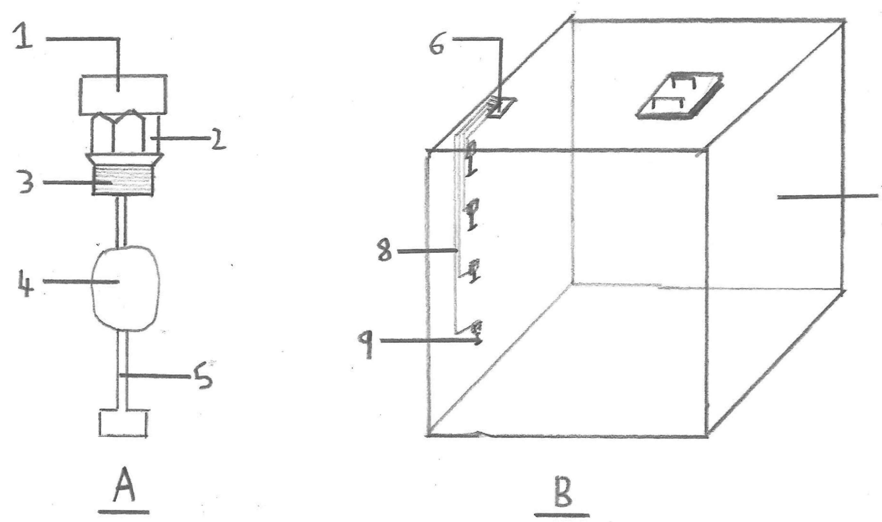


Figure 8: Diagram of a float switch level meter (A) and a possible application (B)

The price of a float switch is its main advantage, as they can be purchased from Chinese manufacturers for around $2. This is an accurate representation of their quality, however, as they are essentially just waterproof actuators with a floatation device. Most of these switches will not come with any display contraption. A display system can be built around them with ease, but the user is still limited by the inferior, primitive technology that they are relying on. Another disadvantage to the float switch is that constant, metallic submersion in water that will be consumed may be quite concerning to the user, as they may be worried about contamination of their water supply.

From this research, I have determined that the main reasons why float switches have not seen mass adoption is their lack of accuracy and difficulty of installation, despite their incredibly low price. While every rural resident, business, government organization or otherwise can afford such a switch, the difficulty of entering a tank, mounting the switch in the desired location, mounting the wiring along the tank and then attaching a warning alert is physically strenuous, costly, and ultimately not economical as barely any useful trend of water usage can be extracted.

Ultrasonic Level Meter

The ultrasonic level meter is the most technologically advanced measurement device I have analyzed. This being said, it is still fairly simple to understand and use on a day to day basis. As the name suggests, the device uses ultrasonic (sound waves that are out of the range of human hearing) sensing to test the depth of water. The ultrasonic sensor outputs a high frequency sound, in this case towards the water, and then measures the amount of time it takes for the echo of the sound to return to the sensor. It uses this time to calculate the distance the sound has travelled, thus measuring how much empty space is in the tank. There are several forms of ultrasonic level meters, utilizing the same ultrasonic technology but with different methodology, form factors and display technology.

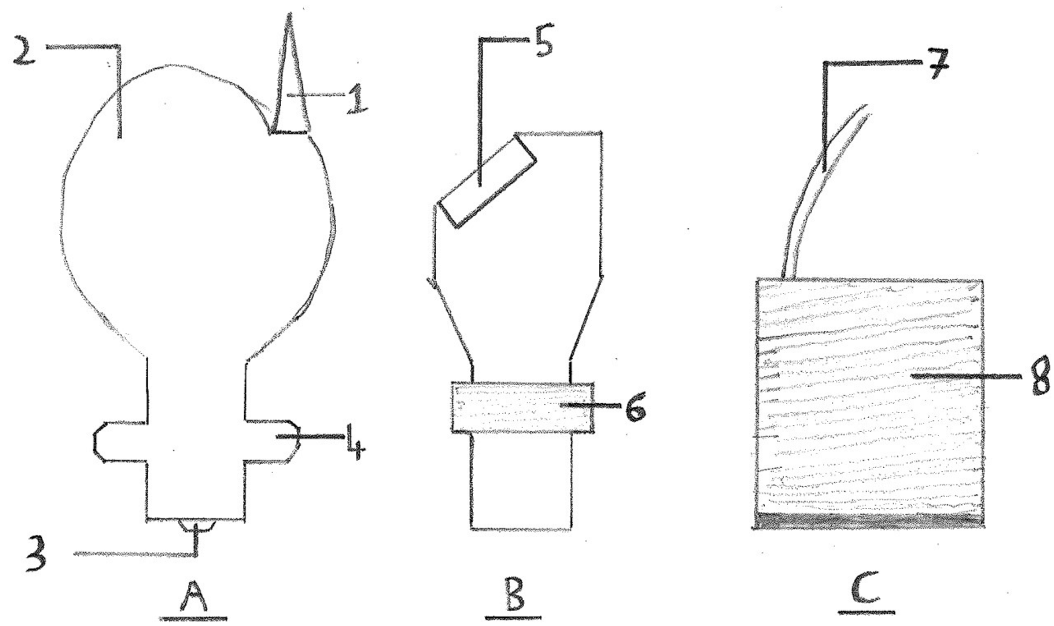


Figure 9: Different designs of water level measurement devices that utilize ultrasonic sensors

Design A uses wireless technology to transfer the data gathered from the ultrasonic module, which is mounted on the bottom (3). The wireless technology used is known as RF, or radio frequency. Using electromagnetic waves, the device can transmit data from an aerial (1) to another unit that will process it. This design will almost always operate at a broadcast frequency of 2.4 gigahertz (GHz). It is held in place by friction, inserted into a hole that is drilled into the tank, and a rounded, aesthetic plastic bulk protrudes from the top of the tank (2). Outreaching plastic "arms" help to hold the device in place in case of a widening of the hole due to erosion etc. This device is far more practical compared to the alternatives due to its wireless capabilities.

Design B, the most common of these designs, uses threading (6) to mount into a pre drilled hole in the water tank. The form of measurement reading is different to both other designs, as a screen mounted on top of the plastic shell (5) directly displays measurement information. I think this is a downside to this device as it still requires physical access to the water tank.

Design C is the most technologically simple of the designs, and is simply a threatened bulk that contains all of the electronics (8), with only a thickly coated cable protruding the top of the unit. As with all of these devices, Design C is screwed directly into the water tank. The cable leads to a control unit similar to that of Design A, but is wired and intended for use very close to the water tank, rendering it useless for most houses, such as my stakeholders, where water tanks are completely separate from housing.

Although the three designs vary significantly in real-world functionality, they share many similarities due to the superiority of ultrasonic technology over the simple actuator of the float switch and the glorified measuring tape of the probe. The main advantage is accuracy. Consumer grade ultrasonic sensors can be accurate within 5cm or less, far outperforming the other two methods in accuracy. Another advantage as no contact with the water is made in installation or even daily use, removing any thought of water contamination. There are several disadvantages to these devices, mainly revolving around cost and measurement displays. The need to drill a hole into the water tank in order to install these devices also poses a problem, as it is unsuitable for the physically disabled and the drilling of a water tank, especially one made of concrete, will probably release sediment and other contaminants into the water.

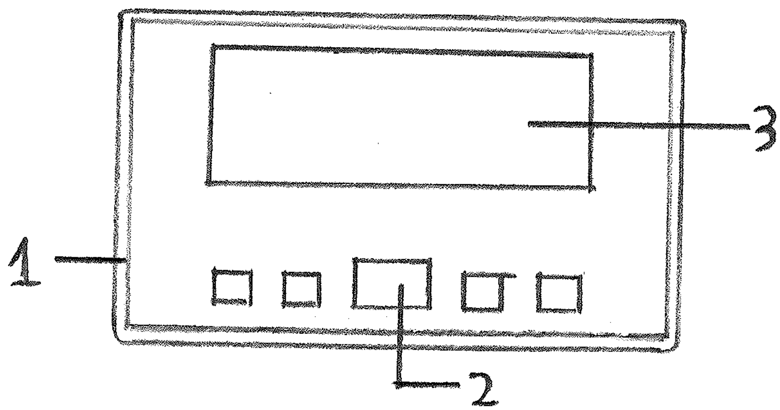


Figure 10: Example of a display unit used by an ultrasonic measurement system, such as Design A and Design C

As mentioned previously, an ultrasonic measurement system will likely have a dedicated system for displaying water level information. Figure 10 is an example of one of these units, which tend to be technologically basic, but aesthetically pleasing. This results in a theoretical reduction in maintenance and having an acceptable place in the user's house, such as in the kitchen. The example unit usually consists of glossy plastic (3) which is usually white. A metallic, or sometimes plastic, curved frame surrounds this (1). Buttons along the bottom (2) can be used to control basic functionality of the device. This functionality can include a clock, temperature gauge, connection to a weather forecast, and humidity gauge (as well as measuring the water level and displaying this to the user).

1.6 - Product Research Evaluation

From researching and analyzing the most popular existing solutions to water measurement, I have determined some attributes that I believe will be needed to create my own solution to the issue of water measurement.

Being able to connect to a device, such as a smart phone or laptop, that a user will likely already own, is another attribute that will important for my product. Existing solutions that offer remote detection of water, such as the ultrasonic level meter or modified probe level meters, require a separate device to be purchased and installed in the home. This increases cost and adds unnecessary environmental waste.

Building on this, another attribute that will be important when designing my product is the price, both of parts and production. The prices of the ultrasonic level detectors, for example, are borderline extortionate. I will take advantage of modern mass-production methods and the abundance of microcontroller manufacturers, particularly in Asia, to source components that offer a compromise between functionality, power efficiency, and cost.

Another attribute of my product I have found through research of existing solutions is that the material must be safe if it comes into contact with water. This means that it must be waterproof, and it must also be made of a material that is not too contaminating in case it falls into the water. An alternative to a waterproof material would be to ensure an incredibly strong mounting point to the tank, reducing the chance of it falling into the water, or making a warning system if the product is submerged or in contact with the water. This would mean that maintenance could take place before the water supply or tank is damaged.

The final attribute I have decided will be important to the viability of my product from my existing market research is the technology it uses. Float switches, for example, have failed to be updated to the digital age, and are still widely used for water tank detection despite their major downfalls. The technology that I will use for the sensing will be determined based on stakeholder consultation, but I will make sure that outdated devices will not be used when at all possible. To this end, a compromise must be made in the form of technological advancement, functionality and simplicity. While technological advancement to an archaic product can be incredibly innovative and beneficial, it can also decrease usability – the more complicated, the more likely it is to break.

1.7 - Design Brief

I have determined a need for a water level measurement system which can be used in a variety of environments, but the main target market is the rural living environment. The product will differentiate itself from existing solutions through a number of attributes:

- The product must be easy to use by someone of low to moderate technological background
- The product must be able to be integrated within the existing physical and technological environment of the stakeholder
- The product must have no physical contact with the water, and be water resistant
- The product must be affordable for a wide range of clients
- The product must use efficient, effective, and reliable technology to measure the water level
- The product must allow for a mostly non-physical water measurement experience

1.8 - Additional Stakeholders

The rest of my stakeholders have been chosen to help with the design and provide valuable input in the creation of the finished product. These stakeholders have been chosen as they each represent a potential target market: home use, business use and/or government use. Insight from industry professionals will be incredibly useful when making decisions that will directly affect its viability in that respective environment. I have also selected a few people who will assist in deciding on the various technologies that will be used in the device, for both hardware and software.

Bailey Tanks – A manufacturer and storefront of plastic water tanks based in New Zealand. Feedback from an experienced company specializing in water use for rural living (as well as farming and other business) will be invaluable in the creation of my water level measurement device. Phil, a customer service representative for the company I reached out to, will be able to give me a business's opinion on decisions I will need to make in the design and production of my product, thus further preparing it for market.

Gallagher Group Limited – A manufacturer, distributer, supplier and storefront of all manner of commercial and domestic products including water measurement technology. Mark from Gallagher has already given me a number of insights into the irrigation business. Feedback from this stakeholder will help shape the product into something that can be used for a wide range of use cases, especially farming – the companies main target market.

Watercare Auckland – The council-owned distributor and infrastructure supporter of Aucklands water services. I have made contact, through the Auckland Council website, to Sally, the education co-ordinator for Watercare. Her feedback will give me a unique governmental perspective, combined with one accustomed to large-scale operations, to key decisions.

Paul Kolston (Hardware Advisor**) –** Dr. Paul Kolstons extensive background in electrical engineering will offer valuable expertise in the design and construction my product, helping me choose the components to best meet any stakeholders requirements. His knowledge of analogue electronics, combined with my own of digital, will offer a unique set of skills that will help make my solution to water measurement reliable and technologically superior to alternative devices.

1.9 - Target Market/Potential Customers

Before delving in to the design, development and manufacture of my product, I must look at who, other than my personal stakeholder(s), could make use of it. According to Statistics NZ, the 2013 census showed that only 16% of 20 to 29 year olds owned a home, whereas 78% of 60+ year olds owned a home. This is a common phenomenon, easily explained by increased wealth with age. It does show that in order for a marketable, mass-adopted product to exist in the context of rural living environment, it must be usable by an older generation of people.

Paul, my hardware advisor, tells me that "*It can be fairly difficult to give electronics for older people to use as it can be an extremely foreign concept to them. I'd say it's fair to say that if a 70 year old wanted a device to 'optimize water usage' as you suggest, they would probably get a workman to install it*".

I wanted a business's perspective on the older generation purchasing such electronic devices rather than relying on just Pauls, so I contacted Mark from Gallagher Systems informing him of my hardware advisors opinion. He said "*Yea, that's about right. We would normally suggest an electrical contractor if the client is physically incapable or so on. You need to remember that installing it can be done by someone with more experience, but they will still need to operate the thing. Keep this in mind*".

This stakeholder consultation has taught me that I can aim for a wider demographic than I originally thought, but will have to take the usability into deep consideration, especially for older users who are not accustomed to technology. The installation can always be done by a third party if needed, but the day-to-day use of technology should be done without any outside help, as my contact from Gallagher told me. From this research and feedback from some stakeholders, I have chosen to target the wide age range of 20 to 80, as they all have the possibility of being homeowners, no matter how likely, and will all benefit from optimizing water usage.

1.10 - Stakeholder Consultation

Mr Gardiner

I have had another consultation with my main client, Mr Gardiner, which was informative and insightful. I asked him a series of more in-depth questions regarding issues with current water measurement solutions, and personally important factors in water measurement.

My client believes that the most important factor in measuring water, for himself personally, is the lack of physical strain – an attribute I have already included in my first design brief, inspired by research. He also would like the system to not only give a reading of how much water remains in the tank, but for it to calculate his average consumption of water on a daily basis, therefore allowing the system to predict how long the water in the tank will last the client. This is an innovative attribute that should be easily implemented in my final product.

Mr. Gardiner has expressed his main concern with existing solutions for water measurement: none of them can connect with his computer. As I have discovered in my research, none of the existing solutions work with the existing technological environment of the client, and a separate device has to be installed to check water level measurements. My client has informed me that this attribute is of utmost importance to him, as he considers it a wasteful inconvenience to have a separate device to read water level.

Another attribute important to my client is that the product must be versatile. He believes that the product must "not be restricted to water", meaning that the measurement aspect of the device should be able to be utilized by a number of contexts. This means that the technology used to measure the water level should be proficient at also measuring solids and other liquids (Mr Gardiner used stock feeding systems in farms as an example).

Finally, upon my mentioning of environmental sustainability, Mr Gardiner made the point that even if the rural resident or other client does not care about the environmental impact of their consumption of water, almost everyone will care about its personal economic impact. This means that I will always make saving water a priority of this device as it has both economic (saving the client from having to buy extra water from a town supplier) and environmental (reducing overall water consumption) repercussions.

Paul Kolston

I have also had a consultation with my hardware advisor, Paul Kolston. Paul agreed that all of the attributes that Mr. Gardiner had requested in his consultation were easily attainable.

Paul made only one suggestion, an attribute. He expressed his opinion that the product should be produced using off-the-shelf components, further increasing the versatility and recyclability of the product. He believes that if the product uses components, such as a microcontroller, switch, diode etc. that can be repurposed once the product has reached the end of its life cycle, the environmental cost would be significantly lower. This is an innovative attribute that I will definitely consider adding to my design brief. The main drawback for this attribute is that electrical components will likely cost far more, thus increasing the purchasing cost of the client.

1.11 - Environmental Considerations

The Auckland Council states that in New Zealand, a water supply system that uses rainwater for potable uses (safe to drink) must be:

- *Protected from contamination*
- *Installed in a manner that will avoid the likelihood of contamination within the water*
- *Installed using components that will not contaminate the water*

All of these attributes were already considered in my original design brief for the water measurement system itself, so will incur to changes to the next iteration of said brief.

According to the Electricity (Safety) Regulations Act of 2010, the installation of my product will fall under *high-risk prescribed electrical work* as it involves the installation of an electrical product near water and/or at elevation, classifying a water tank/system as a hazardous location. This simply means that the installer must ensure that the resulting system is electrically safe and/or does not compromise the electrical safety of existing systems. I will add the attribute to my design brief that the measurement system must be self-contained, meaning that the user will not have direct access to the electronics inside without intention. This would reduce the chance of electrical damage to the user and the product itself. The self-contained nature of the product will also minimize liability for electrical system damage of the manufacturer/distributer of the system.

The Ministry for the Environment states that water takes of 5 litres per second need to be measured and reported. Theoretically, this is only of concern to the client and not myself nor my product, but either way, a rural resident is highly unlikely to be consuming water as this level, so I will not consider excessive water consumption as a factor in my design.

In the context of local society, the product must not be obtrusive to anyone, including that of the client. The device must be small, relative to the water tank, and not protrude an excessive amount from the tank itself.

