BSc Thesis Creative Technology
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Sustainability Improvement through Instrumentation of Water Distribution

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Onderhoud Enschede BV

Abstract

Onderhoud Enschede BV wants to optimize water usage, reduce reliance on potable water, and decrease CO_2 emissions during maintenance operations. More data on their water distribution process should be obtained to achieve this.

This thesis presents the development and evaluation of a non-disruptive logistical data collection system aimed at gaining data insight into the water use of water-based maintenance tasks conducted by Onderhoud Enschede BV. The corresponding research question this study aims to answer is ”How to develop a non-disruptive logistical data collection system for vehicles used for water-based maintenance tasks by Onderhoud Enschede BV?”.

This report provides an analysis of the current water-based maintenance tasks and identifies opportunities for improvement. The primary focus will be on the watering of trees and plant beds. Following this, various methods for monitoring the water level in tanks stored on vehicles used for watering these trees and plant beds are evaluated. Based on these findings, ideas that align with Onderhoud Enschede BV's operational procedures are developed to keep track of water usage when providing water to young trees and plants.

The most feasible solution for this project is to track the rotation of an axle connected to a float mechanism, which correlates with the water level inside the tank. This rotational data will then be converted to determine the water volume. Additionally, this data is combined with GPS information to provide a detailed log of water usage, location, and time.

A prototype system is made and deployed on a vehicle utilized for tree and plant watering. By tracking the weight of the tank while water flows out and simultaneously measuring the rotation of the axle to the tank’s float mechanism, a conversion function is developed to translate the rotation angle into water volume.

After functionally testing the prototype in a real-world scenario, the location tracking successfully indicated the points where trees received water. However, the water volume accuracy is less than desired due to water sloshing and vehicle tilt impacting the float mechanism.

Therefore, future work will focus on investigating other possible concepts to keep track of the water volume inside the tanks of the vehicles used for water-based maintenance tasks at Onderhoud Enschede BV.

Acknowledgement

There are several people I would like to thank for their help and support during my Graduation Project. First, I would like to thank my supervisors Richard Bults and Saskia Hidding for their guidance and support. Secondly, this project could not have been performed without the collaboration of Onderhoud Enschede BV, particularly Han Houdel, who assisted me with applying the prototype in the practical field. Furthermore, I would like to thank Alfred de Vries for all the help in obtaining the materials needed for building the prototype. Finally, I would thank family and friends for their support during the project.

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Chapter 1 – Introduction

This chapter initiates the research thesis. First, a brief introduction to Onderhoud Enschede BV is given in section 1.1. In section 1.2, the problem statement and relevance are explained. Finally, the research question and related sub-questions can be found in section 1.3.

1.1 Onderhoud Enschede BV

The performed research will be done in collaboration with Onderhoud Enschede BV, this is a company based in Enschede, the Netherlands. It is responsible for maintaining and managing various aspects of the public space on behalf of the Enschede municipality. With a workforce of 275 employees, the company undertakes a wide range of tasks, including maintenance and construction work in public areas [1].

This thesis will focus on their water-related maintenance tasks. For instance, only just for maintaining the health and vitality of young plants and trees in the municipality's public areas already calls for more than 10,000 m^3. Figure 1 depicts the total amount of water usage in 2023 for 5 different maintenance tasks. Note that there is no information available on the water usage for watering plant beds in 2023.

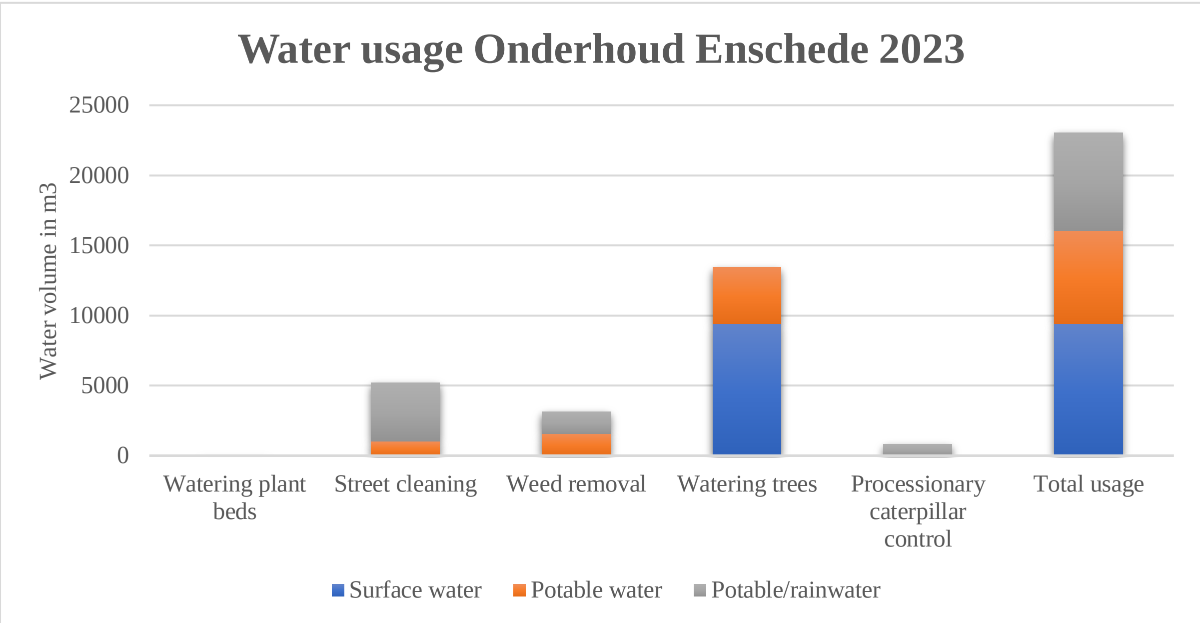


Figure 1, the water usage in 2023 of Onderhoud Enschede BV

To distribute this large water volume, Onderhoud Enschede employs a variety of vehicles equipped with water tanks. Each vehicle can hold varying amounts and qualities of water, such as clean or surface water, primarily depending on its intended use. However, the accessibility of a particular water source can also influence the type of water used.