1.12 - Design Brief Additions

I have chosen to make some additions to my original design brief, mainly revolving around legislative requirements of the product (see section 1.11):

- The product must be self-contained, and require at least low technological intelligence to open and modify
- The product must be versatile to the extent of multiple use cases
- The products electrical system must consist of "off-the-shelf" components. In this context, an "off-the-shelf" component is an electrical component which can be purchased by any person in at least an individual quantity
- The product must have the ability to predict how long remaining water levels will last the client
- The product must not be obtrusive to the client, or other people in the vicinity of the client
- The product must be relatively small

Improving Attributes

I will now conduct research into the design brief which I have built on before this point in the document in order to make it a proper brief to present to my stakeholders. This brief will in no means be binding and final, as I will likely make a variety of additions during the development of my product (with stakeholder approval, of course). I will be converting some attributes of the design brief into specifications - mostly numerical values that will represent the attribute. For example, an attribute may be: *The product must have a long battery life*. A corresponding specification could be: *The product must retain full functionality for 5 hours on battery power.*

The product must be affordable for a wide range of clients. This attribute must take into account what is deemed “affordable” for such a product to a wide range of potential customers. The median income in NZ, as of 2017, is $48,000 annually. This equates to $923 (3 sf) of weekly income. A tax rate of 15.5% applies to this level of income, resulting in a net profit of $780. $392 of this is spent on housing, with a further $100 on food and $55 on utilities. After all of these deductions, $233 is left. A flaw that I found in my research of the existing solutions to my issue was the price, such as the ultrasonic monitor which cost upwards of $200 and the level meter that cost around $75. Since the average median earner in New Zealand has $233 of spending money each week, albeit before unexpected costs, I will have no issue in determining a price when it comes to what my client can most likely afford. My main factor will be beating the ludicrous prices of the competitors. For this reason, I will set my expected cost of the final product for purchasing to be no more than $75. This is highly subject to change, just as all of the specifications/attributes are, as I may decide on adding features later in the design process that will result in a far higher product value, or vice versa.

The products electrical system must consist of “off-the-shelf” components. This attribute, suggested by hardware advisor Paul, attempts to increase the versatility and recyclability of the product. I have the choice of sourcing the electrical hardware from a New Zealand storefront, such as Jaycar, or an online retailer/wholesaler, such as Aliexpress. The main advantage to purchasing from a domestic retailer is supporting the local economy. The main disadvantage is the cost. Take the 555 timer, the undisputed most popular integrated circuit ever produced. As of 16/03/18, at Jaycar electronics, it costs $2.70, or $1.85 if I purchased 25+ (see: figure 7). On Aliexpress, the 555 costs $0.80 for 20, or an equivalent of $0.04 each (see: figure 8). This price difference is extremely significant.

Figure 7: 555 on Jaycar website

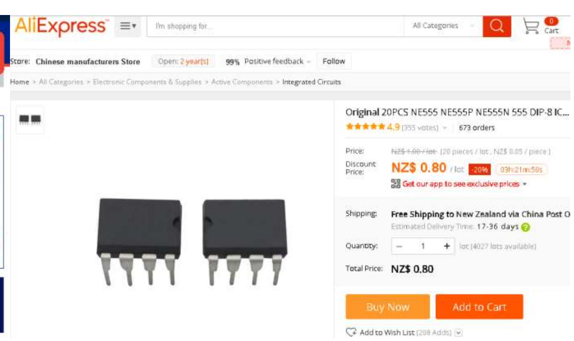


Figure 8: 555 on Aliexpress website

A disadvantage that buying electrical components off of Chinese suppliers such as Aliexpress is the shipping time, often taking up to 4 weeks to arrive. This will make prototyping more time consuming. To decide which type of component supplier to use, I have consulted some of my stakeholders, who say:

Gallaher tanks: "*We use Chinese parts for most of our products because it's way, way, cheaper for us and the customer. Most non-electrical components we buy like plastic or steel are normally sourced from America* [USA] *or here in NZ".*

Mr Gardiner: "*I buy all of my electronics from Aliexpress and Banggood".* [when asked about ethical sourcing of products]: *"I suppose I care as much as the next person about slave labour and such in electronics production, but buying stuff locally is far too expensive to even consider, so I would still buy from China i'm afraid*".

Paul Kolston: *"I haven't purchased significant amounts of electrical components for years, but when I did, they were mostly from Australia. However, I am well aware of the massive industrialization of China and how electrical engineering is essentially dying in other countries because of it, so I would highly recommend purchasing components from them, especially considering how your example shows how much cheaper it is. You might want to consider shipping times, at least in the development of your prototype".* This shipping time comment was interesting and is something that I will definitely take into account.

Figure 9: Photograph showing the space between the maximum water level and open space inside of the water tank of the client

The product must be relatively small. This attribute is especially vague, as size is a relative measurement in the domestic/rural living context. Both interior and exterior measurements are important, as the product must fit in the water tank enough to meet its purpose, as well as fit in aesthetically and physically with the surrounding natural environment of the client. The exterior size of my client's water tank is essentially a cylinder with a radius of 1680mm and a height of 2700mm. The hatch opening periphery is 427x470mm. As figure 9 shows, the amount of space above the maximum water level is minimal, with around 250mm in height. Combined with a smaller size having the effect of increasing versatility of the product, an important attribute, I would like to see the part of the product that is potentially located in the inside of the water tank no larger than 180x180x180mm. This will, of course, be somewhat variable based on different conceptual design ideas that I will create and confer with my client about. Mr Gardiner has given some feedback on this specification, saying: "*That seems fine, so long as installation is easy and it doesn't get submerged by water all the time*".

The product must be able to be integrated within the existing physical and technological environment of the stakeholder. I will not be making this attribute a specification per say, as it has far too broad a definition. Instead I will make the attribute more specific as I believe it is far too vague for me to adhere to and for my stakeholders to give feedback on:

- The *physical environment*, in the context of my client, is the water tank of the rural living environment. If the product is to be integrated into the physical environment, the product must be mounted effectively to the water tank and not impede the functionality of the water tank. Since the product will already be attributed to not make physical contact with the water, impedance of the water tank functionality is unlikely. For this reason, I will stress importance on the mounting of the product. The mounting must not increase the size of the product significantly, must hold the system in place, and be constructed out of cheap and recyclable material – by main client's request. These attributes will be implemented into the final design brief of the product.
- The *technological environment*, in the context of my client, consists of the various technological devices that my client obtains, as well as the network and related infrastructure that contributes to their functionality. Mr Gardiner tells me that his technological environment is far more complex than what the vast majority of people will be used to due to his home automation system. This system centres around several Arduino-based microcontrollers and Raspberry Pi single-board computers and allows him to monitor and control various electrical systems at his house, such as lights and internet connectivity. I have decided to not dedicate too much time in to implementing my device in to Mr Gardiner's system for a few reasons – firstly, the overall target market of the water level measurement system will be unlikely to have such a complicated system, thus making functionality for connection with such a home automation system being a fruitless endeavour and likely adding no benefit to the average potential customer. Secondly, Mr. Gardiner has informed me that given his past experience with electronics and with setting up his automation system, it will be easy for him to integrate my device into his technological environment, so I need not consider doing it for him. Given this, I will assume that the *technological environment* of the client will consist of a router and modem connecting them to the internet and that they will subsequently have devices capable of connecting to the internet, such as a laptop, desktop and/or smartphone.

1.13 - Final Design Brief

The final goal of the product is too save water through accurate, effective, and easy water measurement. The product will be a water measurement system that is mounted on a rural resident's consumable water tank before filtration. The product must allow for a mostly non-physical water measurement experience. Rural living is the main context that the product will be designed around, but an attribute that is of utmost importance in the design and creation of the water measurement system is versatility, so the final product should be able to be utilized in a plethora of technological/social environments. The water measurement system must contain the following attributes:

- The product must be self-contained, and require at least low technological intelligence to open and modify. This will mean that the product will be encapsulated by a water-safe material that can be opened using screws and/or bolts. It will also mean that the product will have no excessively extrusive components, and make no physical contact with the water. This attribute will increase the durability and recyclability of the product as a whole. The part of the product that is potentially inside of the water tank will not exceed the size of 180x180x180mm.

- The product must be versatile to the extent of multiple use cases, meaning that the end product will measure distance in a way that can be repurposed, e.g. detecting whether a door is open or closed through the detection of a door. This attribute will mean that the cost, an important factor for the main stakeholder, will essentially be reduced as the possible use cases of the product will be far more varied, thus making it able to be reused when a water level meter is no longer needed, for example.
- The products electrical and physical systems must consist of "off-the-shelf" components. In this context, an "off-the-shelf" component is an electrical/material component which can be purchased by any person in at least an individual quantity. These components will be sourced from Chinese retailers. This attribute is another dedicated to both reducing the up-front cost of the device as well as increasing the recyclability/reparability. Off-the-shelf components mean that if the product reaches the end of its life cycle, the microcontrollers and other electrical components will be able to be repurposed.
- The product must have the ability to predict how long the remaining water will last the client. This is of utmost importance to the main stakeholder, and is something that other stakeholders have informed me is missing from the vast majority of existing solutions to water level measurement.
- The product must not be overly large and/or obtrusive to the client, or other people in the vicinity of the client. This is a social consideration for the client (as well as for the wider potential target market) so that the product will not be an eyesore for neighbours. It will also greatly reduce any logistical exercise required during installation. Because of this, the product must be able to be integrated within the existing physical and technological environment of the client.
- The product must be easy to use by someone of low to moderate technological background. When I state "low to moderate", I refer to a user who can use a smartphone/laptop computer with competence. This attribute will mean that the potential client base for the product will be greatly increased. This is of little importance to my main stakeholder, who is well-versed in technology, but existing manufacturers/salespeople of water level measurement devices say that user-friendly systems are far more effective on the marketplace.
- The product must cost no more than $75, another attribute designed to increase the potential target market of the product, allowing people from a range of economic backgrounds to take advantage of the potential innovation of this product.
- The product must use efficient, effective, and reliable technology to measure the water level, further ensuring that the finished product will be fit for its main intended purpose.

At every key decision in the design and manufacturing of the product, stakeholders must be consulted to ensure that the product is fit for purpose. The main stakeholder's opinion and input, Mr Gardiner, is of utmost importance, and will be consulted for less crucial decisions if need be.

Product Design

2.0 - Introduction

Now that I am fully accustomed to my stakeholder's requirements, I will begin on formulating possible design ideas for the water level measurement product. Firstly, I will use Sketchup, a free computer-aided design software, to model the client's water tank. This will be used to test potential designs against the real-world physical context, allowing stakeholders to make more informed decisions on the viability of a potential design.

2.1 - Environment Modelling

I began this process by measuring every relevant dimension of the water tank itself, followed by the lid. The lid was difficult as it consists of two different dimensions – the top section is wider than the bottom section so that the lid does not fall into the tank, held in place by the inside of the tank angling inwards.

Figure 9: Photograph of a measurement being taken of the size of the lid of the client's water tank

Figure 10: Photograph of the underside of the water tank lid, showing how insects are living on it

The act of measuring the water tank, an example of which is shown on Figure 9, posed no difficulty, although I did note how uncomfortable it was to lift the lid off of the tank to access it as it is very heavy and held in place somewhat precariously. I also noted that several groups of insects, the most predominant of which were woodlouses (commonly known as slaters), living on the underside of the tank lid. This may pose problems and will be something I will consider when formulating design ideas.

I then used the measurements to mock up the water tank and lid in Sketchup, as shown in Figures 11, 12, 13 and 14.

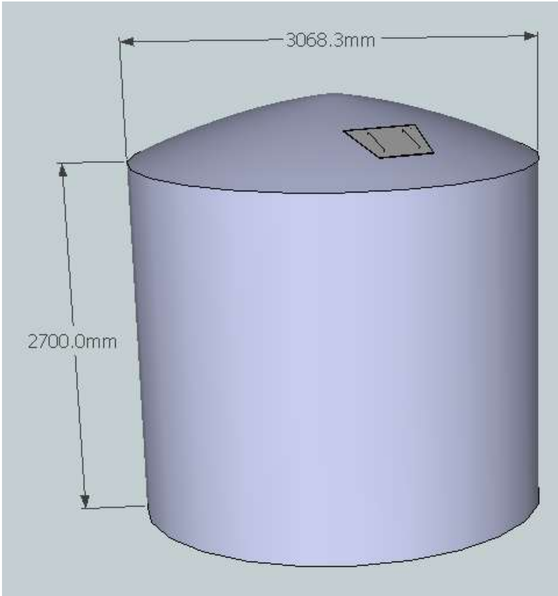


Figure 11 (above-left): Side view of my 3D model of the client's water tank

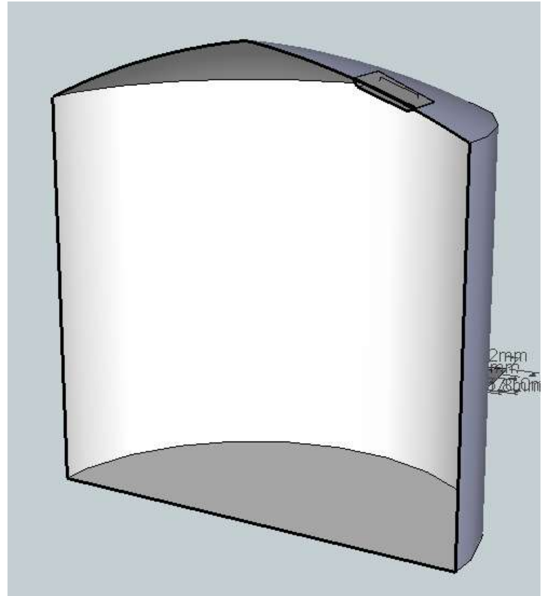


Figure 12 (above-right): Interior view of my 3D model of the client's water tank

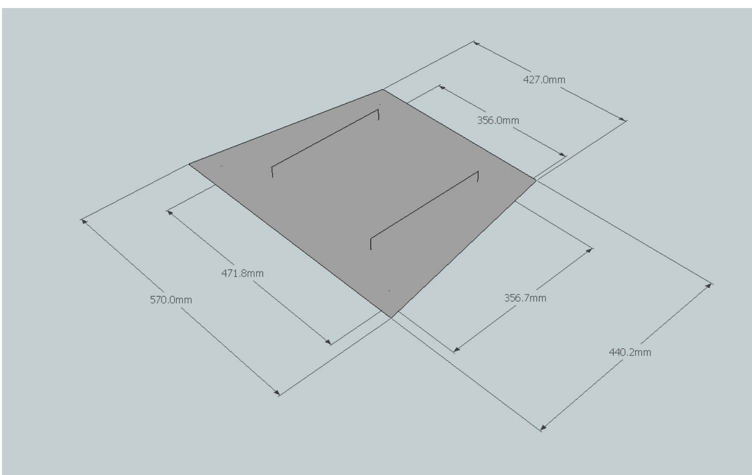
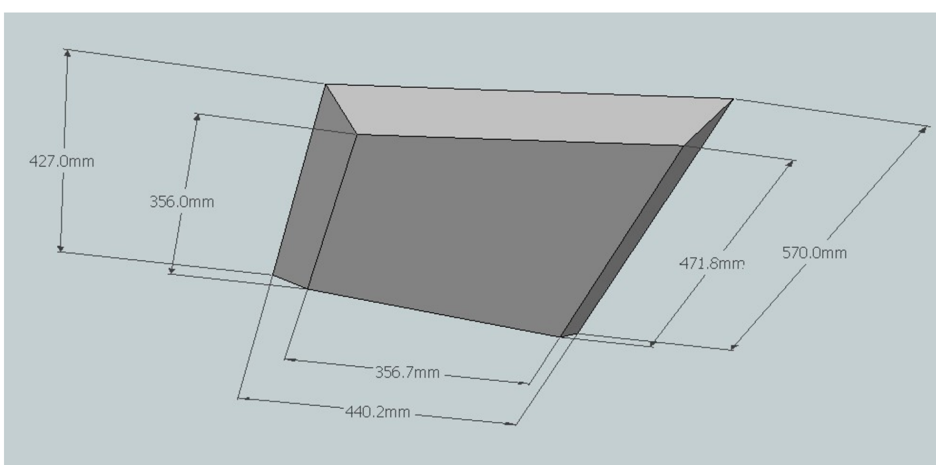


Figure 13 (left): Top view of my 3D model of the client's water tank lid

Figure 14 (right): Bottom view of my 3D model of the client's water tank lid



2.2 - Design Ideas

I must specify that in all of these design ideas I have ignored the electrical components to a certain extent, focusing on the physical, material device so that I can pick the electronics based on the amount of space that I will be able to work with. A stakeholder, Paul Kolston, recommended this way of designing to me, despite my initial apprehension. I figured that the device should be built around the constraints imposed by the size and various technological requirements that the electronics may impose, to which Paul stated: "*I can guarantee to you that the electronic components will not restrict your design. Assuming that it* [the water level measurement device] *roughly will be comprised of a microcontroller or two, battery, measurement sensor, transmission device and maybe a few other diodes etc., they will be so insignificant in size constraints that it would be far more beneficial to your design process to design the actual physical unit itself rather than the electronics.*"

While I took on this suggestion wholeheartedly, Mr Gardiner promptly suggested that I should at least determine the measurement technology that I will be using in the device, since it may "*greatly impact the size and form factor of the device*". My contact from Gallagher systems agreed, and I set up a consultation with him to give me input on the technology that I can potentially use.

"*The main technology we use in our systems are barometric sensors. They are pretty expensive, but also very accurate for sealed, industrial water systems. Other potential non-contact system I can think of is ultrasonic. Actually, using infrared light might work as well, although I have not done research into it*".

Barometers: Barometric sensors measure atmospheric pressure. They are commonly used in meteorology to predict changes in weather. In the context of water tanks, the level could be measured using barometers as when more water has filled the tank, the higher the air pressure inside of the tank would be. Unfortunately, as discovered in my water tank research, the vast majority of domestic, residential water tanks contain non-sealed overflow pipes at the maximum water level so that if too much water fills the tank it will automatically empty. This is determinately to the usefulness of atmospheric pressure sensors as the air pressure inside of the tank would be fairly regulated due to this opening, greatly reducing the reliability of any measurement. Another issue with barometers for my device is that obtaining semiconductor-level barometers is relatively expensive and difficult to implement into electrical systems. Figure 15 is an example of a surface mounted diode that measures atmospheric pressure.

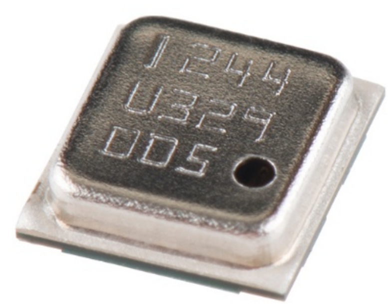


Figure 15: Example of an SMD barometric pressure sensor. Source: Sparkfun Electronics

Ultrasonic: Ultrasonic transceivers emit and receive ultrasound signals. Ultrasound is sound frequencies that are too high to be heard by human ears. Ultrasonic sensors can detect most materials and thus are useful for a plethora of contexts. In the context of water tanks, the ultrasonic sensor, mounted on the top of the tank, could emit an ultrasonic frequency which would bounce off of the surface of the water and be received by the same sensor. The amount

Figure 16: Example of an HC-SR04 ultrasonic sensor. Source: Sparkfun Electronics

of time that the frequency takes to return to the sensor can be divided by the speed of sound (~340m/s based on temperature and humidity) to calculate the distance that the frequency travelled and thus the distance between the top of the tank and the top of the water level. This would make water level measurement simple. Ultrasonic sensors, such as the example of Figure 16, are easy to obtain and implement into electrical systems, a main advantage of barometric sensors.

Infrared: To fully understand infrared technology, I have contacted a stakeholder, Paul Kolston, who has studied physics for decades: "*Ultrasound propagates via the compression and rarefaction of the particles of the medium through which it is moving, and the speed of propagation is determined by the stiffness and mass of this medium. These properties are very different for air and water, and so there is a large impedance discontinuity at a water surface. This results in a large proportion of ultrasound incident perpendicular on a water surface being reflected directly back. In contrast, electromagnetic radiation such as infrared and visible light does not rely on a medium to propagate (e.g., it can also pass through a vacuum), and so is much less affected by the material properties of the medium. For example, if you look directly down onto the surface of calm water, you can see straight through it, indicating that only a small proportion of the light is being reflected back*."

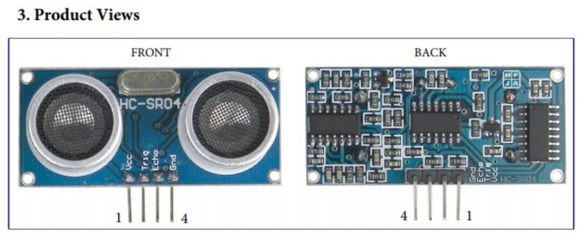
In short, this means that it is physically impossible, or at least extremely difficult, to use infrared technology (or any other technology that relies on electromagnetic radiation) to measure water level, making it unsuitable for my context.

<u>Conclusion</u>

The three suggestions of technology given by Gallagher systems sparked some informative research into the possible technology to use in my device. Infrared is not really a usable option, leaving barometric and ultrasonic sensors. Barometric sensors are arguably the most accurate of solutions, but only in a perfectly sealed environment. Since the water tank used by my client, and the "*majority of people in a 'rural living environment'*"(Watercare contact), are not hermetically sealed, the barometric sensor will be far less reliable than the ultrasonic sensor. Combined with the higher ease of use, I have decided to choose the ultrasonic sensor as the technology for my water level measurement device. This will align with the non-contact and low price design brief attributes.

I have also decided on the exact electrical component that will act as the ultrasonic transceiver for the measurement device, the same one shown on Figure 16. The HC-SR04 is by far the most popular ultrasonic sensor, making it cheap (around $3) and giving it lots of online support which may be vital in the development of my product. Figure 17 (next page) shows a datasheet/diagram of the device. The two cylindrical, mesh covered objects are transceivers. The HC-SR04 will output differing levels of voltage based on the distance, or time, that it measures.

Figure 17 (right): Diagram of HC-SR04 ultrasonic sensor. Source: MJP



4. Module Pin Asignments

	Pin Symbol	Pin Function Description
1	VCC	5V power supply
2	Trig	Trigger Input pin
3	Echo	Receiver Output pin
4	GND	Power ground

Design 1

The first design utilizes the small gap between the lid and the interior of the tank for mounting, allowing for an extremely simple and unobtrusive installation process. This is extremely important to my client as previously discovered, and so I have made it a vital part of the designing process. Figure 9 is a drawing I made of the various components and functionality of this potential design, showing the main electrical containment unit (2), the support arm that will be placed in the aforementioned gap (1), the base that will sit on the top of the unit (3), and the transmission aerial for broadcasting measurement information to the user (4).

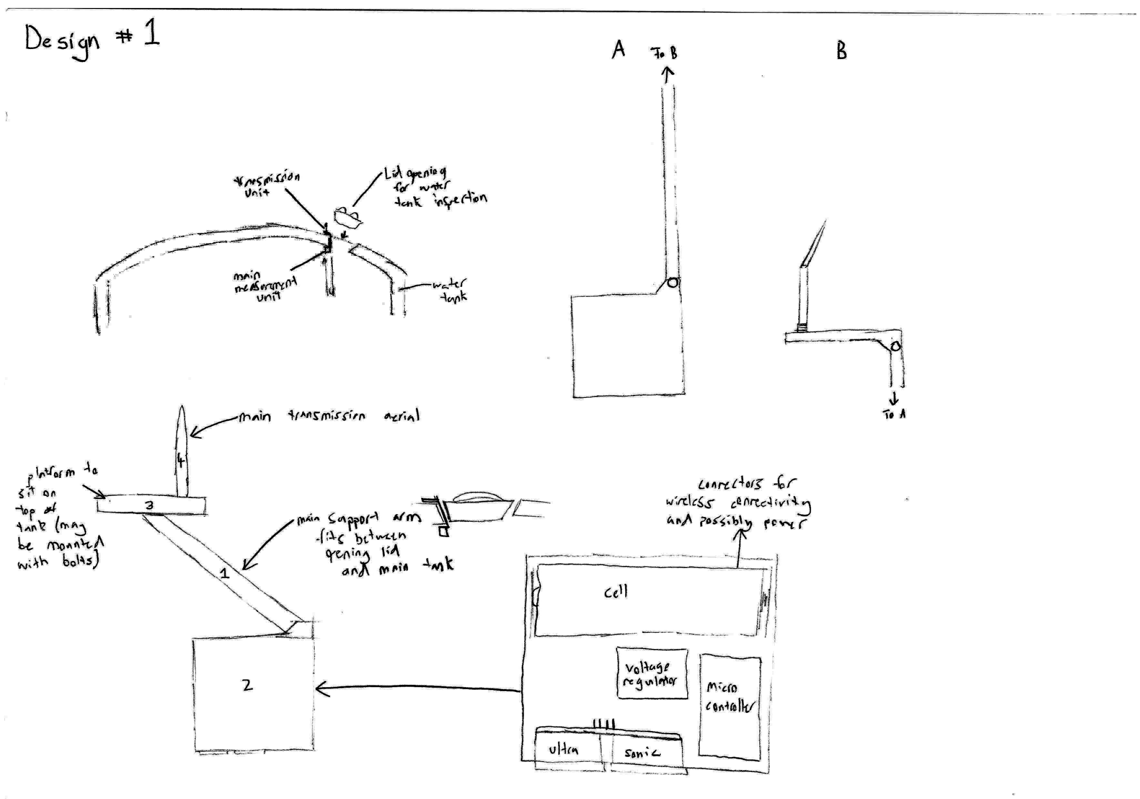
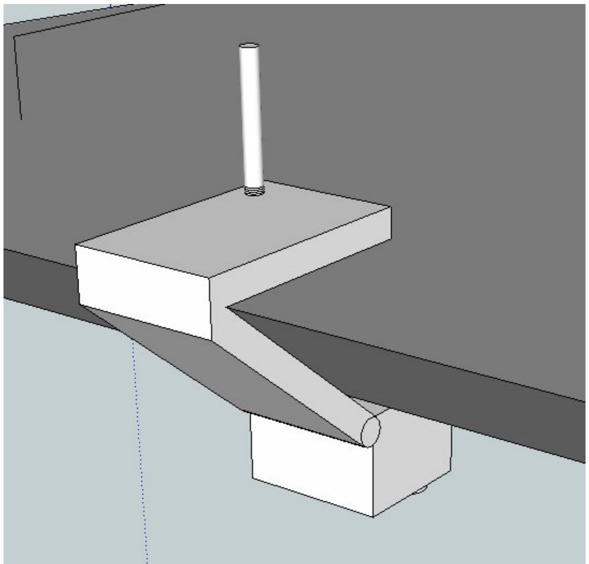


Figure 18: Drawing of conceptual design 1



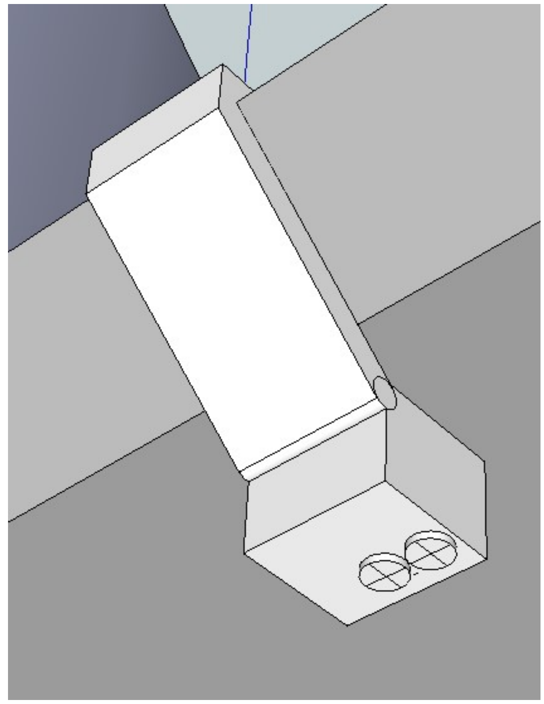


Figure 19 (above-left): Top view of 3D model of design 1

Figure 20 (above-right): Underside view of 3D model of design 1

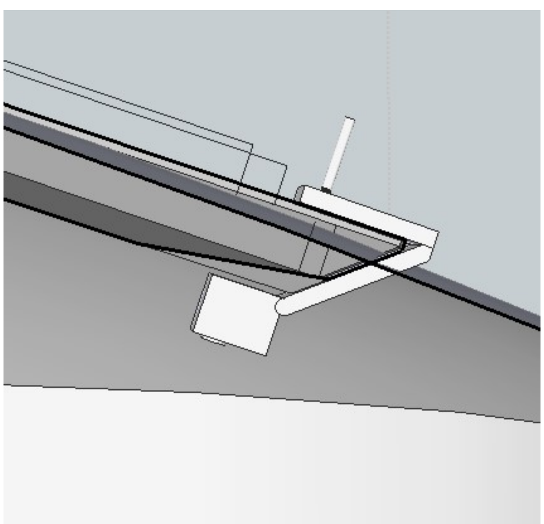


Figure 21 (middle-left): Side view of 3D model of design 1 placed in context, mounted between the lid and top of the water tank

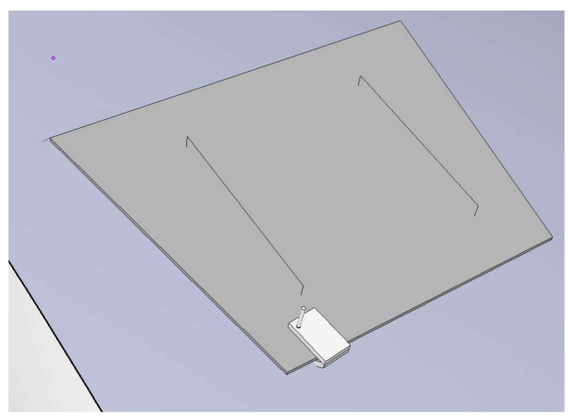


Figure 22 (middle-right): Top exterior view of 3D model of design 1placed in same context of Figure 21

The support arm (1) will contain wires that connect the microcontroller or other transmitter to the aerial so that transmissions of water level data can be transmitted effectively. Both units that make up this design – the measurement unit (A) and the transmission unit (B) – will be hinged to account for the interior and exterior curvature of the top of the water tank. This is outlined more in Figures 19 through 23 below. The physical component of installation would be relatively simple – the lid of the water tank would be removed, the device would be placed on the outside gap between the lid and the tank and (once the electronic components and transmission unit have been angled to account for the tank curvature) the lid would be placed on top, holding the unit in place. The thickness of the support arm (1) could be fairly variable as it is not going to be holding up much weight. If desired, the transmission unit (B) could be mounted using bolts for added security, but I do not believe that this will be necessary due to the great friction of the heavy concrete lid and the tank.

Stakeholder Feedback
Mr. Gardiner*: The design looks like it might form a pivot point and the lid will see-saw across it. I'd also be concerned installing it and if the lid ever needs to be removed in the future because it seems likely to fall in. I'm also concerned that over time the hinged part at the bottom will gradually sag and move away from its calibrated angle – it would be difficult to know if this has happened without looking in until it's too late and the tank is dry. Also you would need a separate design for a plastic tank because of their screw lids.*

Paul Kolston: "*Cool idea, but the arm thickness [of Design 1] looks far too high to keep the lid in a secure position. The higher gap might lead to weathering inside of the tank which is not ideal at all.*"

Bailey Tanks: "[Design 1 is] *an interesting design that seems like it would be easy to install and maintain. It may be perfect for your stakeholder, but what about people that have a different type of water tank? Most plastic water tanks use screw top tanks that are pretty much completely airtight so your device will not be able to be mounted at all with these tanks – this will greatly decrease your potential customer base*".

Gallagher Group: "*This design* [1] *is not particularly viable as the space from the lid and the tank will be susceptible to contamination. The ease of installation is obvious but does not make up for this fact. I also think you should make the top of the unit removable for easy access to the electronics for maintenance etc."*

Watercare Auckland: "[Design 1] *looks good for your client Sam! I think that the gap that will be created between the lid and the tank will be too large leading to contamination of the water supply, something you may want to consider. The ability to angle the unit is a good idea, just make sure that the hinge is stiff enough so that it does not move around after it has been set up. It also seems like this design would only work with that one type of water tank, so would probably not be ideal for any large-scale operation"*.

Design 1 Conclusion
The feedback to this design was invaluable, pointing out some extremely concerning weaknesses in the concept – specifically the lack of variability in terms of water tank type as well as the risk of water contamination. I did some research which reinforced the opinions of the stakeholders, uncovering how most plastic water tanks do in fact use an airtight screw-type lid with no space for even the transmission wire of design 1. This means that while the design may be ideal for the client, it will not be applicable to a wider population which is in direct conflict with my original design brief. For this reason, I will not be using this design unless significant changes are made, as the mounting solution is not viable for a wide target market which I need to consider as well as my stakeholders requirements. I have already mentioned the prevalence of organisms on the underside of the lid of the water tank (photographed in Figure 10), and the increasing of the size of the lid gap (as my contact from

Gallagher Group outlined to me) will likely lead to an increasing change of water contamination which is of utmost concern.

Design 2

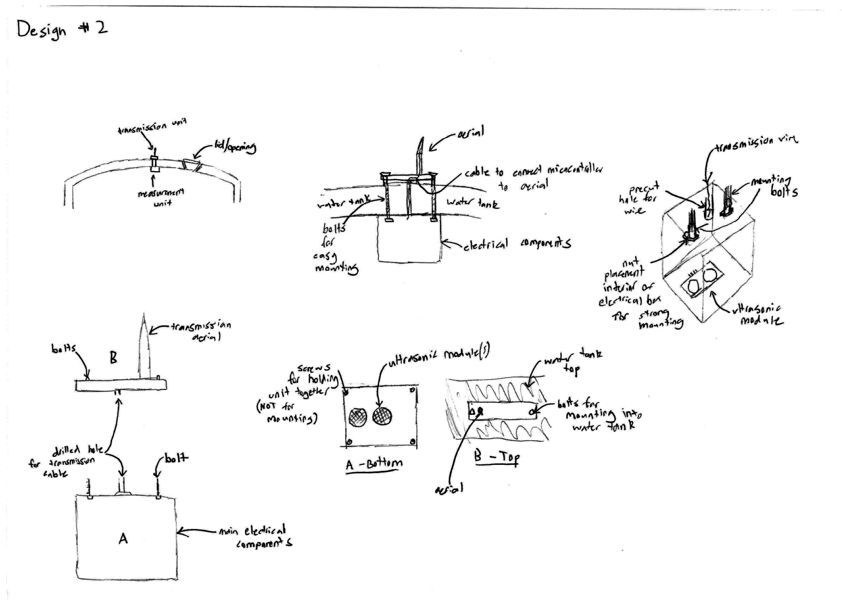


Figure 23: Diagram of my second potential design

The second conceptual design makes no use of the lid opening, thus removing potential issues outlined by stakeholders - contamination and lack of versatility. Again, the device is comprised of two units: (referencing Figure 23) the measurement unit (A) and the transmission unit (B). Much like design 1, the transmission unit sits on top of the exterior of the water tank, while the measurement unit is placed inside of the water tank, above the water level. Mounting is the main difference between these two conceptual designs, with Design 2 connecting the two units with bolts running through the shell of the water tank. With the removal of reliance on the water tank lid on mounting now placed simply on the shell of the tank the type of water tank is now essentially irrelevant, making the product far more versatile, aligning with the design brief. During installation, three holes will be drilled in the tank where the device will be placed. Two of the holes are for bolts for mounting and the other is for a wire that will connect the microcontroller to the transmission aerial.