1.2 Problem Statement

To clarify the project's relevance, this paragraph will briefly outline the challenges regarding the sustainable execution of maintenance tasks and the related importance for Onderhoud Enschede BV.

As the climate is changing, global temperatures are rising in many parts of the world. Especially in cities, it can form major problems due to the urban heat island effect [2]. As a result, urban vegetation is beginning to play a more important role in our lives, as it enhances air quality and assists in cooling the city. At the same time with our finite supplies of clean water and the goal of reducing CO_2 emissions [3], the need to ensure sustainable water distribution for maintenance tasks within urban spaces is growing. This challenge is also relevant for the municipality of Enschede [4], where efficient water management is essential to achieve a sustainable way of working. This specifically means reducing the CO_2 emissions of water distribution and the use of potable water.

In the current situation, there is insufficient information available on how much water each tree or plant bed is receiving. This makes it difficult to use water efficiently and raises the possibility of over- or under-watering. Additionally, using the water more efficiently could reduce frequent trips to distant water sources, which as a result reduces operational costs, saves fuel consumption and therefore reduces CO_2 emissions.

Furthermore, potable water is being used for maintenance tasks due to technical specifications of the use of water distribution technology or (low-cost[1]) availability; clean potable water is frequently easier to obtain than rainfall or surface water. This is an undesirable practice that ought to be changed, given that the demand for clean water will be rising in the upcoming years [5]. Therefore, the motive of this research is to address the need of Onderhoud Enschede BV to gain more insight into the water distribution process for the 5 identified maintenance tasks (see Figure 1).

1.3 Research Question

In collaboration with Onderhoud Enschede BV, this research aims to investigate how data-driven insights can be leveraged to optimize the water distribution process in terms of efficient water usage, thereby reducing the use of potable water and reduction of CO_2 emissions. An innovative solution will be required to gain an understanding of how much water is used for the performed maintenance tasks: the watering of plants and young trees, controlling pesticides, weed removal and street cleaning. The solution should help to identify areas of lack of efficiency or even waste of water in water distribution processes, resulting in the following research question:

”How to develop a non-disruptive logistical data collection system for vehicles used for water-based maintenance tasks by Onderhoud Enschede BV?”

To provide a structured approach for working to an answer to the research question, the project is divided into two subquestions:

“What are the feasible technologies to measure the volume of water tanks for the variety of used vehicles?”

“How to efficiently measure and store location-based water intake and water discharge for the five most important maintenance tasks?”

[1] https://www.vitens.nl/Tarieven-en-voorwaarden#

Chapter 2 – Background Research

This chapter's objective is to provide background information on Onderhoud Enschede BV's current way of working and a comparison of their procedures with those of other municipalities. Then the equipment and methods utilized by Onderhoud Enschede BV to perform the maintenance tasks are covered. Next, possibilities of techniques to measure location-based water intake and release of specific maintenance vehicles are discussed. This is important to gain knowledge about the purpose for which water is used during each specific maintenance task.

2.1 The water-based tasks of Onderhoud Enschede BV

This section will elaborate on the current way of performing the 5 water-based maintenance tasks at Onderhoud Enschede BV and compare them to other municipalities to identify areas for possible improvements.

2.1.1 Watering plants and trees

Onderhoud Enschede BV supports the growth of young, fragile trees by providing them with extra water. In 2023, they supplied approximately 9,408 m^3 of surface water, mostly extracted from the Twente Canal. In addition to the surface water, almost 4,032 m^3 of clean water was needed for young trees containing water bags. These already rather substantial quantities of water do not include the amount of water required for watering the plant beds at Onderhoud Enschede BV in 2023, as no information was available for this process. The reason why these maintenance tasks of "watering trees" and "watering plant beds" are combined in this section is because they are carried out similarly. To supply the necessary water to the city's young trees and plant beds, Onderhoud Enschede BV uses vehicles with large water tanks, which will be examined in section 2.2.1.

To know which vegetation requires water, an employee at Onderhoud Enschede BV performs soil tests at different locations throughout the city. Using a gouge, he obtains a soil sample that provides information about the moisture level around the plants and trees. In addition, the employee examines the foliage on the trees and plants and creates an irrigation schedule based on his observations. Recently, Onderhoud Enschede BV also started working with remote soil sensing, using 16 capacitive sensor systems from the company ConnectedGreen [6]. The main benefit according to the Chief Commercial Officer and Co-CEO René Voogt from Sensoterra [7], (the company manufacturing sensors for ConnectedGreen) is that when the system indicates that the soil is still sufficiently humid, it is not necessary to check for water need [8]. In addition, the sensor systems offer the advantage of better insight into optimal watering patterns which could help provide trees and plants with the water intake [9, 10]. These sensor systems shouldn't entirely replace human monitoring at Onderhoud Enschede BV, as they only provide information on soil moisture and not the health of the trees. However, they may be employed as decision support tools in the future, reducing monitoring visits and hence CO2 emissions.

Even with this knowledge, there is still the issue of not exactly knowing how much water is applied to a certain tree or plant bed, as there is no measurement equipment or other mechanism in place to measure the amount of water discharged from a vehicle. In the current situation, there are plastic barriers around the majority of the trees, mainly preventing the water from immediately dispersing, but also giving a general idea of how much water has been released onto the tree. As these water basins from GreenMax [11] (see Figure 2), can hold up to 100 liters. Naturally, this is not a reliable indicator and a tree may get more or less water than it needs.

Figure 2, water basin around a tree

The majority of the plants and trees are provided with surface water extracted from the Twente canal, but also clean water is used for the young trees containing a water bag. These "Aqua bags" by GreenMax [11] are filled with clean water and slowly release the water, reducing immediate water drainage into the soil (see Figure 3).

Negative side effects of using these water bags are the restriction of tree roots spreading out to create a stable tree and clean water should be provided to prevent debris from getting blocked in the little holes of the bags [12]. Therefore, even if it might reduce the quantity of water required, it still needs more valuable drinking water.

Figure 3, GreenMax "Aqua Bag" containing tiny leak holes

Most municipalities use similar techniques to Onderhoud Enschede BV, including Utrecht. They provide young trees with surface water during dry periods for up to three years after planting [13]. Ensuring that the young trees establish themselves well and survive the critical early stages of growth. For the watering, surface water is used as well.