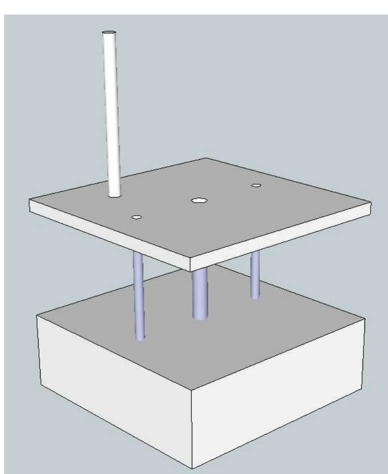
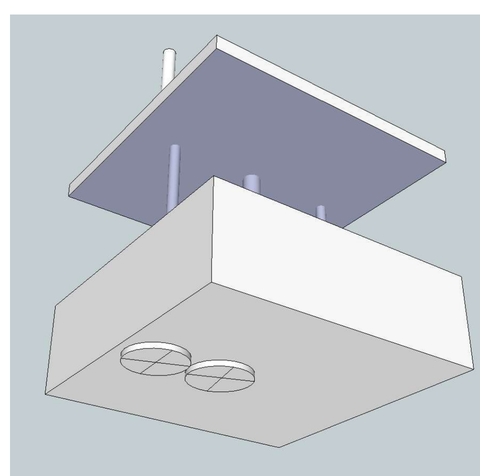


Figure 24 (left): Top view of 3D model of Design 2

Figure 25 (right): Bottom view of 3D model of design 2



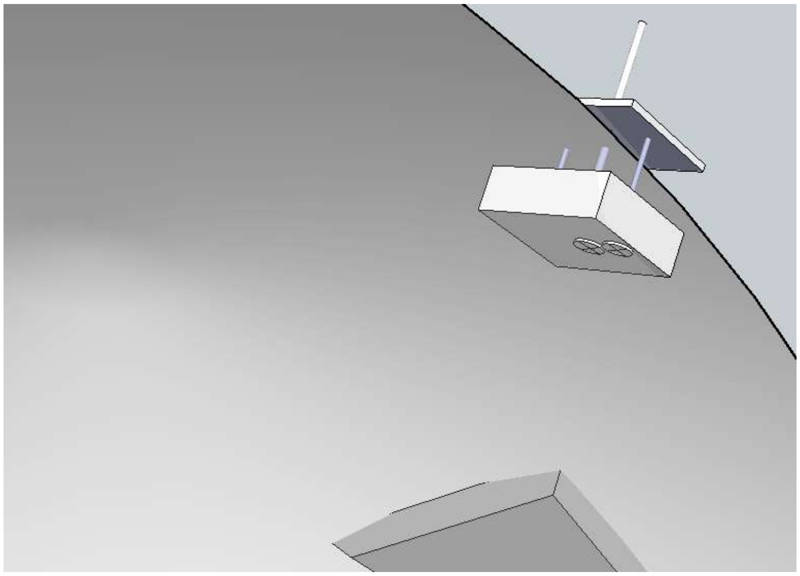


Figure 26: Side view of 3D model of Design 2 placed in context, mounted inside of the water tank

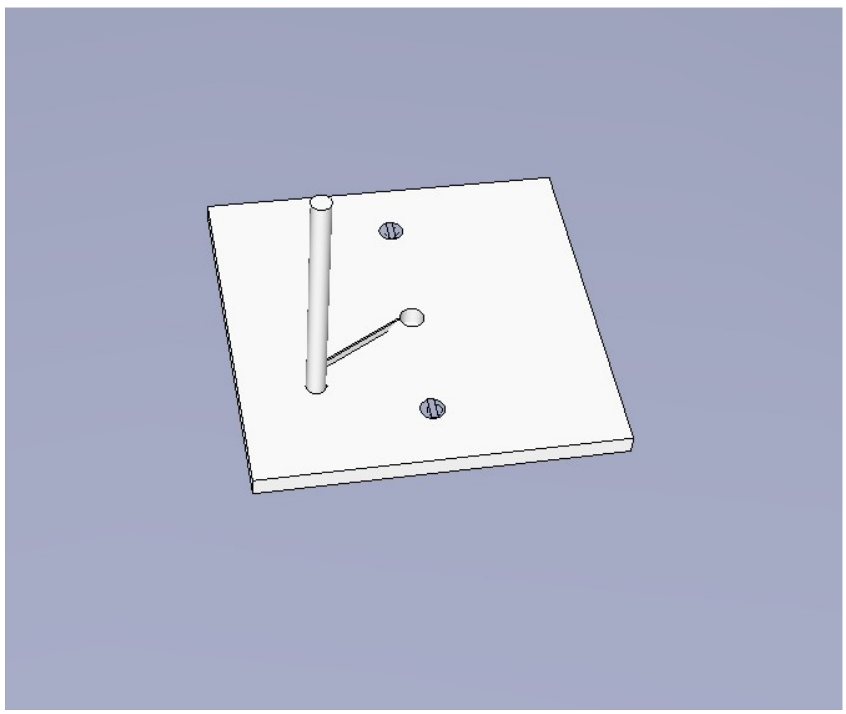


Figure 27: Top view of 3D model of Design 2 placed in context, mounted on top of the water tank

The main, overwhelming issue with this design as it would be far more difficult to install no matter what type of water tank will be used. If the device was installed near the water tank lid you could avoid physically getting inside of the water tank during installation, but it would still likely require two people. Drilling into the shell of the water tank is also something that would be preferable to avoid. I will have to see whether my stakeholders believe that it is worth these sacrifices in order to make the product more applicable to a wider target client base. Another, although minute, advantage to this device is that the user could remove the water tank lid for maintenance etc. Without removing the water level measurement device itself as Design 2 will be independent from the lid.

Stakeholder Feedback

Mr. Gardiner: *Drilling all the way through seems extreme for such a light device. If this not in the lid, then installation will leave concrete/concrete dust in the tank? It would also be difficult to reach if not in the lid (and thus any maintenance or battery replacement would be more difficult). It could be done in the lid when the lid is removed, but only one hole needs to go all the way through – the other 2 could just be with small masonry anchors or concrete screws? Unless of course it's a plastic lid, in which case you would almost certainly need to bolt it. Having the hole through the tank/lid, even if it's siliconed, would likely lead to water running down the wire of the antennae and infiltrating your box. If you extend the length of the wire and loop it back up to the box, then any water that does infiltrate (or condensate) should run down the wire and drop outside the box.*

Paul Kolston: "*Design 2 looks far more difficult to install. As you say, it would probably require two people and maybe even getting inside of the tank. It would also require knowledge of materials e.g. how to drill, whether to put pilot holes etc. Despite this, it looks like it solves the contamination issue which is good*".

Bailey Tanks: "*Design 2 looks better than the first, but the drilling of holes into the tank is kind of dodgy. Think about the material (especially the concrete) that might fall into the water during installation. I understand that the filter of the water system would easily filter this stuff out, but I think that the average consumer would be pretty worried about that so you might want to consider an alternative*".

Gallagher Group: "*This design [Design 2] is far more viable than the last. Perhaps you should consider having the measurement device built in to the water tank when selling the water tank, it may be more attractive to the consumer as they won't have to install anything*".

Watercare Auckland: "*I prefer this [Design 2] to the previous design as you are not really introducing any more contamination into the water, although the hole for the wire looks like it would be a trap for water and would eventually lead to damaging the electronic components of the design*".

Design 2 Conclusion

Design 2 seems to have more positive stakeholder feedback than design 1. The ability to install the device into any type of water tank is greatly appreciated by the stakeholders, although some were concerned about drilling into the tank itself. Paul indicated that this would make installation far more strenuous, reducing the appeal to the potential user. Mr Gardiner had very insightful comments, such as his idea to install the device into the lid instead of the tank. This would mean that a hole would not have to be drilled completely through the tank, and that drilling could take place away from the tank so that detritus falling into the water would not be a concern.

My contact from Gallagher Group suggested building the device into a water tank before it is sold, which I disagree with entirely as a lot of homeowners will already have their water tank as it will be included with their house. It would also mean that I would have to work with manufacturers and suppliers of the water tanks themselves, adding another unnecessary layer of complexity in the design and development of my product. This would also decrease versatility of the product as it would likely end up being hard-mounted to the tank, which is in direct conflict with the design brief.

Design 3

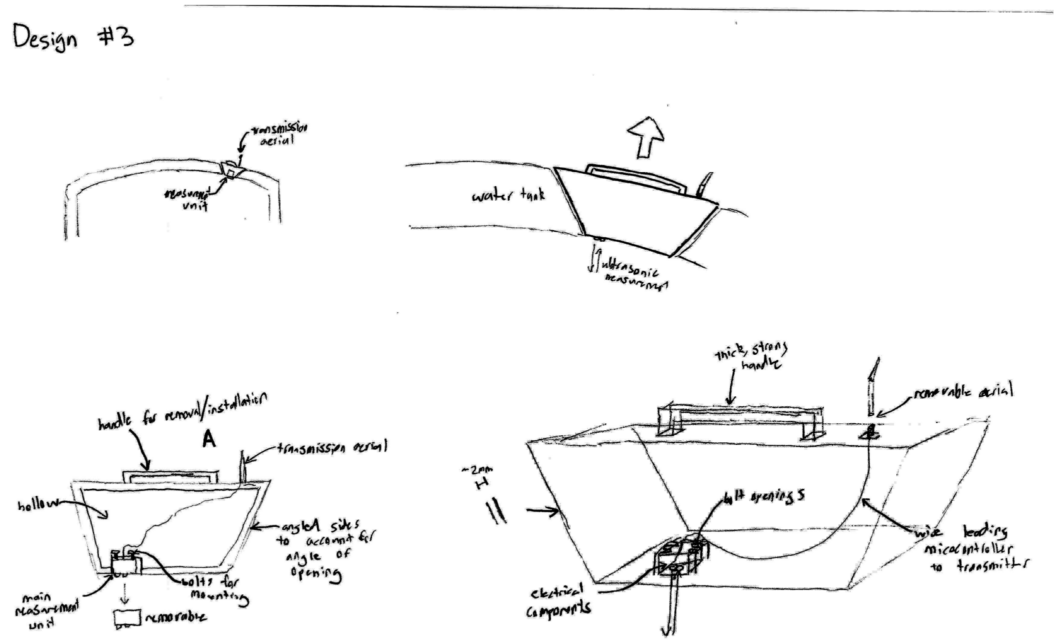
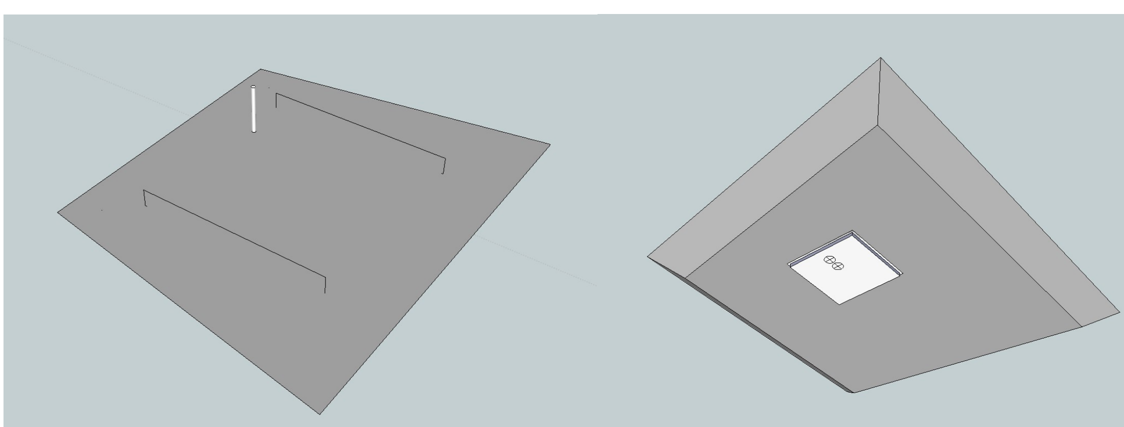
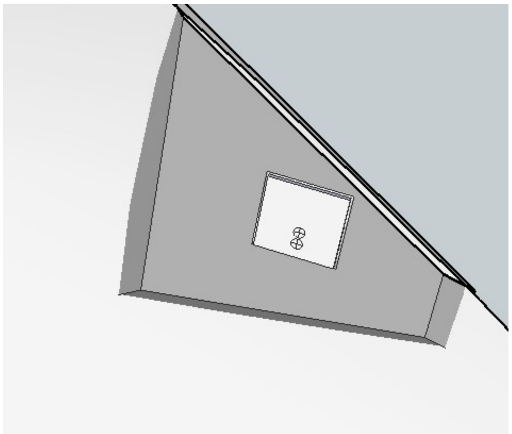


Figure 28: Diagram of my third potential design

Design 3, shown on Figure 28, was produced as a possible solution to the issues outlined by stakeholders and realised by myself in the previous two designs. Instead of the device being comprised of two units that are mounted inside and outside of the water tank, connected with a wire and/or bolts for mounting, Design 3 replaces the water tank lid entirely. Design 3 essentially consists of 3 units that are connected together into a lid: the electrical/measurement components, the aerial/transmission unit, and the shell that comprises the lid. It may initially look as if this design, much like Design 1, can only work with the specific model of water tank used by Mr Gardiner, but this is not the case. Figure 28 shows that the electrical components can be removed and installed in any type of shell, so a different lid type can easily be manufactured and the electrical components installed.

Figure 29 (below): Top and bottom 3D view of Design 3





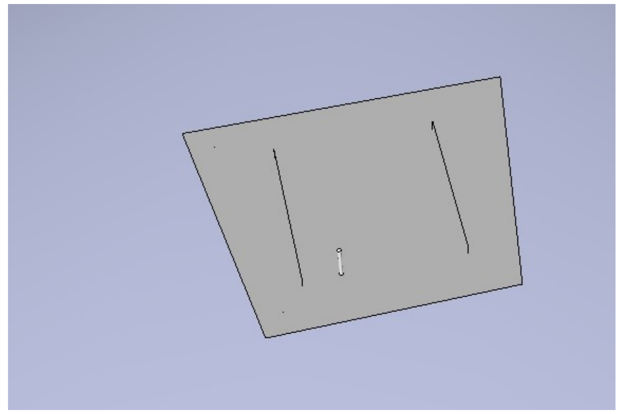


Figure 29 (above-left): Side-bottom view of 3D model of Design 3, placed in context

Figure 30 (above-right): Top view of 3D model of Design 3, placed in context

This solves all problems outlined by stakeholders. No new contamination is introduced through the expansion of the gap between the lid and the tank as a whole new lid is developed and can be custom fit. The physical installation method is by far the easiest, simply entailing the removal of the old lid and placement of the new lid. Design 3 also matches the design brief attribute of versatility since the measurement/electrical components can be removed without dismantling the whole device, allowing the user to repurpose the measurement itself for anything they require.

Stakeholder Feedback

Mr. Gardiner: *This does seem to solve many of the previous issues, but this would be much more difficult for you? I don't know that lids are any standard shape/size. My particular lid doesn't fit very well and has chips out of it so I wouldn't mind a new one, but I think you will find it very difficult to create each one for each client – it might need to be custom? I think this would also add significantly to the cost, even if was only plastic lid. If the lid was light enough, I think there is a good chance it would blow off a concrete tank since it won't be screwed on. I know with my tank the overflow is not completely connected and is southerly facing, so a strong wind would likely lift the lid, especially if the lid fits well. This potentially may also happen with better-constructed concrete tanks if the temperature/pressure/wind is just right?*

Paul Kolston: "*Interesting... [Design 3] would make installation super easy. I think you should make it out of something other than concrete, and i'm sure you will consider this later, so that it would be lighter and less insecure when replacing the lid or checking on the water*"

Bailey Tanks: "*This design looks interesting, but I am not sure if I understand. I see that you are making a lid which will contain all of the measurement equipment, but the shape of the lid is clearly only usable for that specific type of concrete water tanks. Can you create a model of what the product would look like if installed into one of the circular, plastic lids used in most consumer plastic water tanks? This might give me a better idea...*"

[See Figure 31 below]

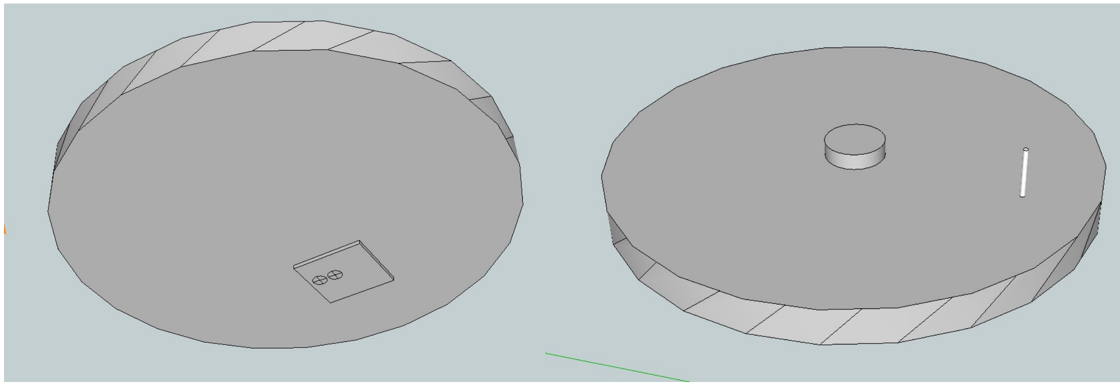


Figure 31: Top and bottom view of Design 3 implemented on a circular, screw top lid common with plastic water tanks

Thanks, this makes it far more clear to me. I understand that you will be able to manufacture several types of lids and the electronics can be installed/remove easily. This is your best design in my opinion, but you must consider the manufacturing costs of many different types of lid sizes"

Gallagher Group: "*This model is the best you have designed. [Design 3] looks like a very good idea, so long as you consider how you will mass-produce several different types of lids to install measurement components into – this will add significantly to the cost and difficulty in prototyping etc.*".