2.1.2 Cleaning Streets

The streets of Enschede got cleaned with around 1040 m^3 of clean water and 4160 m^3 of a combination of clean- and rainwater, this is because Onderhoud Enschede BV collects rainfall and stores it in an underground basin at the Noord Esmarkerrondweg. This rainwater gets filtered (see Figure 4) [14], and when possible, used to fill up most of the vehicles used for cleaning streets, and weed- and pesticide control. The reason why clean water or filtered rainwater is used for these maintenance tasks is that surface water likely contains debris which could clog the nozzles of high-pressure washers, which are present on the street cleaning vehicles as well as the equipment used for processionary caterpillar and weed control.

Figure 4, Hydra rainmaster trio selfcleaning rainwater filter

Even though not much information is released by municipalities about the type of water used in their street cleaning vehicles, it is reasonable to infer that similar to the sweeping vehicles utilized in Enschede [15] and the vehicle type employed in Rotterdam [16], other street cleaning vehicles across Dutch municipalities likely necessitate clean water in their tanks, given the comparable operational requirements and considerations highlighted in the vehicle datasheets of Rotterdam and Enschede [17]. Eradicating water use during street cleaning is hard as water not only suppresses dust during brushing, it also helps remove debris, stains and excessive dirt, which is the potential breeding ground for weeds [18] [19].

In addition to developing opportunities to lower the amount of (clean) water used during Onderhoud Enschede BV's water distribution process, this paper also aims to investigate the possibility of reducing CO2 emissions during the maintenance tasks. The municipality of Utrecht is concentrated on the same aspect, striving towards the reduction of CO2 levels. Their newest development is the introduction of the first sweeper vehicle to run solely on green hydrogen and produce no harmful emissions such as carbon dioxide [20]. However, because of its manufacturing, storage, and transportation costs, hydrogen is still rather energy-intensive today [21]. Consequently, even though Onderhoud Enschede BVs could reduce their CO2 emissions by utilizing this newest vehicle type, it would be more environmentally friendly to reduce the distance that vehicles must travel by carefully choosing the water source that is used and by optimizing routes—which could be made possible by having a logistical data collection system.

2.1.3 Weed Control

In 2023, 1575 m^3 of potable water and 1575 m^3 of a mix of potable and filtered rain water were utilized for weed control. Before 2016 Onderhoud Enschede BV employed chemical weed control. Since 2016 glyphosate is no longer allowed for weed control [22], they have shifted to a different approach. Utilizing a hot clean water spraying device that drives across sidewalks and roadways while sprinkling weeds with 98°C hot water. As a result, the plants will die due to extreme moisture loss brought on by cellular damage. This method of weed control can be found in several other municipalities throughout the Netherlands, including Soest [23] and Utrecht [24].

In Utrecht, weeds are also removed by treating the plants on all sides with hot air. The advantage is that it does not require any water, but treating weeds with hot air can be slower than using hot water, as the target range is smaller and the plant has to be exposed to heat for a sufficient duration [25]. In line with hot air methods, various municipalities, including Amsterdam[26] utilize flame treatment to burn weeds at the root level. However, while saving water, it's important to note that such strategies are energy-intensive[27].

In Dijk en Waard [28] weed removal is done completely differently, steel brush trucks are used to remove weed. Similar to hot air, no water is involved in this process. While effective at removing visible parts of the weed, steel brushes might not always get the entire root system, leading to regrowth and the aggressive nature of steel brushes can cause damage to the surfaces being treated [29]. The benefit is that you obtain immediate results. This allows for quick assessment and retreatment if necessary.

2.1.4 Pesticide Control

For the preventive measures against the processionary caterpillar, Onderhoud Enschede BV used 800 m^3 of the combination of potable- and filtered rainwater. This water helps to spray bacteria and nematodes onto trees to control the spread of the oak processionary moth.

Previously, the oak processionary moth was only treated curatively by vacuuming the nests. According to Petra Klein Breukink, the District Management Team Leader at the municipality of Enschede this was no longer sufficient [30]. Therefore, the municipality opted for preventive treatments, using the bacterial preparation of XenTari[31] sprayed onto the leaves of a tree and using Entonem[32]. Entonem is a product that contains specific types of nematodes used for biological pest control. This approach is used in areas where special butterfly species are present, as there is no side effect on other caterpillars. However utilizing nematodes has some drawbacks, according to

Maastricht's municipality [33]. It can only be sprayed at night contributing to noise pollution and it results in a much-decreased spraying capacity, which results in considerably higher control costs.

The advantage of the newly adopted preventive method is that the spraying machine provides an electrostatic to the pesticide, which draws the substance to the tree like a magnet. This results in much less loss of pesticide and reduces the need for frequent spraying [24]. In addition, Breukink notes that there are planning benefits. "Because we can start the treatment earlier, our contractors can better distribute their manpower and machinery."

Other municipalities, including Huizen and Apeldoorn [34, 35], have found completely different ways to combat the processionary moth. For example, caterpillars' natural enemies, such as parasitic wasps and a variety of bird species, are attempted to be lured to stop the caterpillars from maturing. This involves hanging tit boxes and planting a large number of botanical bulbs near trees. Even though, by taking these precautions not everything is prevented. So extra removal of caterpillar nests is performed by sucking them up. Preventive spraying is no longer performed in Zwolle as well [36]. There, numerous butterfly filter hotels have been suspended in trees since July 2022. These butterfly filter hotels are filled with caterpillar nests containing caterpillars that are pupating. Insect larvae of natural predators like parasitic wasps and hoverflies are frequently seen in these nests. The natural predators can fly out through tiny escape holes, but the oak processionary moth is stuck. Because of this, the moth is being controlled, while the number of natural predators in these places will rise.

For Onderhoud Enschede BV, promoting the establishment of natural enemies may prove to be a beneficial strategy, since it reduces the need for regular pesticide treatments. Not only does this conserve water used during such treatments, but it also lowers fuel consumption and CO_2 emissions as the pesticide treatments are performed by car.

2.1.5 Discussion and Conclusion

Watering Plants and Trees

Real-time data on the soil moisture state around young trees and plants can be made possible by the incorporation of remote soil moisture sensor systems. Even though, the systems are unlikely to completely replace human observation, as this provides more advanced insights about the health of young trees and plants. An indication of the soil humidity can result in analyzing optimal watering schedules, as well as potentially reducing human monitoring trips, which might lower CO_2 emissions since the trips are made by car. Additionally, the creation of measurement instruments on the water-related equipment at Onderhoud Enschede BV offers insightful information on the amount of water used for maintenance duties at the organization.

Cleaning Streets

Onderhoud Enschede BV uses filtered rainwater in addition to clean water for cleaning public spaces. Surface water cannot be utilized due to potential clogging of the high-pressure equipment's nozzle. However, when focusing on the CO_2 emission for this maintenance, there could be made an advancement in reducing carbon dioxide emissions from street sweeping vehicles. Carbon emissions could be reduced by making the switch to green hydrogen-fueled sweeper vehicles, as seen in Utrecht. Optimally, the most sustainable option is reducing the driven kilometres of the vehicles by optimizing routes and strategic water source selection. This could be achieved when having a better overview of the logistical water distribution process.

Weed Removal

Onderhoud Enschede BV utilizes hot clean water and filtered rainwater spraying for weed removal, Alternatives that do not require water at all could be hot air or mechanical brushing. Having the benefit of no water waste but also limitations, including potential damage to surfaces and an increase in energy use.

Pesticide Control
Employing biological agents such as nematodes or bacteria for pest control shows innovation in minimizing ecological impacts. Yet, this approach faces operational challenges, such as night-time spraying requirements and increased costs. An alternative could be to stimulate the presence of natural enemies of the processionary moth. This not only uses less water to do the operation, but it also results in fewer vehicle trips being made to spray, which lowers CO_2 emissions.

In conclusion, Onderhoud Enschede BV could improve their operational efficiency and achieve a more sustainable way of working in terms of water use by obtaining data on the water-involving maintenance tasks. With precise tracking of water use and implementing data analytics, Onderhoud Enschede BV can better predict future water needs and allocate their water supply accordingly during dry spells.

Reducing water usage isn't always the most sustainable strategy. In certain scenarios, using less water can lead to higher energy consumption. For example, street cleaning gets more challenging to collect debris without using water, potentially requiring more frequent and energy-intensive cleaning efforts.

Another advantage of having a logistical water distribution data collection system is that it can offer useful information on the best water source selection, enabling vehicles to aim for a shorter transit distance from the point of water intake to the task's completion, hence minimizing fuel consumption and CO_2 emissions. Therefore, this research aims to develop a system that keeps track of water use, providing Onderhoud Enschede BV with the tools to improve its water distribution more effectively.

Additionally, integrating greener technologies and natural pest control methods would further contribute to the company's operations with sustainability goals.

2.2 Equipment and Technical Specifications

This section will describe all vehicles and equipment used by Onderhoud Enschede BV to perform water-related maintenance tasks. This will provide more technical specifications and possible design constraints needed to develop a water use measurement installation in a later stage.

2.2.1 Watering Plants and Trees

To provide all the necessary water to young trees and plant beds, Onderhoud Enschede BV owns four vehicles of two different brands, JAKO landbouwmachines [37] and Beverdam Machinery BV [38]. Both types of trucks contain up to 6000 litres of water inside a closed, cylinder-shaped tank, an example of a similar vehicle can be seen in Figure 5. Usually, they get filled twice a day with surface water from the Twente Canal. The pump which is used to fill the vehicle's tank is the Battioni Pagani vacuum pump MEC 5000 [39]. This pump can extract water at a flow rate of up to 6150 litres per minute. Meaning in the optimal scenario it will only take one minute to fill up the entire tank. When one of the valves in Figure 6 is opened to regulate the water flow, the water exits the tank through an attached hose. The two different valves enable switching to a larger spraying installation and a hose that is comparatively smaller to reach more specific areas.

Figure 5, an example of the vehicle which is used to water plants and trees

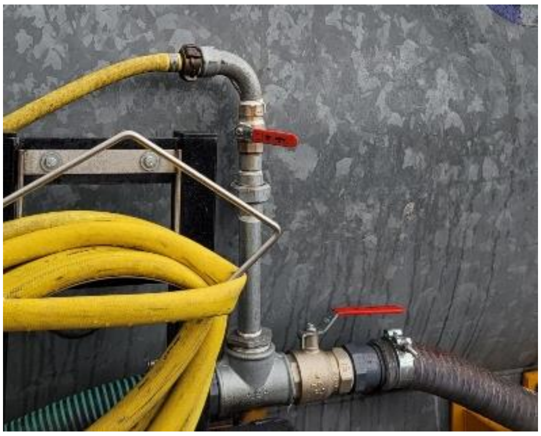


Figure 6, the valves to regulate water outflow

2.2.2 Cleaning Streets

For street cleaning the Bucher CityCat 5006 [15] is used (see Figure 7). The vehicle uses a spraying mechanism to help remove dirt from the street, it contains up to 880 litres of water and gets filled 2 times on a regular day of use. For refilling, a hose gets connected to the vehicle and the tank cover is opened (see figure 8).