Watercare Auckland: "*This is an innovative idea Sam! This looks like it would work for even the industrial-type water tanks used for districts in Auckland and around New Zealand since you could design the lid easily with the electronics being independent of the lid. If I were to choose this would be the best design you have thought of!*".

Design 3 Conclusion

Overall, my stakeholders' feedback for design 3 was the best of all of the designs. However, the issues outlined, especially by Mr Gardiner, leads me to thinking that this is not a viable design. The cost is the main issue, as any physical material in that quantity, combined with the costly designing process, will likely put the product at a price far above the maximum $75 limit as stated in the design brief. The issue of low weight outlined is not a major issue, as I could weight the lid (adding even more to the financial cost). Despite this, Design 3 still boasts some major advantages, such as installation and development ease (at least, when it comes to the electrical system).

<u>Design Ideas Conclusion</u>

The stakeholder feedback I received was invaluable to this decision-making process. I was completely ready to design and build a product based off Design 3 until my main client, Mr Gardiner, pointed out the major flaws it presents. I have instead chosen to completely adhere to his feedback, choosing Design 2 and making some alterations to ensure it will be fit for purpose in the broadest sense.

2.3 - Physical Design Alterations

As mentioned previously, I have chosen Design 2 for the basis of my water level measurement physical design. However, many issues were outlined and suggestions were made by stakeholders that need to be address in order to ensure that the product will be fit for purpose. Firstly, the mounting of the device will now occur through the lid of the tank to reduce possible sediment deposition. Secondly, I will change the mounting system so that a mounting hole does not need to be drilled all of the way through the lid, increasing ease of installation. Finally, I will include a system of ensuring that no water enters the electrical system of the device. My contact at Gallagher systems has told me that "*a lot of the electronics we use in our systems are covered with silicon sealant to reduce any corrosion because of the high humidity in the tanks*". This seems to be a simple, cheap and effective solution that I will utilize in my design.

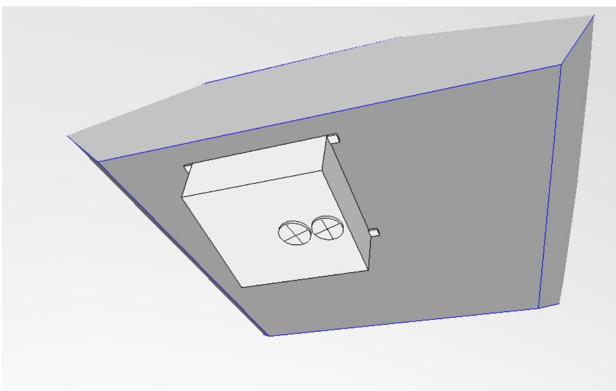


Figure 32 (left): Updated 3D model of Design 3, showing alternative mounting solution and location

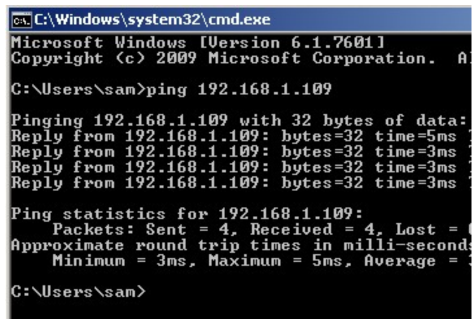


Figure 33 (right): Results from Raspberry Pi internal tank ping test showing 100% response rate

Mr Gardiner also had the insight that an aerial may not be needed if the Wi-Fi signals could escape the concrete or plastic shell of the water tank. I asked Paul Kolston about this, who said: "*Not sure.* [Concrete tanks are] *very thin, but also contain a steel mesh that could act as a Faraday cage* [a structure that blocks electromagnetic radiation]*, depending on the net size relative to the wavelength of the electromagnetic signals. The Wavelength of 5Ghz* [modern day Wi-Fi signals] is *about 10cm, so mesh could at least partially block it. For a plastic water tank, this would be fine as I doubt there is any steel mesh and the plastic is often even thinner."* My contact from Gallagher systems confirmed the claim that plastic water tanks don't have metal cages. Since Paul was not certain about Wi-Fi transmission working through the concrete tanks, I decided to test it by taping a Raspberry Pi (discussed further in section 2.4) to the inside of the tank along with a power supply and pinging to it on the same wireless network on a different computer, about 20 metres away. As shown on Figure 34, this working perfectly, confirming that a lack of aerial would be fine for a concrete water tank. I will, however, propose that a wire may be passed through the gap between the lid and the tank which will lead to an external antenna in situations, such as farms, where a great distance may be present between the tank and the client's computer. This will be a great compromise as the gap will not be enough to expose any more sediment already present and will allow better reception in a way that does not require drilling all of the way through the tank. Gallagher systems have even told me that the wire would be so insignificant that it would be able to be passed through the screw-type lids of plastic tanks.

Now that these changes have been made I can see that this design much better aligns with the design brief, especially the attributes/specifications of cost, size and ease of installation. I am extremely grateful for the feedback given to me by stakeholders as it has allowed me to make changes that I never would have thought of that will reinforce the effectiveness of this product.

2.4 - Circuit and Hardware Concepts

Now that the physical design has been envisioned and decided upon, I will embark on the designing of the electronic and software components that will comprise the main functionality of the water level measurement device.

I have already established that the product will use ultrasonic measurement technology, specifically the H2-SR04 ultrasonic sensor. In terms of hardware, I will also need to establish the main microcontroller(s), the battery, the aerial and another other components that will allow these other components to communicate with one another, e.g. resistors and capacitors. Mr Gardiner has recommended that I look into the hardware before the software as the hardware choices especially that of the microcontrollers that will process the measurement information, will likely determine what software/programming languages can be used. Firstly, I will mock up a diagram that shows how these potential components will be utilized.

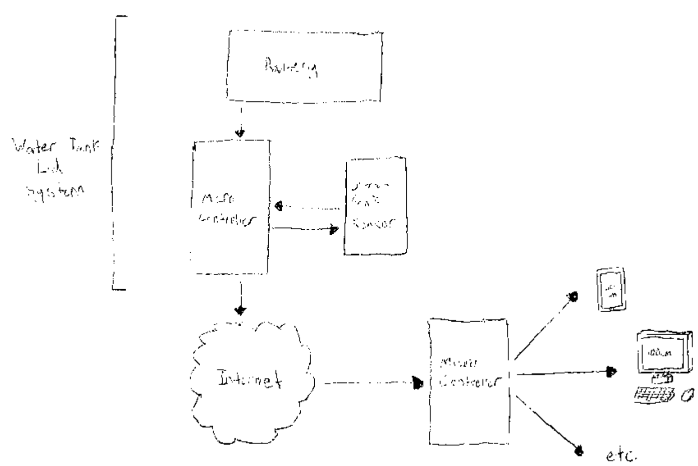


Figure 35: Diagram outlining the potential electrical/software components of the device

As Figure 35 shows, the overall functionality of the device will consist of the following: Battery supplying power to the microcontroller, which is supplying power to the ultrasonic sensor, receiving measurement data in turn. This data is sent through the internet to a second microcontroller, which acts as a hub that sends the measurement information to various frontend devices such as a smartphone or computer – essentially anything with an internet connection.

I have shown this design to Mr Gardiner, who has made several recommendations. Firstly, the frontend of the system should consist of a website that can be accessed through a browser rather than an app. Secondly, he suggested that the data may not need to go through a second microcontroller to process the data and present it to the users, and that given the power of even basic electronics these days a single Wi-Fi-enabled (or other internet-connection technology such as Ethernet) microcontroller should be satisfactory. I will keep these recommendations in mind when deciding my components (outlined over the next few pages).

2.5 - Microcontroller and Programming

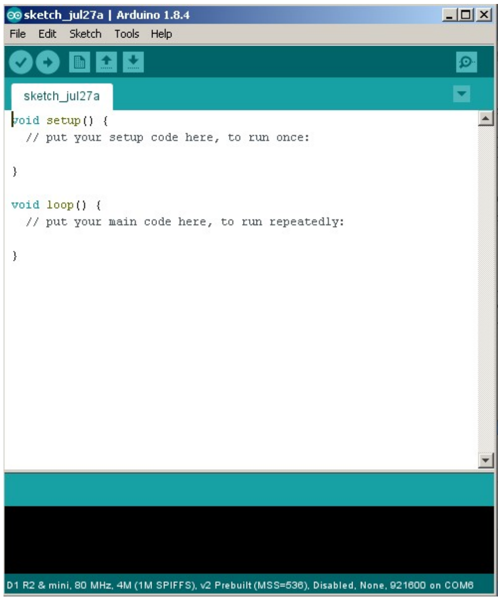
There are several choices for microcontrollers that can be used, conforming to the general design brief specifications of a low economical price, small physical size and using 'off-the-shelf' components. The ecosystems I will explore are the Raspberry Pi and Arduino. The Rpi and Arduino systems are by far the most popular consumer-available, mass-produced microcontrollers which, along with my stakeholder's experience and recommendation of them, are why I will examine them as a whole and then focus on one, choosing the exact microcontroller system that I will use for the measurement portion of the device.

Arduino (and Arduino-based clones)
Arduino is an Italian company that designs and develops open-source software and hardware, mainly to be used by hobbyists and students. The Arduino ecosystem is vast, not limited only by the microcontrollers developed by the company itself – since Arduino products are open-source, a huge community has been fostered around cloning and developing cheaper alternatives that can still run and same software and interact with the Arduino IDE (which mainly focuses around the programming language C). Arduino boards come with a variety of functionality and specifications, mostly based on how much you pay. If I were to focus on the Arduino ecosystem, I would almost certainly use a clone due to the lower price and same functionality.

Arduino Ecosystem Pros	Arduino Ecosystem Cons
• Cheap, especially of the Chinese-built clones that offer the same functionality • Open-source • Huge community • Low power consumption • Small form factors	• Not too much extra functionality • Can be difficult to program and interact with • Arduino mainly works with C programming language which I am unfamiliar with

Figure36: Examples of Arduino and Arduino-based microcontrollers (left to right) D1 Mini Leonardo, LolIn ESP8266. Sources: Aliexpress.com & Arduino.com

Another huge advantage to the Arduino ecosystem is the Arduino IDE. This free, open-source development environment means that every microcontroller has the ability to use the same programming language (C) and utilize the well-built functions that are built into it. If desired, other languages can be run on arduino boards by flashing alternative firmware onto them. This can prove to be difficult in my experience, so I would not be overly enthusiastic if I had to do so with my device. An example screenshot of the Arduino IDE is shown below on Figure 36.



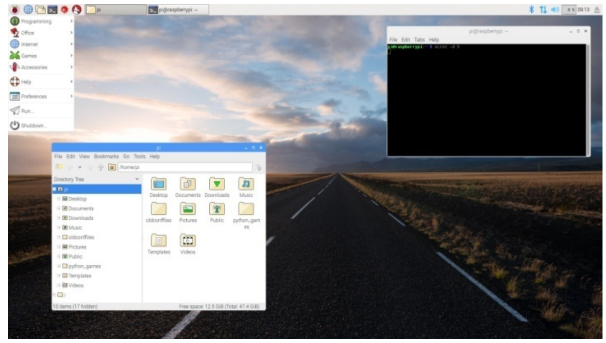


Figure 37 (left): Example image of the Arduino IDE

Figure 38 (above-right) Example image of the Raspbian OS Desktop (Rpi)

Overall, the Arduino ecosystem is quite ideal for the use case of my measurement system. The microcontrollers match the design brief attributes of a low cost, recyclability, low size and they are 'off-the-shelf' components that can be purchased from a variety of retailers.

Raspberry Pi (and clones)

The Raspberry Pi Foundation has developed Raspberry Pi Single Board Computers (SBC) mainly for educational purposes, but they have also been picked up by hobbyists. The difference between a microcontroller and a SBC is that an SBC can run full operating systems where generic applications, such as web browsers and programming IDEs, can be installed (an example of an Rpi desktop can be found on Figure 38) whereas a microcontroller runs embedded software that has to be flashed onto the device. This means that the Rpi has far more versatility than the Arduino, consequently adding to the financial expense. The Rpi can be purchased as several models, the most popular of which are the Rpi 3B and the Rpi Zero. These are fundamentally the same in terms of running a generic operating system, but vary significantly when it comes to specifications and price – this is the same with the clones, such as the Orange Pi, that are available.

Raspberry Pi Ecosystem Pros	**Raspberry Pi Ecosystem Cons**
• Open-source • Huge community • Can essentially run any programming language due to generic Linux OS • High hardware versatility due to wide variety of inputs and outputs	• Relatively expensive • Extra functionality is likely wasted, therefore making extra power consumption and ports etc. unnecessary • High power consumption • Supply issues due to excessively high demand of cheaper models therefore not suitable for mass-production

It may be noted that I have listed 'open-source' as a pro for both devices. I, as well as stakeholders Mr Gardiner and Paul Kolston, believe that open-source software and hardware are good things because, as Paul puts it: "*Open-source hardware and software can be adapted to a huge range of applications that the original producers would either never have envisioned themselves or would not have had the resources to develop. There is a huge* *community of people worldwide who have surprisingly large amounts of the time, ability, and inclination to develop, apply, and test the use of open-source hardware and software in a multitude of different tasks, in a way that could never be achieved within a proprietary framework. For example, manufacturers of proprietary security software (and hardware) claim that to release their source code would make it vulnerable to hackers (the obfuscation argument), whereas open-source proponents claim that releasing the source code allows many more people to properly test it for vulnerabilities."*

Figure 39: Examples of Rpi and Rpi-based microcontrollers and SBCs (left to right) Orange Pi, Rpi 3B+, Rpi Zero W. Sources: Banggood.com & Raspberrypi.org

Microcontroller and Software Environment Choice

I have chosen to use the Arduino ecosystem for the measurement portion of my device after evaluating and discussing the alternative with my stakeholders. The Arduino boards are cheaper, smaller and have lower power consumption than the Rpi. They do offer less versatility, but I do not see this as a significant issue as I will not need a whole SBC for this part of the system, simply a microcontroller to measure and transmit (no excess processing is needed). Now I will need to decide on the exact Arduino board to use for the system.

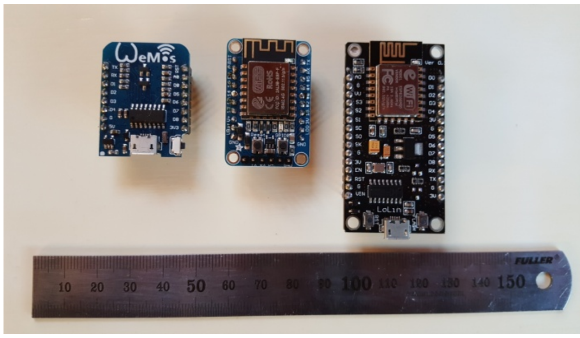
Mr Gardiner has recommended that I buy a board that is based off of the ESP-8266 Wi-Fi microcontroller. He has used it in the past and says that it will be ideal for this scenario. I can buy a variety of boars that utilize this cheap, each offering different added functionality as well as inputs and outputs. I have purchased an Adafruit Huzzah (officially supported by Arduino), a Nodemcu V3 and a Wemos D1 Mini (some of the most popular ESP boards to see which best will match my stakeholder's requirements and conform to the design brief. To test the boards, I will flash them with some sample code I created that will perform a basic distance measurement with the ultrasonic sensor and output the result into the serial output (read through the arduino IDE and the serial-to-digital converter onboard the Arduino boards). The code (Figure 40) and the circuit (Figure 42) are a good indicator of the base-level functionality of the prototype device, allowing me to make an informed decision for the microcontroller.

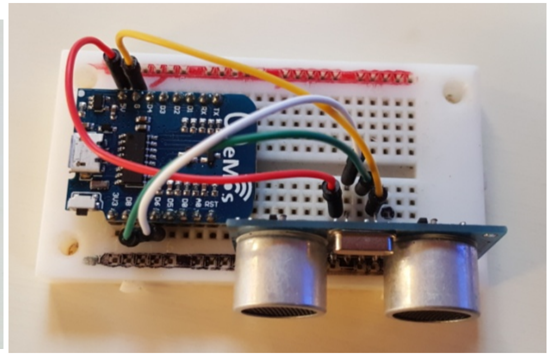
```
/*
Arduino Test Circuit
  Takes a basic ultrasonic measurment, calculates distance, then returns
  value to serial output
Last edited: 30/07/18
 */

const int trigPin = 12;             //Set pin D6 (12) to trigPin
const int echoPin = 13;             //Set pin D7 (13) to echoPin


long duration;
int distance;                       // Defines distance and duration variables

                                    // Initializer, runs once when the
void setup() {                      //    device is turned on
  pinMode(trigPin, OUTPUT);         // Set the trigPin as an output
  pinMode(echoPin, INPUT);          // Set the echoPin as an input
  Serial.begin(9600);               // Start the serial communication
}

void loop() {

digitalWrite(trigPin, LOW);         // Clear the trigPin
delayMicroseconds(2);               // Pause for 2 microseconds

digitalWrite(trigPin, HIGH);        // Output voltage to trigPin
delayMicroseconds(10);              // Pause for 10 microseconds
digitalWrite(trigPin, LOW);         // Clear the trigPin


duration = pulseIn(echoPin, HIGH);  // Reads the echoPin, returns the sound
                                    //    wave travel time in microseconds

distance= duration * 0.034 / 2;     // Calculating the distance

Serial.print("Distance: ");
Serial.println(distance);           // Print the distance on the Serial Monitor

delay(2000);                        // Pause for 2 seconds, then run again
}
```

Figure 40: Arduino test code, returns ultrasonic measurement information to Serial output

Figure 41: Picture of the three microcontrollers that I purchased for testing (left to right: Wemos, Huzzah, NodeMcu)

Figure 42: Picture of circuit with Wemos installed for testing purposes





All three of these microcontrollers passed this test, but to varying degrees of difficulty and success. The Huzzah does not have a serial-to-digital converter installed, so an expensive ($35) cable was required for flashing and monitoring. This is a major flaw in my opinion, making recyclability and versatility less desirable for a future user. The Nodemcu was the most difficult to get running. Initially I received an "*esp_comm_failure*" error that resulted in no communication with the device. I spent hours deleting and re-flashing firmware, code (even going so far as to replace and factory Arduino firmware with a Lua-based third-party alternative) eventually to success. The Wemos D1 Mini was the only device that I have no qualms with, performing with no difficulty. Figure 43 shows the serial monitor with the Wemos D1 Mini installed showing the output of the code (you may notice an issue of a strange value, an issue I will have to write an exception catcher for later).

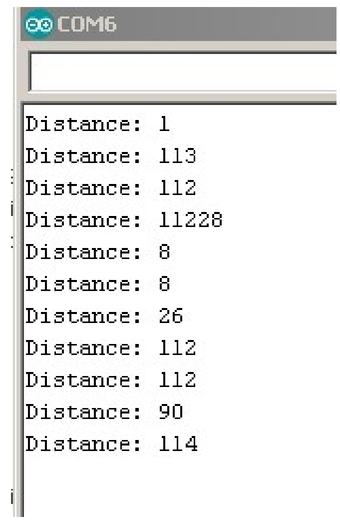


Figure 43 (right): Serial output of Arduino test code

After performing this experiment, I have chosen that the best microcontroller to use for the measurement portion of the water level measurement device is the Wemos D1 Mini. It performed the best, with no programming, flashing or hardware issues. The Wemos (referred to as such hereon) is small, cheap (at ~$8) and easily purchasable by anyone in great quantities. I am confident that if a bulk order was purchased, and if this product was to be mass-produced, that the price would reduce even more.

2.6 - Other Component Choices

I am choosing to design the prototype of this device on a combination of veroboard and breadboard. Breadboard will be used for the majority of the circuit design, as it is easy to remove and modify circuit components, but does not offer longevity and physical security of components. Veroboard will be used for the final prototype circuit as it is cheap, durable (acting as a mounting point for components) but is still modifiable unlike a printed circuit board (PCB). Obviously a bespoke PCB would be used in the mass-produced product, but it will not be as effective as veroboard for the prototype.

The battery that I will be using for the prototype will be an array of 1.5V "AA" type batteries. I have chosen these batteries as they are easy and cheap to obtain, can be rechargeable (although this reduces the voltage to 1.2V) and do not take up much space. I will use four of these batteries, resulting in a total output voltage of 6V (practical voltage will vary due to charging levels). The Wemos runs on 5V, so this output will easily power it. I have designed a basic circuit diagram for the prototype in PCB Design and Make, shown on Figure 44.

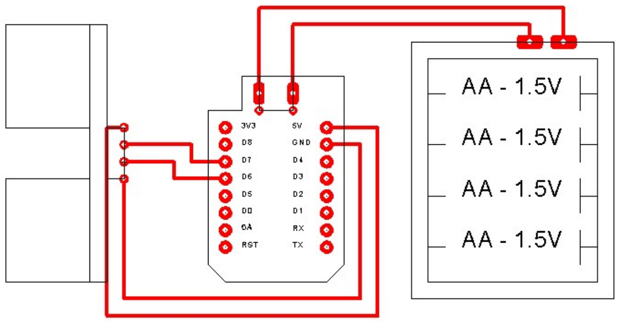


Figure 44: Circuit diagram of initial design prototype

2.7 - Electrical Design Alterations

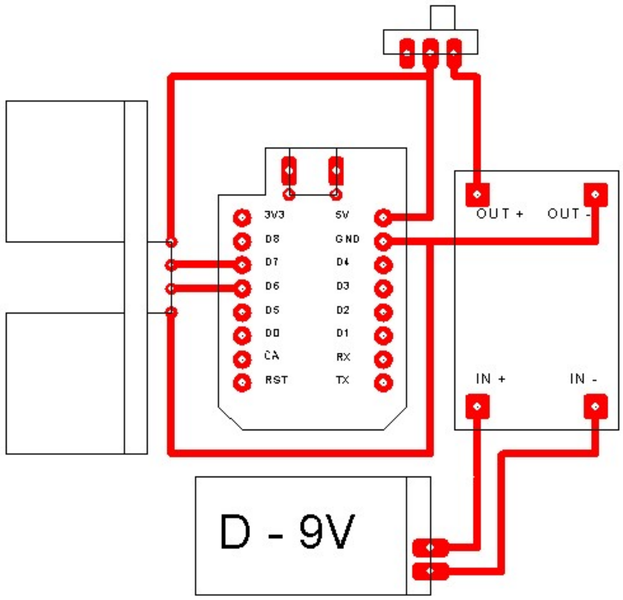
My initial electrical/software concept design consists of a Wemos D1 Mini as the main measurement processor, an H2-SR04 ultrasonic sensor for measurement, and an array of four AA batteries. Transmission of measurement data will occur through the onboard ESP-8266 Wi-Fi transceiver to a microcontroller/SBC (that will be decided upon during the development process) for processing. This will make the data available to be accessed from the client's computer (whether that is a laptop, phone or otherwise). My stakeholders and I have chosen these components as they best conform with the brief, ensuring that the product is cheap, effective, recyclable and physically small.

The first alteration that needs to be made, outlined by Mr Gardiner, is the battery solution. While the four AA batteries may provide enough voltage when fully charged, as they run out they will quickly reduce voltage to a point that will not power the Wemos. I have instead decided to replace this battery with a standard 9V "D" type battery. I have chosen this based on recommendation from Paul Kolston, who said "For your prototype it will be easy to install and use although you will probably need to convert it to a different voltage since I doubt any microcontroller you use will accept 9V+". This is good advice, as the Wemos runs on 5V, so I will need a step-down voltage converter. I have chosen the XL6009 Adjustable Voltage Regulator (Pictured on Figure 44) for the prototype, solely because it is popular and cheap. The final voltage regulator will have to be thoroughly tested on reliability and energy efficiency.

Figure 45: XL6009 Adjustable Voltage Regulator (source: Banggood.com)

Another quick alteration is that I have discovered that the Wemos can be powered directly through the 5V and GND pins. I will power the board through these pins as it will leave the micro usb port open, allowing greater flexibility in debugging. This change is shown in the final prototype circuit design (Figure 46). You can also see that I added a switch. This is simply for increased usability when debugging/testing and will help save battery.

Figure 46: Planned circuit diagram of prototype device



The diagram of Figure 47 shows the overall planned functionality of the prototype. The ultrasonic sensor will receive power and physically transfer data to the Wemos, which will transmit the data wirelessly to the Raspberry Pi. The Rpi will physically display this data onto a monitor for the viewer to detect water level. Obviously in the future this will involve much more functionality and complexity, but this diagram simply illustrates base-level functionality

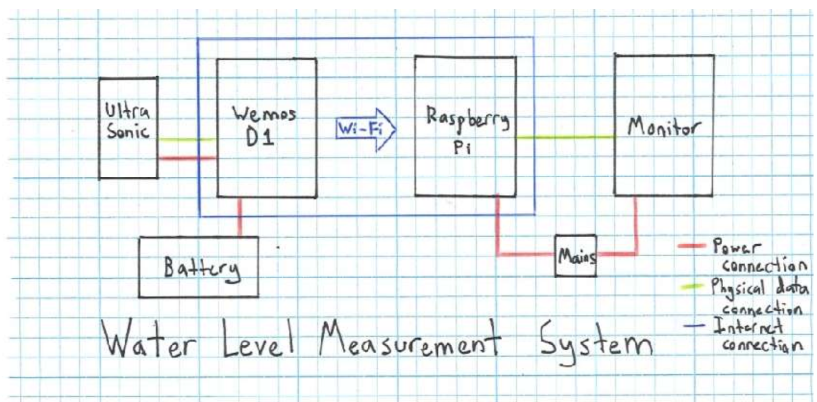


Figure 47 Diagram of prototype system

2.8 - Final Design Concept and Conclusion

The final design concept for the water level measurement device has now been completed. This design, assured with the following stakeholder feedback, conforms to many of the design brief attributes and specifications ensuring that the final prototype device will be fit for purpose. The design brief attributes of utilizing off-the-shelf components, physical size and price are already assured. The total financial cost (including component shipping) of the design of Figure 46 is (Wemos $8, HC-SR04 $3, XL6009 $4, switch $0.5, D battery $2.50) only $18, leaving $57 for the main material components of the product to meet the specification of <=$75. This pricing does not even include a bulk, mass-production discount. Other attributes, such as ease of use, prediction of how long water will last and versatility in multiple contexts should be all easily implemented in code during the prototype development phase.

Stakeholder feedback
We are on tank water. We only have 1 tank and although it's reasonably large we worry about running out of water during the summer months. It is also a time when we have increased demand for water as we tend to have family come and stay with us over summer. We try to be frugal and conscientious with our use of water over the summer but find it very difficult to monitor our water level and how effective our water saving habits are. After some brief rain we have no idea how much of the tank has been filled up unless it is pouring out of the top. We can hit it on the side to establish the level, but it doesn't seem to be very accurate and as our tank is half buried it is very difficult to tell how much is actually left in the tank, or how much is left based on our usage. We try our best to avoid paying for a tanker to deliver water (it's normally free from the sky!).

Mr. Gardiner: "*I don't know a ridiculous amount about electronics, but this all seems fine. I mainly experiment with Raspberry Pis but Arduinos appear to be way cheaper and consume far less power, which would be ideal if it is isolated in a tank like you say it will for extended periods of time. I think the main part of this project will be making sure the data is easily accessible for the user, and as long as the electronics are cheap and reliable, they should not matter as much as the frontend. Also making sure that the electronics are completely protected from water damage is important – maybe look into covering them in silicone sealant or something similar*"

Paul Kolston: "*The circuit seems good, but as I have said the variable resistor will be completely unnecessary in the final product. I also think that you could maybe add some LED indicators for debugging or to give the user visual feedback when using the device. Another suggestion is that the switch should be placed before the variable resistor/voltage converter as this will (very) slowly consume power, reducing energy efficiency of the product*"

I have decided to add LEDs on the breadboard prototype circuit tester, but will not add them for the final product as I believe that the visual feedback will be useless as the nature of the product is that it will be placed inside of the tank and so no LED will be visible – this would only be useful for maintenance and installation purposes, which I do not believe are sufficient enough to warrant additional components such as LEDs.

On Mr Gardiner's suggestion, I have looked into protecting the electronics with a sealant of some sort. Paul says that he has used silicon sealant on mains wiring in the past, and that seems to work for him. If the box that the electronics are housed in is water tight, this might be a redundant step, but redundancy in this case is probably beneficial as electrical damage to the electrical components would be devastating. I will not encompass any of the electronics that I work on with the prototype in any form of sealant as it will make prototyping far too difficult, but would definitely look into it when considering the mass-production of a final product.

I have also decided to, upon Paul's suggestion, wire the switch to the positive output of the battery and the positive input of the voltage converter to increase energy efficiency.

Prototype Development

3.0 - Introduction

Now that the conceptual design has been envisioned and documented, I will now begin working on a prototype device. The prototype should do everything that the final product can do, but may utilize less efficient manufacturing/designing practices – this is so that the prototype can be rapidly completed. Mass production will still have to be considered for the feasibility of the final product and the prototype must be still be fit for purpose in the broadest sense.

3.1 - Server Host Choice

For prototyping purposes, the Raspberry Pi 2 B+ will be used as a receiver and processor of the distance information that will be sent by the Wemos. The Rpi is too expensive to use in the final device, but will facilitate more rapid prototyping due to its wide community and support for a plethora of programming languages and interfacing. I will return to this board choice later to find a cheaper alternative that will better match the requirements of my stakeholders and the design brief.

MQTT

A crucial part of this product will be the communication between the measurement unit and the processing unit. I have already determined that the technology used will be Wi-Fi, but I still need to decide on the software application or protocol that will facilitate these transmissions and allow processing. For now, I have envisioned a one-way form of communication where the measurement unit systematically transmits the water level at regular time intervals to the processing unit (now determined to be an Rpi) where it will be hosted to a smorgasbord of internet-connected devices such as a laptop. The technology that Mr Gardiner has suggested to me to help achieve this is Message Queuing Telemetry Transport (MQTT). MQTT is a low-latency protocol that is commonly used in home automation systems (such as my main client's). Mr Gardiner has explained MQTT to me, and my experimentation and research with it has reinforced his persuasions.

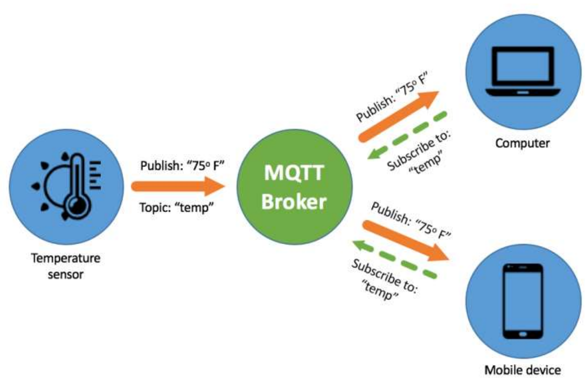


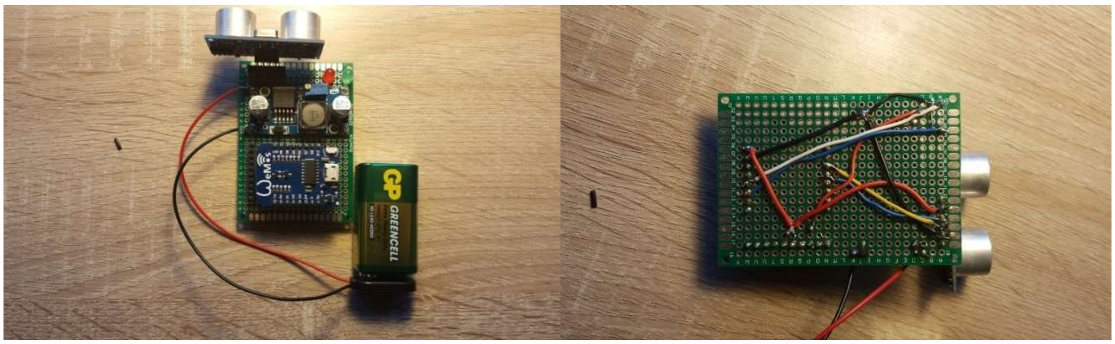
Figure 48: Simple diagram outlining basic usage of MQTT (source: Appcelerator Inc)

Figure 48 shows a broker that has received an input from a temperature sensor. This is then 'published' to clients who are 'subscribed to the MQTT 'temp' topic. In the context of my device, the temperature sensor represents the measurement unit and the broker will be the Rpi. There are many MQTT libraries for both devices so implementation should be simple.

3.2 - Design and Testing

I have now developed the circuit outlined on Figure 46. I have made some basic alterations that do not affect real-world functionality. For example, I have added PCB extensions/female jumpers for the HC-SR04 ultrasonic sensor and the Wemos microcontroller so that I can remove them easily if issues arise and have to be debugged during the prototyping process (as they inevitably do). This also protects the components from prolonged heat of the soldering iron that may lead to damage. The circuit is shown on Figure 49, and now must be programmed.

Figure 49: Prototype circuit for water level measurement device



It should be noted that two LEDs have been added to the circuit, something I did on an impulse during the soldering process as I figured that it would be useful to have a visual indicator of connection or function for debugging.

I have written some code in C using the Arduino IDE that will connect the Wemos to the MQTT broker through Wi-Fi and submit distance measurements periodically. In order to test this I have set up the Rpi with a standard Raspbian (Debian-based ARM operating system) installation, installing paho-mqtt (Python MQTT library) and mosquitto (MQTT client and broker). In order to connect the two, I need to input the IP address of the MQTT broker, which is now the Rpi, and the SSID and password of the local network into the Arduino code before flashing. These values are constants to increase usability.