Figure 7, Bucher CityCat 5006 used for street cleaning

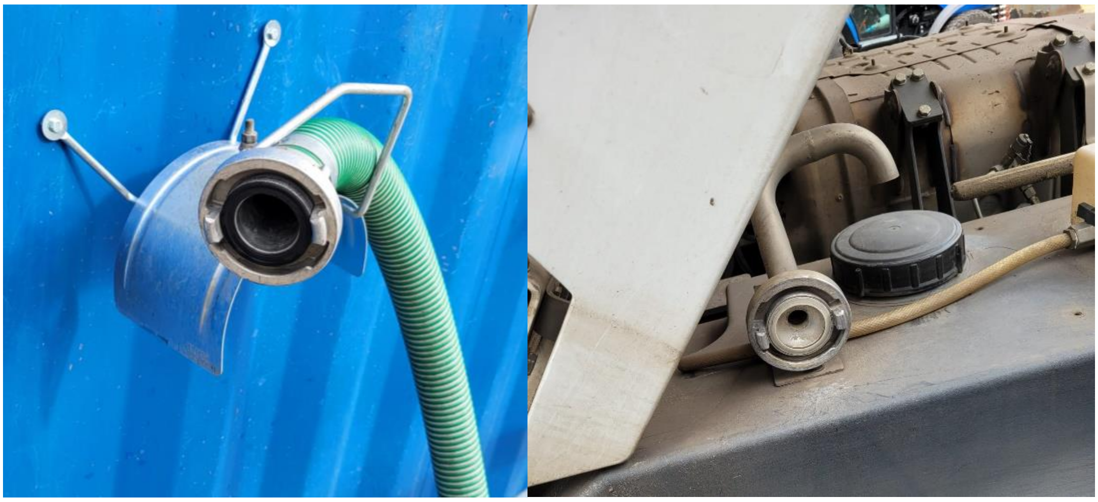
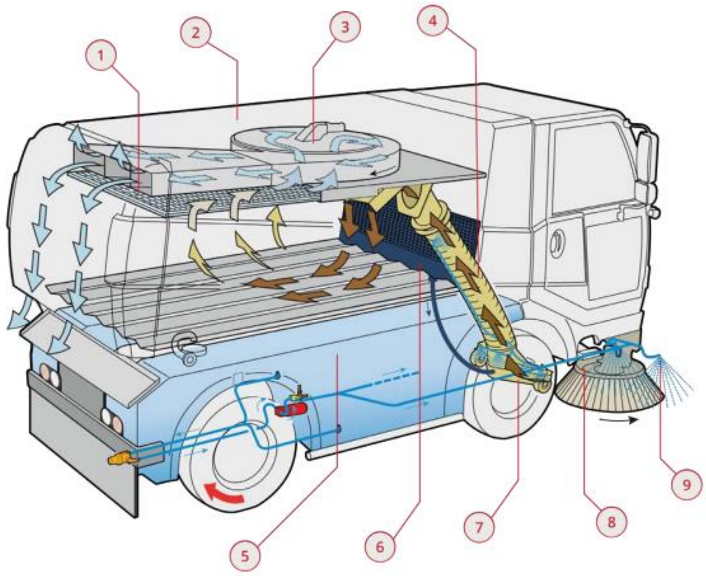


Figure 8, the connection mechanism used for refilling

As briefly mentioned in the earlier chapter, the vehicle gets filled either with clean water or filtered rainwater, because surface water contains debris which could clog the nozzles of the high-pressure hose. There is however a water recirculation system. Water gets collected, filtered and then redirected back into the system to be used again (see Figure 9). This means that clean water is only needed for the nozzles on the brushes, which significantly reduces the clean water consumption of the sweeper, enabling it to operate approximately 2.5 times longer without the need for refilling. However, a lot of water does not wind up in the recirculation system and is wasted when the extra high-pressure hose located on the side of the trucks is turned on to clean a specific area more accurately.



1. Large, easy to clean mesh inside the hopper to prevent clogging by leaves
2. Large 5.6 m³ hopper with water recirculation system
3. Fan arrangement on top of the hopper for optimal air flow
4. Bucher DNA straight suction hose with water nozzles for dust suppression
5. Big 880 l fresh water volume with tank placement for a low point of gravity
6. Recirculation system which feeds the used water directly to the suction intake
7. Wide 800 mm suction intake, laterally adjustable
8. Pulled brush system, whole system laterally adjustable
9. Water nozzles for maximum dust suppression, adjustable from cab

Figure 9, the water circulation system of the Bucher Citycat

2.2.3 Weed Control

As Figure 1 illustrates, the main uses of water are for cleaning streets and watering plants and trees. Onderhoud Enschede BV also has additional equipment for the water-intensive maintenance tasks combatting pesticides and weed control. Onderhoud Enschede BV utilizes hot clean water spraying machines, which are moved around on a trailer. The hot clean water spraying machine, called Heatweed mid 3.0 [40], is connected to a 1000-litre tank (see Figure 10). They get filled with clean water and rainwater, preventing the hose nozzle from clogging due to debris in surface water. The tank has a similar refill connection mechanism as the one shown in Figure 7. Alternatively, the tank may be refilled by unscrewing the cap and inserting a hose.

For weed control, the system utilizes a low pressure of around 0.1 bar, which is effective in delivering the heated water directly to the weeds without causing soil erosion or damage to surrounding infrastructure. For cleaning applications, the pressure can be adjusted up to 50 bar. This higher-pressure setting is used for removing dirt, grime, and even graffiti from surfaces. The maximum water outflow is 8-10 litres/min

Figure 10, Heatweed mid 3.0

2.2.4 Pesticide Control

The processionary caterpillar control is done with the Tifone VRP 1000 Line Sprayer (see Figure 11) [41], which holds up to 1000 litres of clean water or filtered rainwater and is moved around on a trailer. The machine is used on an irregular basis, but more frequently active in the spring and summer as the processionary moths are emerging around that time. With its nozzles that can be adjusted for manual and automatic settings, this sprayer minimizes waste and its impact on the environment while applying pesticides precisely. The system's design includes a suction hose and an automatic mixing-flush system that draws pesticides directly from the container and mixes them immediately, ensuring consistent application. The machine could be connected to a larger water tank to ensure longer operation time and reduce refill frequency. The clean water tank of the sprayer enables to cleaning of the hoses, and nozzles after use, which is essential for preserving equipment performance and avoiding clogs.

Figure 11, Tifone VRP 1000 Line Sprayer [32]

2.3 Sensor Technologies in Water Systems

This section will provide relevant solutions on the numerous options available for keeping track of the volume inside water tanks, encompassing a range of sensor systems required to gain insight into the possibilities to develop non-disruptive instrumentation on the water-based maintenance vehicles of Onderhoud Enschede BV.

When it comes to maintenance tasks that Onderhoud Enschede BV performs, a large potential exists for sensor technology to acquire data and gain insight into the water use per maintenance task. Sensor systems that keep track of the water in and outflow of a maintenance vehicle during the day can offer valuable data by providing real-time insights into use patterns [10]. Therefore, to gain more knowledge about the variety of possibilities for measuring water usage, literature research about different ways to keep track of water volume in a tank has been performed. This provides a better understanding of how types of sensor and monitoring devices function in water distribution systems, and their advantages and disadvantages.

Note that many of the examined methods involve the measurement of the water level and converting this to water volume accordingly. This could become quite a challenge when working with complex tank shapes, which require more than some simple mathematical calculations [42]. This problem could be solved by initially calibrating the tank with known water quantities and noting the related water levels. A metered water input may be used to automate this process. Subsequently, it is possible to create a conversion chart or mathematical connection between the volume and the water level data, which will enable the estimation of the water volume in the tank based on the water level observations [43].

2.3.1 Ultrasonic Sensing

To measure the volume in a tank using an ultrasonic sensor system, the system should be installed at the top of the tank (see Figure 12) [44]. The ultrasonic sensor emits ultrasonic waves, which are reflected to the sensor when hitting the surface of the water inside the tank. By measuring the time it takes for the waves to return, the sensor system can calculate the distance between itself and the water surface.

When equipping ultrasonic sensors within the water tanks of the vehicles of Onderhoud Enschede BV, there are some important considerations. For instance, as the ultrasonic sensor has to be implemented inside the tanks, this complicates implementation and maintenance. This could be necessary when the sensor malfunctions or provides unreliable readings, which may occur due to several circumstances. The sensor could slightly shift in place, changing the angle of incidence and supplying inaccurate readings as a result [45]. Additionally, the system has difficulty obtaining exact readings due to possible vehicle tilt while stationary, the sloshing of water when being in movement, and ultrasonic sensors are sensitive to humidity, which is expected to occur within the tanks [42] [46]. Lastly, aside from the previously noted challenge of translating water level to volume in a complex tank shape, an irregular shape can also lead to unpredictable bouncing of the ultrasonic waves, resulting in many echoes that can be confusing to the sensor [47].

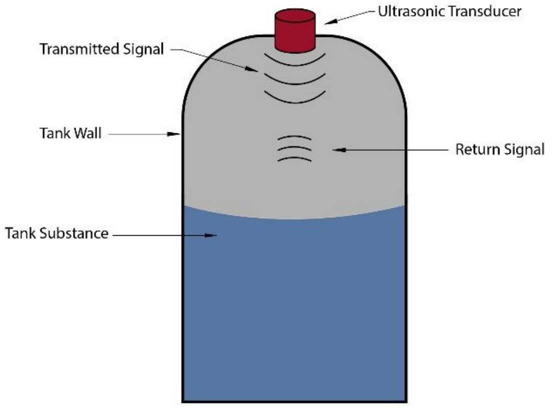


Figure 12, the working of an ultrasonic sensor in a water tank

2.3.2 Pressure Sensor

Another option is to install a pressure sensor at the axle of the tank to measure the pressure caused by the water column. There is a direct correlation between the volume and the pressure on the axle, as one kilogram of water equals one litre.

These sensors are adaptable enough to be used in all of the various tank sizes found in Onderhoud Enschede BV's vehicles since they can withstand high pressures. One potential drawback is that the pressure sensor needs to be installed at the lowest position of the tank, which might be difficult in some configurations due to inconvenient tank shapes. In addition, the pressure sensor presents the same problems in that access to the tank's inside is necessary and movement of the vehicle impacts the measurement as well as the tilt of the vehicle even when stationary.

2.3.3 Capacitive Sensors

Capacitive sensors, which measure the water level by sensing changes in capacitance between two metal electrodes, are another potential solution to monitor the water volume inside the Onderhoud Enschede BV water tanks. Capacitive liquid level detectors sense the liquid level in a reservoir by measuring changes in capacitance between conducting plates which are immersed in the liquid, or applied to the outside of a non-conducting tank [48] [47]. Implementing this sensor could give inaccurate readings for conducting metallic tanks and is therefore not feasible for the tanks of street cleaning and watering vehicles at Onderhoud Enschede.

Even though capacitive sensors offer accurate measurement, they may be impacted by variations in temperature [49, 50]. This situation may arise when the vehicles of Onderhoud Enschede BV absorb water at varying temperatures. Also, like the ultrasonic and pressure sensor, tank access is required and the sensor has to be in contact with the water. This could result in the electrodes of capacitive sensors becoming fouled or coated with materials from the water, especially if the water is dirty or contains a high level of minerals, influencing the accuracy of the sensor. Another aspect influencing the accuracy of capacitance level sensors is the tank's geometry because the placement and configuration of the electrodes, along with the shape of the tank, affect the distribution of the electric field and the electrode's surface area contact with the liquid, leading to variations in capacitance measurements. [51]

The benefit of using a capacitive sensor is that it is quite robust against the movement or tilt of the vehicles.

2.3.4 Magnetic Level Gauge

Using a level gauge (sight glass) is what seems to be the simplest way to monitor the water level in a tank. This transparent level gauge is made out of a transparent tube that allows for direct observation of the liquid level [52]. An advantage is that gauges might be mounted on the outside of the water tanks, making them easier to maintain than instrumentation put inside the tank.

To collect the water level digitally, a magnet with a floating device could be added to the tube. The movement related to the water level can then be tracked by a series of magnetic sensors providing a non-invasive measurement method. More about this way of sensing can be found in section 2.3.5.

2.3.5 Mechanical Float Level Gauge

Closely related to the previously mentioned magnetic level gauge, a float level gauge keeps track of the water volume in a tank [47]. This section will cover the mechanical variant as this is the most common type found in a broad range of applications. From large industrial tanks to domestic water uses such as monitoring the water level in a toilet water reservoir. As implied by the name, the float gauge uses a float that rises or falls according to the water level due to the buoyancy principle [53]. The corresponding movement is then translated to an external indicator, which displays the current level on a scale [54].

Mechanical float gauges are simple and suitable for applications where very precise measurements are not required. When implementing the sensor on driving vehicles, the measurements could be affected due to water sloshing inside the tank [55], which is something that should be taken into account for application on the vehicles of Onderhoud Enschede BV. Float level gauges are already present in some equipment of Onderhoud Enschede BV (see Figure 13) but are not providing any digital data needed for water use analysis. Digitalizing the analogue float gauge could be done by integrating a potentiometer or IMU device. More on this will be covered in the ideation phase of chapter 4.