Figure 50: Sample code for Wemos-ultrasonic MQTT publisher

```
// Looping function for publishing distance data (MQTT)
void loop()
{
  if (!client.connected()) {
    reconnect();
  }
  client.loop();

  int distance = measurement();

  snprintf (msg, 75, "Distance: %ldcm", distance);
  Serial.print("Publish message: ");
  Serial.println(msg);
  client.publish("distance", msg);

  digitalWrite(GREENLED, HIGH);
  delay(500);
  digitalWrite(GREENLED, LOW);
  delay(3000);
}
```

Figure 50 is the section of the code that publishes the distance that is measured by the ultrasonic sensor. A separate function exists that returns the distance as an integer (essentially the same methodology as in Figure 40), which is created locally in this sample as the integer ‘distance’. This integer is formatted into a readable sentence which is then published using the Arduino MQTT libraries. The green LED is pulsed so that I can physically see that this section of the code is running. This section of code will repeat indefinitely.

```
// Wifi network and MQTT server details
const char* ssid = "";
const char* password = "";
const char* mqtt_server = "192.168.1.109";
```

Figure 51: Constant input for server address, network SSID and password

This code ran successfully, although not until after certain tweaks were made. I had some loose connections on the circuit board due to my soldering iron not being set hot enough – the joints were cooling too quickly. I was also outputting the wrong level of voltage to the Wemos which was fixed easily with the adjustable voltage regulator. I also eventually changed the publishing message to simply the integer (although it is still outputted as a string) of the distance measurement so that I can perform calculations with it without any string slicing with the host Python code – It also just makes more logical sense to perform as little calculations as possible on the measurement device to conserve power. The client code (Figure 52), output of this code (Figure 53) and the testing zone I used for this section (Figure 54) are shown below.

```
pi@raspberrypi: ~
  GNU nano 2.7.4                File: mqtt_subscriber.py

import paho.mqtt.client as mqtt

MQTT_SERVER = "localhost"
MQTT_PATH = "distance"

def on_connect(client, userdata, flags, rc):
        print("connected with result code ", str(rc))
        client.subscribe(MQTT_PATH)

def on_message(client, userdata, msg):
        print(str(msg.payload))

client = mqtt.Client()
client.on_connect = on_connect
client.on_message = on_message

client.connect(MQTT_SERVER, 1883, 60)
client.loop_forever()

                               [ Read 18 lines ]
^G Get Help   ^O Write Out  ^W Where Is   ^K Cut Text   ^J J
^X Exit       ^R Read File  ^\ Replace    ^U Uncut Text ^T T
```

Figure 52 (left): Sample code used for the client (Rpi – is also broker)

Figure 53 (right, below): Output of MQTT subscriber code on the raspberry pi client/broker. I am accessing the raspberry pi terminal through SSH

```
pi@raspberrypi:~
('connected with
Distance: 0cm
Distance: 13cm
Distance: 13cm
Distance: 13cm
Distance: 13cm
Distance: 13cm
```

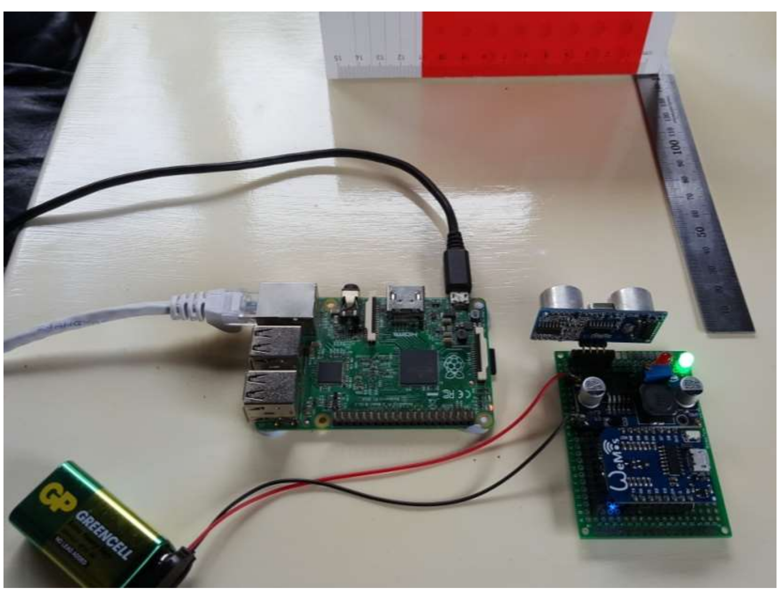


Figure 54 (left): Initial prototype circuit being tested. A ruler and blockade has been erected to test ultrasonic measurement accuracy

Upon Mr. Gardiner's suggestion, I have imported the same paho-mqtt library into my personal computer's Python scripts so that I can work on the code without needing to ssh into the Rpi. This also means I can use a superior development environment which, in my case, is Pycharm.

3.3 - Prototype Updates/Programming Development

I will now begin developing the programming side of the water level measurement device and the associated MQTT broker. I have chosen to use Python 3 for the broker and C for the measurement unit. The Wemos can run essentially any programming language I choose, simply needing to re-flash firmware. The most common alternative for C for ESP8266 devices is Lua, which is designed for embedded applications such as my device. I have chosen C over Lua as it is far more of an industry-standard language and so may prove to be more versatile if companies would like to make alterations to the device's functionality if it were to be applied to a large scale. The consumer should not know of any difference whether Lua or C is chosen as the frontend should be simple to use either way. I have chosen Python 3 for the broker as it is a widely-used language for consumer devices, making it easy to integrate on any hardware I choose for the broker. An added advantage is that I am proficient in Python and so will be able to develop a more efficient program than if I was using Java, for example. Both Mr Gardiner and Paul Kolston have approved this decision, the former having taught me Python in my schools programming course and the latter having high, useful experience in C from university.

The first version of my MQTT client code subscribes to the 'distance' topic that is published by the measurement unit. The distance (in cm) comprises this topic, which the client code uses to calculate the percentage of liquid left in the tank. This is done using the simple calculation: $(distance) \times 100 \div (tank\ depth)$. As Figure 55 shows, this initial code uses a constant for tank depth for easier modification.

Figure 55: MQTT client code version 1 (see commented explanation on the right)

```python
import paho.mqtt.client as mqtt                                        # Utilize paho python MQTT client
import datetime                                                        # For timestamping measurements


MQTT_SERVER = "192.168.1.107"                                          # IP of server/broker
MQTT_PATH = "distance"                                                 # Name of topic to subscribe to

TANK_DEPTH = 100                                                       # Height of interior of tank (in cm)

total_messages = 0                                                     # Gives user number of total messages


def on_connect(client, userdata, flags, rc):                           # Function that subscribes to topic
    print("connected with result code ", str(rc))                      # once server has been connected
    print("server ip: ", MQTT_SERVER)
    client.subscribe(MQTT_PATH)


def on_message(client, userdata, msg):                                 # Function runs when message received
    global total_messages                                              # Localize total message number integer
    total_messages += 1                                                # Update total message number integer
    print(datetime.datetime.now())                                     # Print timestamp
    print("Water level: {}%\n".format(int(msg.payload) * 100 / TANK_DEPTH))  # Print water tank level, calculated
                                                                       #   using distance from esp and total
                                                                       #   tank height constant


client = mqtt.Client()                                                 # Create client
client.on_connect = on_connect                                         # Run appropriate function when connected
client.on_message = on_message                                         # Run appropriate function when messaged

try:                                                                   # Attempt connection
    client.connect(MQTT_SERVER, 1883, 60)

except TimeoutError:                                                   # Connection times out, inform user
    print("connection timed out. please try again...")

client.loop_forever()                                                  # Loop program and client connection
```

This code performs its function perfectly, but said functionality is nowhere close to meeting the specifications and thus cannot be considered fit for purpose. In order to increase usefulness of the product, time series data must be recorded. To do this, I will utilize the "PyMySql" module which allows Python to interact with MySql databases. I have chosen MySql, and to utilize a database for the measurement data overall, as it is reliable, widely used, easy to understand and to manipulate data. I will be using MySql Workbench to create an SQL model and to interact with the live database that I will hopefully be updating through the next version of client code that I create.

Currently, the database model will only consist of one table, the primary key of which will be the date and time of the measurement with another column for the distance measurement. The datetime column will have the CHAR(25) datatype because the output for the datetime python module is always 25 characters long and consists of integers and punctuation. The distance column will be VARCHAR(5) as the percentage level remaining will vary in size and has the % indicator and so cannot be simply an integer. These can, and likely will, be easily changed in the future.

Figure 56 (below): First table in the measurement database

Figure 57 (right): Some example measurements I have taken in testing the code and database using the second version of the client code, discussed below

datetime	distance
2018-08-11 19:46:00.885260	27.0%
2018-08-11 19:47:39.148880	30.0%
2018-08-11 19:50:27.918533	29.0%
2018-08-11 19:53:22.514520	27.0%
2018-08-11 19:55:17.590102	0.0%
2018-08-11 19:57:06.664340	32.0%
2018-08-11 20:04:33.828917	10.0%
2018-08-17 18:36:02.300034	38.0%
2018-08-17 19:09:01.826750	28.0%
2018-08-17 19:13:24.496774	27.0%
2018-08-19 14:47:26.933385	6.0%
NULL	NULL

measurements - Table

Table Name: measurements

Column Name	Datatype	PK	NN
datetime	CHAR(25)	☑	☑
distance	VARCHAR(5)	☐	☐

Figure 58 (below): Updated code for inserting measurements into SQL database

```
        water_level = "{}%".format(int(msg.payload) * 100 / TANK_DEPTH)

        query = "INSERT INTO `student2018111546`.`measurements` (`datetime`, `distance`)" \
                " VALUES ('{}', '{}');".format(datetime.datetime.now(), water_level)
        cursor.execute(query)
        print("cursor executed")
        cnx.commit()
```

Figure 58 shows a snippet of the developed client code. You can see that instead of printing the MQTT subscribed message (see Figure 55, line 32) an SQL query is created with the water tank level and current date and time formatted within. This query is then executed, inserting a new row into the created database.

3.4 - Electronics Updates

The first development that I have made to the electronic system is replacing the expensive Rpi to an Orange Pi. The Orange Pi Zero is cheaper, easier to obtain through online suppliers and can do everything that the Rpi can do in the context of my product. The same MQTT client (Mosquitto) has been installed and product functionality is exactly the same with the major benefit of the Orange Pi only costing $8 (Banggood) compared to the ~$60 of the Rpi (3B, Surplustronics). I am not comparing the Orange Pi Zero to the Raspberry Pi Zero due to the massive shortfalls in manufacturing that have led to it not being readily available anywhere. Informing Mr Gardiner of this development, he suggested that I experiment with using cloud-based solutions as "[cloud-based MQTT servers] *can be free for individual users and make it way easier for you since you don't need your own physical broker. It would probably also make it easier for me and for any other possible owners of the final product"*.

This feedback seems interesting and the potential benefits seem obvious so I have chosen to do some experimentation with online MQTT brokers. Firstly, I tested the Eclipse IOT (internet of things) MQTT broker. This broker utilizes the Mosquitto MQTT software which I used with the Rpi prototype. Unfortunately, my testing of Eclipse was not very successful. Upon each running of the publishing subroutine the program would be disconnected and thus would continuously attempt to reconnect, interrupting the publishing process. This has resulted in a successful message publish rate of around 25% which is not acceptable. Mr Gardiner suggested that I should read the documentation on how much traffic is allowed on the broker per user. The Eclipse website is extremely simplistic and I could not find this information. Despite this, I still attempted a lower connection rate, reducing frequency of publishing from 5 seconds to 1 minute and still received the same disappointing success rates for publishing. As an alternative, Mr Gardiner has recommended HiveMQ. HiveMQ is an enterprise-level MQTT broker for paid use in industry, but can be used for free for lower connection rates. This seems to be a great prototyping opportunity as if it is successful on a smaller scale I will be able to consider large-scale server use for the potential final commercial product.

3.5 - Physical/Materials Updates

I have purchased a simple plastic box from Surplustronics, A NZ-based electronics retailer and distributor, to install the electronic components of the water level measurement system for prototyping purposes. This idea was given to me by an advisor, Mr Lambert, my electronics teacher. Mr Lambert told me that provided that I comprehensively research and decide on a final physical "box" for the product (along with the mass-production difficulties that will be involved based on material choice and previously-determined design), a simple ABS plastic box will be an accurate representation of what the final product may use. This will mean that it will be able to be tested for fit-for-purposeness by myself and my stakeholders. I will further research materials and mass-production techniques for the final product later in this document.

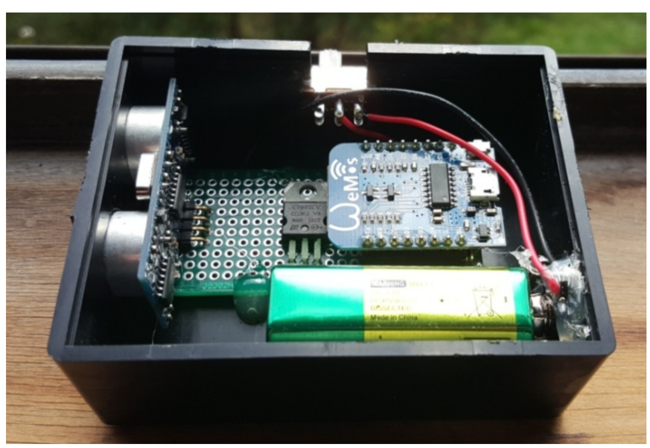


Figure 59: Photo of electronics installed in plastic prototyping box

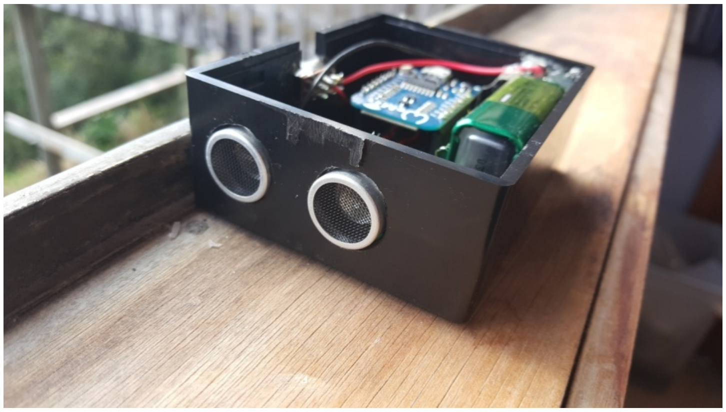


Figure 60: Photo of prototype "bottom" showing the ultrasonic transceiver protruding

Figure 59 and 60 show how the electronics fit inside the box without issue. A switch protrudes from one side of the unit to switch on and off. The circuit boards are simply, yet effectively, held in place with hot glue. The two echo and trig "speakers" of the ultrasonic transceiver protrude from the unit with two holes that have been drilled in the box for accurate and consistent measurement.

3.6 – Programming Updates

Up to this point the water level measurement system prototype as a whole takes a measurement and uploads said measurement to a broker. A client then subscribes to this broker, getting the measurement and uploading it along with the current date and time to an SQL server. This leaves the user of the system with a table of measurements and 'datetimes' (essentially still the same as Figure 57 with simpler datetime formatting). My stakeholders have quite clearly outlined to me that this SQL table is not really in keeping with the original brief attribute of "The product must be easy to use by someone of low to moderate technological background". Through Mr Gardiner's persuasion, I have begun to explore solutions to this user-friendliness issue.

His recommendation is Grafana, an open-source data visualisation and analysis program. It claims to be able to connect to my SQL database and create a visual representation of the data (this will likely be a time series line graph in the water level context) that can be accessed by anyone through a web portal. Grafana would essentially act as the frontend for the prototype so that the user does not need knowledge of SQL to get the measurement data, which is vital to ensure that the system is fit for purpose. While busy with other aspects of the project, I persuaded another stakeholder, Paul Kolston, to look into Grafana to give a second opinion on its suitability for my use case. His approval lead me to download and host a server from my laptop. Opening a browser to the address "localhost:3000/login" brings the default login page (Figure 60)

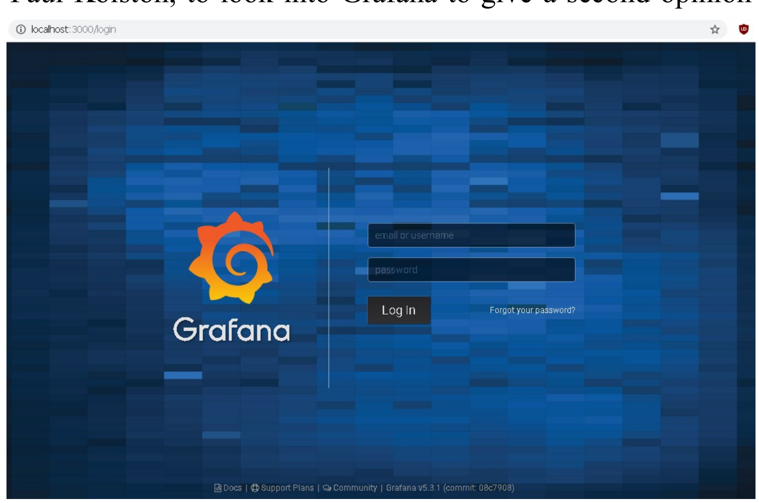


Figure 60: Default Grafana Login Page

I can already see that this user interface is far more approachable than any SQL table. After logging into the default admin account I have managed to add the SQL data source (Figure 61) and can begin to form a graph around the data in the measurements table of the database.

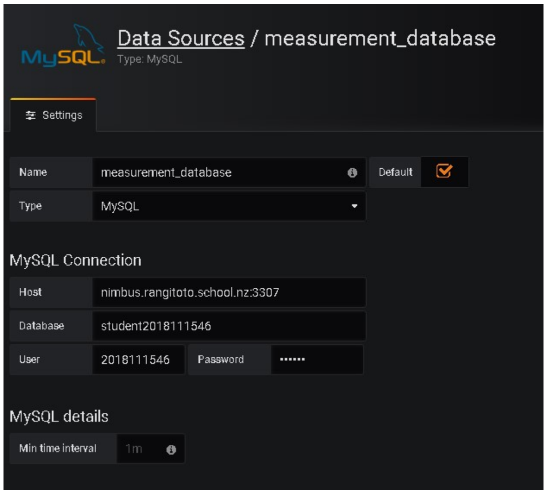


Figure 61 (left): Adding the SQL data source in Grafana

An issue I am currently experiencing is that the datetime column is not being accepted for the default "time" column that is accepted for the time series Grafana graph. As Figure 62 shows, the system demands what they define as a "timestamp or unix timestamp" where my datatype is a string. Going back to the MQTT subscriber code that updates the SQL database, I can see that the datetime is submitted as a string that is returned from the datetime function (Figure 62). I fixed this with help from Mr Gardiner, who suggested I try changing the data types for the SQL model that the database is based on. I found out that SQL has a "DATETIME" data type. Looking into the SQL documentation I found that the format for the DATETIME data type is "YY-MM-DD HH-MM-SS". Luckily, this formatting can easily be achieved using the same datetime module in Python, so I changed the data type accordingly. The original and updated formatting is shown on Figures 62 and 63 respectively.