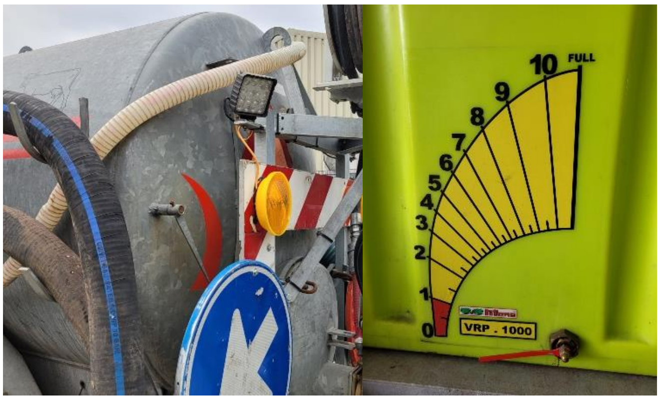


Figure 13, float level gauges present on the equipment of Onderhoud Enschede BV

2.3.6 Flow Meter

One different approach to keeping track of the volume in a tank is to measure the water inflow and outflow. This is something that a flow meter is capable of. It could be connected to the pipes of the water-based maintenance equipment of Onderhoud Enschede BV, so it gauges the volume of water being released onto trees. This means every vehicle's tank's water output line should have a flow meter attached. Additionally, measuring the water inflow can help determine if the tank is filled to its maximum capacity.

This method necessitates a configuration in which the flow meter does not impose any limitations or make any changes that would reduce the vehicle's overall operational effectiveness. Therefore, to discover which flow meter is most suitable for this implementation, different types of flow meters will be analyzed in terms of their working principles and ease of implementation.

Every type of flow meter is comprised of a water-passing chamber and a water-volume-measuring gadget. The water flow rate through the meter must be known, to obtain exact volume measurements. To ensure precise control over the amount of fluid moved through the system, several types of mechanisms are used. The most common mechanical flow meter options include a Piston, Rotary Vane or a Nutating Disk (See figure 14).

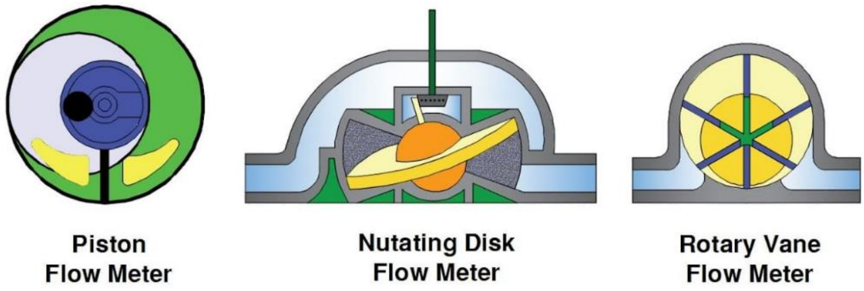


Figure 14, a simple illustration of several mechanical flow meter systems

Piston meters

Piston flow meters function by rotation, oscillation, or reciprocation. In each of these movements, the pistons move fluid like how a syringe works—that is, with every piston movement, a fixed amount of fluid is drawn out. Their standout features include high accuracy, wide flow range capability, and reliability with minimal maintenance needs. However, their larger size may limit their suitability for space-constrained environments [56], which could form an issue for Onderhoud Enschede BV as they should be implemented on moving vehicles.

Nutating disk meters

Nutating disk meters feature a disk that moves in a nutating motion as water passes through, providing volume measurement. They are known for their compact size, affordability, and accuracy in measuring low to moderate flow rates. However, they may not be suitable for applications with very high flow rates, and their sensitivity to flow condition changes might necessitate calibration and maintenance to prevent potential blockages or damage from debris [57]. Therefore, their primary usage is in household applications and is not considerable enough to be utilized for more industrial equipment of Onderhoud Enschede BV.

Rotary Vane meters

Rotary Vane meters utilize a turbine or rotor positioned within the water stream, where the rate of rotation is proportional to the flow velocity. These meters excel in accurately measuring high flow rates [58], which is very useful for the vehicles providing water to the trees and plants as they deal with large volumes of water and high flow rates. Furthermore, Rotary Vane meters introduce minimal water flow rate drop compared to the other types of flow meters. This characteristic is very beneficial in situations when it is important to maintain consistent pressure levels since the flow rate is proportional to the square root of the pressure gradient ($F \propto \sqrt{P}$) [59]. In the context of Onderhoud Enschede BV, this property is required for the processionary caterpillar's equipment to sustain a certain amount of pressure ensuring the functioning of the spraying mechanism.

Rotary Vane meters are also relatively straightforward to install and integrate into existing piping systems. Thus, their compact design and compatibility with various pipe sizes and handling and maintaining high flow rates make them a practical choice in the setting of Onderhoud Enschede BV.

Discussion and Conclusion

For the equipment at Onderhoud Enschede BV, high flow rates are predominant which makes Rotary Vane meters the preferred option. However, when selecting this option, every vehicle's tank's water output (and preferably input) line should have a flow meter attached.

Also, the accuracy might be impacted by several things, such as reduced water pressure or debris lodged in the meter [60]. Naturally, there is a greater chance of a clogged meter when using large amounts of surface water, which could make the solution less favourable for the vehicles extracting surface water.

2.3.7 Additional Measurement Techniques

The above-mentioned sensors are the most used sensors to keep track of water levels in a tank, which can be converted to volume changes in a tank. Logically, besides the water flow meter, there are more sensors and methods available to keep track of the water inflow and outflow of a tank. Examples include load sensing and timing of the water inflow and outflow. These methods will be covered in more detail in the Ideation phase (see Chapter 4).

2.4 The Data Collection System

To make the data on water usage for each maintenance task more valuable, it is essential to link water consumption data with the time and location of use. The bigger objective is to develop a data collection system that displays this information on a dashboard. This will enable Onderhoud Enschede BV to enhance its water distribution management by optimizing vehicle routes through improved selection of water sources and potentially reducing the reliance on clean water by identifying viable alternative sources. This section will cover how the system could integrate the data to gather the necessary insights.