Figure 61 (below): Grafana wrong time data type error message

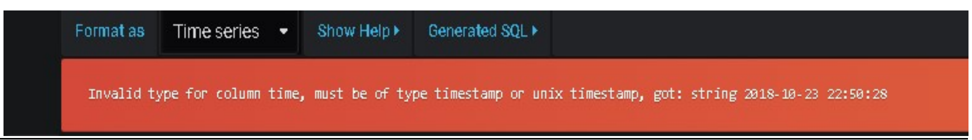


Figure 62 (right, above): Original datetime formatting

```
rmat(datetime.datetime.now())
```

Figure 63 (right, below): Updated datetime formatting

```
".format(datetime.datetime.now().strftime("%Y-%m-%d %H:%M:%S"),
```

Another issue I have encountered is that the reporting of percentages of water level has been incorrect this entire time. The original calculation was $(distance) \times 100 \div (tank\ depth)$. Let's say that the tank height is 100cm, for example, and the ultrasonic sensor is reporting a distance from the top of the tank to the bottom at 76cm. This calculation would result in the water level being at 76%, when it should be 24% as the ultrasonic sensor is measuring empty space, not water! I discovered this issue when trying to get the Grafana time series graph to work, and have decided to fix it in the python code itself by changing the calculation (shown on Figure 64)

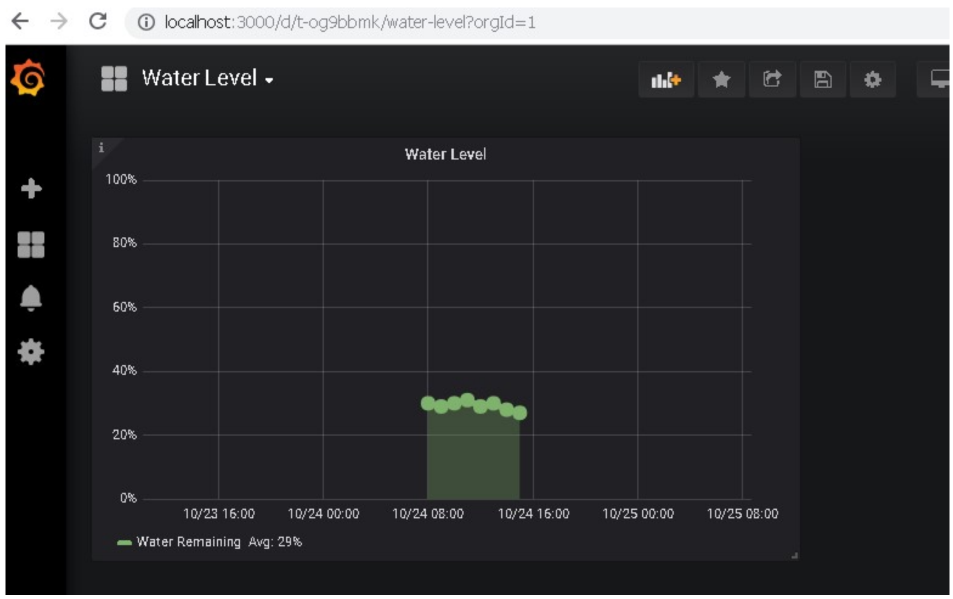
Figure 64: Water level calculations in Python

```
# Old calculation
water_level = "{}%".format(int(msg.payload) * 100 / TANK_DEPTH)

# New calculation
water_level = (((TANK_DEPTH - int(msg.payload)) / TANK_DEPTH) * 100)
```

You can also see that I am now also saving the "water_level" variable as an integer instead of a string with a percentage indicator. I have made this change as Grafana time series graphs only accept integers and floats for the Y axis variable(s). I have decided to make it an integer as I do not believe that this context needs the precision of decimal point percentages. Much like most aspects of the frontend and MQTT server hosting, this can be changed very easily if more precision is needed.

After all of these changes and bug fixes, Grafana now appears to work perfectly. Figure 65 is a screenshot of the Grafana dashboard with a time series graph displaying some random measurements I took around my room with the prototype device. This also shows that the both the prototype electronics/software and Grafana frontend are adhering to the brief attribute of versatility as it is clearly working in another use case. Note: The graph and axis labels show "water level", but this can be changed extremely easily in the Grafana settings. I will further emphasise this when analyzing the final prototype.

Figure 65: Example Grafana dashboard



3. 7 - Mass Production

The materials and processes of the final product, rather than the prototype that I have developed, must be considered to ensure that it the prototype has the potential to be fit for purpose in the broadest sense when developed for the intended consumers.

After much consultation with my stakeholders from Gallagher Systems and Bailey Tanks, I have decided to use Polythylene terephthalata (PET) plastic. This plastic is the global standard for water/other consumable liquid bottles. PET is the most widely produced plastic in the world and is highly recyclable, increasing the sustainability of my final product – just as the electronics can be used for other purposes at the end of the products life cycle, so can the plastic shell which encompasses it. The shell would be formed using injection moulding, where the molten PET is injected into a mould. Air or some other gas will be air pumped into the centre of the molten PET, forcing it to be pushed against the sides of the mould where the plastic will harden. This will result in an open space in the centre of the mould, perfect for placing electronics. It is extremely difficult to quantify the financial cost of creating the plastic shell in this way, so when determining the predicted cost of the unit I will simply use the cost of the shell of the prototype, despite it likely being at least twice the cost.

Previously I also looked into covering the electronics in silicon sealant to add another level of moisture protection. My testing of the prototype showed that this step would be unnecessary as the device suffered no damage in the two weeks that it was inside of the tank. Obviously this may be re-considered for different environments, but for now Mr Gardiner has been pleased with the resilience of the prototype and agrees with me in this regard

3.8 -Final Prototype Evaluation

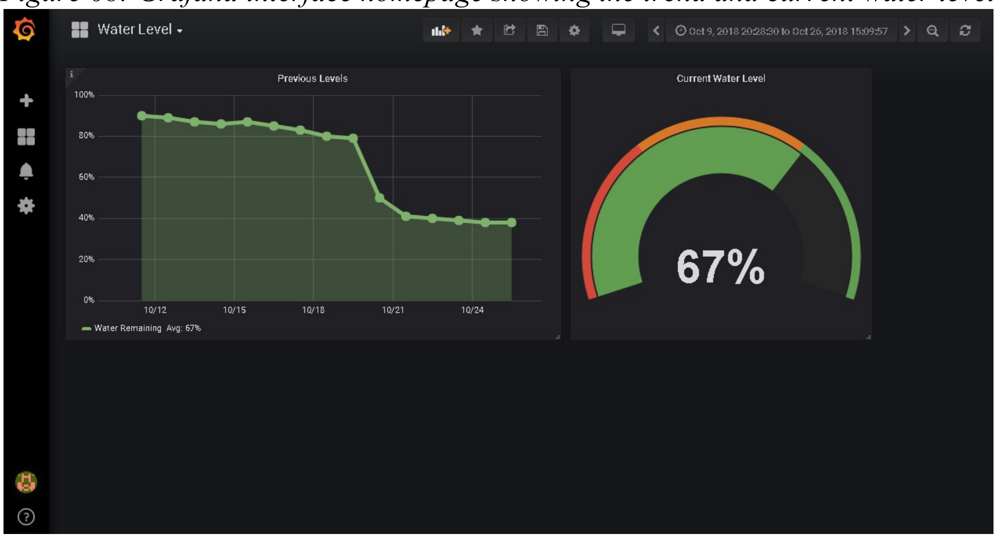
The final prototype of the device has been placed in the water tank in order to fully evaluate whether it is completely fit for purpose and adheres to all of the attributes and specifications outlined by the stakeholders and myself at the start of the year. I have collected time series data in the two weeks between the 11^{th} and 25^{th} of October to ensure that it can work for extended periods of time. The battery was changed multiple times throughout this time period as the prototype does not have efficient battery usage states or solar panel/other form of isolated power generation that is intended for the final product. The proper mounting system has also not been developed, also intended for mass production for the final product, so I mounted the system using a combination of two-part epoxy resin (to hold the box itself) and blu-tack (to place the device on an angle to account for the curvature of the tank and to hold the box while the epoxy dried). This is shown on Figure 66.

Figure 66: Final water level measurement device mounted on the lid of the water tank

Figure 67: My main client, Mr Gardiner, analyzing the prototype

To summarise, the final prototype operates using a series of interactions between electrical and software systems. Firstly, the box that is installed in the water tank that revolves around an Arduino microcontroller. This takes an ultrasonic measurement of distance and publishes it to the MQTT broker at a predetermined time interval (for my final testing purposes, this was once every 24 hours). This MQTT broker is subscribed by the client, which in my case was my laptop running a Python program – this could just as easily be any computer such as an Orange Pi. When the client receives a measurement from the box, it performs a calculation to determine how much water is left in the tank based on the height of the tank. This percentage of water remaining is then inserted, by the same client, into an SQL database. Grafana, the my chosen frontend for the prototype, displays the data of the water tank level on a time series graph, updating every time a new insertion is made into the database. Note that the idea is that the end user for the intended product will only see the Grafana interface, cutting out all of this complication.

Figure 68: Grafana interface homepage showing the trend and current water level



The time series data collected for the testing of the prototype is displayed on Grafana on Figures 68 and 69. The graph can be manipulated, such as zooming in on a specific time period. The general trend is downward, consuming 1 to 2cm of water per day. Figure 69 highlights the massive gap between the 19^{th} and 21^{st}. At 11:00am on the 20^{th} the pool began to be topped up with water to prepare for the summer holidays, resulting in massive consumption of water. This shows how effectively trends can be outlined with the system

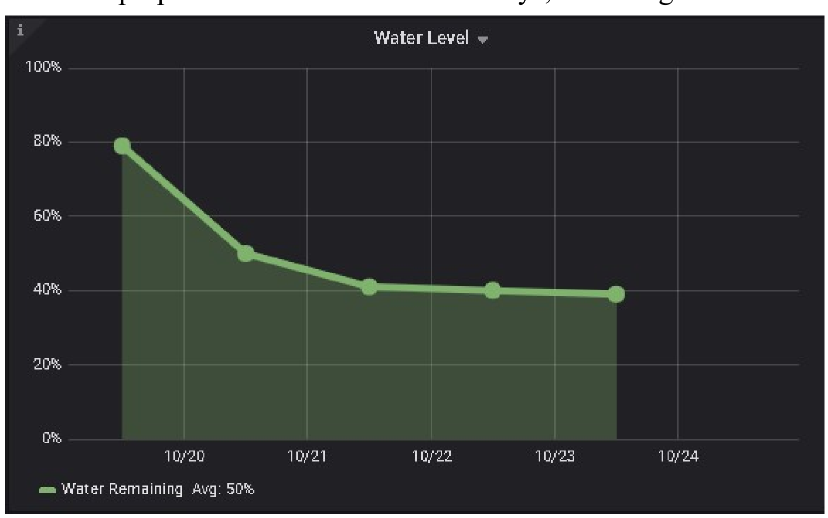


Figure 69: Grafana time series graph zoomed in to a specified time period

The client program may seem unnecessary (Paul asked me: "*why can't the Arduino just insert the data into the SQL database?*"), but I have chosen to keep it in the final prototype as it allows for far easier customization after the box has been installed. This also means that the box itself has a layer of potential complication removed, and since this portion of the prototype will be the most difficult to fix, this is extremely advantageous.

Before getting feedback from the stakeholders, I will personally evaluate the prototype against all specifications and attributes of the design brief (found on pages 23 – 24).

Attribute/Specification	**Prototype Evaluation**
The product must be self-contained and be easy to open and modify. The product will make no physical contact with water. It will be no larger than 180x180x180mm.	The physical size of the prototype device is 67(75)x87x33mm (75mm includes the switch access from outside the case). The product does not make any contact with the water, except through ultrasonic transmissions. Looking at Figure 59, a small notch is present in the case where the switch is mounted. This hole allows a tool-less removal of the top of the case, making it extremely simple for anyone to open.
The product must be versatile. It should be usable in other contexts.	See below this table for an example of how the prototype can be used in another context.
Product must consist of easily purchasable "off-the-shelf" electrical and physical components.	The prototype is comprised of completely off-the-shelf components, including easily accessible open-source software. The final product would likely consist of a proprietary plastic shell, but this remains easily recyclable.
Product must have the ability to predict how long the remaining water will last the client.	Grafana offers a massive range of features, and time series data analysis is one of them. Simple calculations can be performed either by the end user or the developer to achieve this functionality – or the client can just analyze the time series graphing themselves.
Product must be easily integrated within the existing physical and technological environment.	The device uses Wi-Fi, which the vast majority of households utilize. If not, an RF module can easily be added by the developer for the final product. As mentioned the device is small so will be easily integrated in the physical environment.
The product must be easily used, even by those who do not have high technological skills.	The Grafana interface I have experimented with proves this, see Figure 68 to see how effectively the measurement data is presented to the client.
The product must not cost more than $75.	The financial cost of this prototype device was $26. This is without any form of bulk discount or taking into account the lower costs of mass-producing a custom box. This is well below the brief specification of a $75 maximum cost, even if you accounted for shipping, software development and so on. In this regard, the device is an objectionable success.
The product must utilize efficient, effective and reliable technology to measure the water level.	The Arduino microcontroller that powers the measurement portion of the device is modern and has been reliable in my testing. The same goes for the MQTT hoster and my Python client program. SQL is an industry-standard database system that has and will be used for decades into the future. The only possible way that my

	prototype falls short on this attribute is for efficiency, specifically power. The server computation and thus non-client based power consumption are minimal, but the Arduino has not been set up to optimize power. I have no doubt that this excessive power consumption can easily be fixed for a potential final product.

To test versatility (i.e. the ability to utilize this prototype in contexts other than rural water tank level measurement), I have decided to set the device up to check whether my bedroom door has been opened recently as a form of security alert. I quickly took the ultrasonic distance measurement data that is subscribed from the client Python program and performed no calculations on it, as it had been previously for the measurement of water levels, inserting it into a new table in the same database that is accessed from Grafana. I added a new Grafana panel (see Figure 70) to view the distance from the device to the door (physical setup shown on Figure 71). If the panel reads 0 – 1cm, the door is closed, otherwise open. This change in functionality took me less than 10 minutes (for both hardware and software) to set up, and the device is clearly now usable in a different context.

Figure 70 (left): New Grafana panel for simple bedroom security system

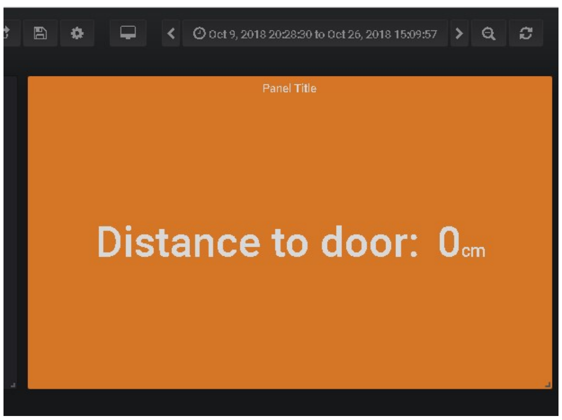


Figure 71 (right): New rudimentary setup for prototype for simple bedroom security system

I could easily add another black microcontroller box to the same system, allowing me to measure water tank levels and perform other tasks like this, something that did not even occur to me in the past. All it takes is simple programming formatting alterations and Grafana configuration. Not only has this ensured the versatility of the prototype, it has shown me how recyclable this product has the potential to be. If the ultrasonic sensor fails, for example, a temperature sensor could replace it to offer more useful data for the client.

3.9 - Stakeholder Feedback

Mr. Gardiner: *"Samuel has created a very versatile product that I am very happy with. It is incredibly cheap to produce, yet can accomplish so much. As it integrates with MySQL and MQTT it is easy to not only analyse any data produced, but also to integrate with other home automation systems and use for a multitude of different tasks. In its current form it would take only a small software update to have it automatically order water when the level is low and the forecast for the next week doesn't contain rain (not that I wanted this, but because of how he's designed it, it's incredibly easy to add). It can also be used to detect movement/the presence of people – by positioning one inside and having it measure more regularly you could use it to trigger your lights turn on when someone comes home after dark, or off when* *no-one is home (thanks to its integration with MQTT). There are so many possibilities without physically changing the device, and only minor software changes. There is nothing on the market as versatile and as cheap as this, and it's easily reconfigured. In the current context for water level measurement it only needs a few software changes to probably add significantly to battery life, but due to his design it would be easy to add a small solar panel with rechargeable batteries as he already regulates voltage. Samuel has been incredibly innovative in how he has combined cheap, easy to source components with open-source software, into a nice secure little box with many possible uses.".*

Paul Kolston: "*I have no issues with this prototype; it seems to do a perfect job. I can imagine a lot of people would make fantastic use out of this device*".

Bailey Tanks: "*I look forward to giving one of these a go. Your programming of the 'Grafana' interface looks especially enticing from a buyer's point of view, and certainly beats the display units customers currently have. If this means you can access the level information from anywhere, I think that your product will be extremely marketable, especially at that price point. Thanks for contacting me!*".

Gallagher Group: "*It has been enjoyable to go through these developments with you. The final prototype looks like it does its job well. The online interface you have used looks like something innovative I haven't seen before as well. Well done*".

Watercare Auckland: "*This looks to be a fantastic device Sam! I look forward to seeing future developments. I think you've done an excellent job!"*

3.10 - Personal Feedback and Conclusion

I could not be more satisfied with the prototype and the stakeholder feedback. While it is true that I have given prioritised weighting to the main client, and to those who provided more meaningful and plentiful suggestions throughout the technological process of developing this device, all of the stakeholders have been vital in the design, development and ultimate success of this prototype. Calling the device a prototype does not even seem particularly fitting as it is overwhelmingly fit-for-purpose even in its current state. I can certainly see myself further developing and refining this system in the future, and believe that it fills a need that will make it adoptable and useful to clients beyond those in the rural living environment. Internet of Things is a budding industry which my device will easily be integrated within – granted, certain considerations such as privacy and data security need to be considered for me to be comfortable with putting my product on the open market for people to purchase and use in their own homes and businesses.

This entire process has taught me huge amounts about programming, 3D-modelling and material design, electronics and interacting with clients to ensure that a product will meet their requirements. Some stakeholders gave me basic explanations as to what they wanted, forcing me to extrapolate based on other clients feedback – this has led me to believe that it is imperative that any technological project have a wide range of stakeholders, even people who may not seem to be linked to the product, leading to a better representation of a potential market for the product to be developed for. I truly believe that this product can and will be able to improve the quality of life for a massive number of people, especially those who would not be able to check their water tank level (for example) due to physical disabilities.

Thank you for reading,
Samuel Kolston

Word Count: **23,969**
Page Count: **60**