2.4.1 Location and Time Tracking

The start locations from where the maintenance vehicles drive out are the Noord Esmarkerrondweg 419 and Vlierstraat 103. Onderhoud Enschede BV uses the ArcGIS system to manage the locations and watering status of plants and trees [61]. Vehicles often drive significant distances from these locations to refill their vehicles' water tanks, because it is the standard procedure or appears to be the simplest. This could be prevented when obtaining a better overview of the amount of water used at each registered location, as more efficient routes and water sources could be established due to better planning advantages. To gain a better understanding of the way the routes are organized and where all the water gets distributed, the location of the vehicles from Onderhoud Enschede BV should be tracked. The most common option to achieve this includes using GPS, as it offers great accuracy, providing location information within a few meters most of the time. Another benefit is that Coordinated Universal Time (UTC) can be obtained from the satellite clock [62].

2.4.2 Data Transferring

Naturally, all the measured data should be put together. This could be done manually but is quite labor extensive and the data collection system should be as non-disruptive as possible. Therefore, to enable reliable and efficient real-time data collection, a wireless connection should be set up. The most practical way to handle the measured data is to send it to an edge device[2], where it can be analyzed locally or forwarded to the cloud for further analysis. This is where the emerging Internet of Things (IoT) technology comes into play. By leveraging IoT technology, data can be sent directly to a database, enabling continuous monitoring and minimizing the risk of human error associated with manual data transfer [63]. However, this approach also increases the risk of sensitive data leakage due to the wireless connectivity and data sharing inherent in IoT systems [64].

[2] An edge device is an endpoint on the network, the interface between the data centre and the real world.

Chapter 3 – Methods and Techniques

This chapter covers every step required to complete the research project. These steps follow the Creative Technology design process [65] (see Figure 15), which is an iterative design approach allowing for continuous change and development.

The Creative Technology Cycle has four distinct phases, including Ideation, Specification, Realization, and Evaluation. The research project will be connected to and explained for each of these four sections below.

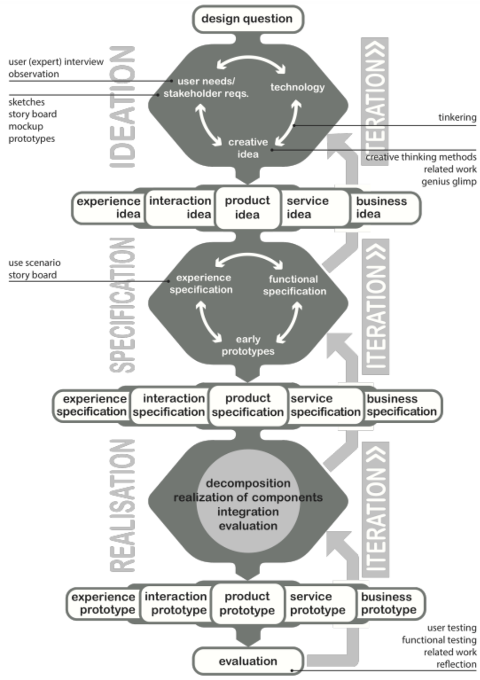


Figure 15, the Creative Technology Design Process

3.1 Ideation Phase

The ideation phase started with defining and analyzing the stakeholders of the project. Each stakeholder will be analyzed based on their influence and interest in the project. To do this in a structured way, an Interest/Power grid has been used [66] (see Figure 16). To elicit the preliminary requirements for the prototype system, semi-structured interviews with primary stakeholders and observations of the machinery and locations at Onderhoud Enschede BV are conducted.

After constructing the preliminary requirements, they are categorized according to their importance. This will be done by making use of the MoSCoW technique [67]. By categorizing the preliminary requirements as must, should, and could be implemented, it is ensured that the most critical needs of the stakeholders are prioritized first.

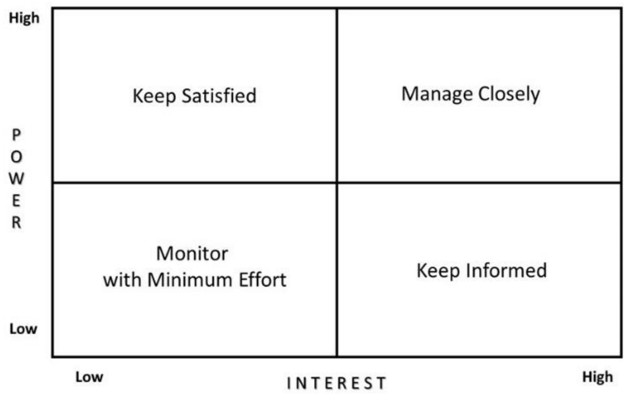


Figure 16, the power/interest grid used to analyze stakeholders

To stimulate the generation of more creative thoughts during the Ideation phase, a divergent design methodology is used. This methodology involves generating a variety of possible options without initially evaluating or selecting any particular direction. Brainstorming without any constraints promotes generating innovative solutions by breaking away from conventional thinking. After the concept generation, the design space is narrowed down by evaluating aspects such as modularity, accuracy, feasibility, and durability of each concept. This process results in identifying a single suitable concept, which will be further developed in the next stages.

3.2 Specification Phase

After exploring the functionalities the system should adhere to and selecting a final concept, the next steps in development can begin. The system's operation will be shown using the concept in a use case. Afterwards, both functional and non-functional requirements are produced based on the set of preliminary requirements. These requirements serve as criteria to which the system should conform and are also utilized for evaluation later on. Finally, the specification phase will include the system architecture. Consisting of a level 0: System Overview, Level 1: System Decomposition and a flowchart of the processes.

3.3 Realization Phase

The project moves on into the Realization phase after an overview of the functionalities of the system is established. This phase will examine more technical aspects, such as hardware and building components to realize and develop a physical prototype. The selected components should be easy to install and interface with the existing vehicle systems and should meet the functional requirements outlined in the Specification phase in Chapter 5.

3.4 Evaluation Phase

In the last Evaluation phase of the Creative Technology Design process, the final product will be evaluated in terms of functionality, usability, performance, reliability, scalability, maintainability, and any other relevant factors. This will involve evaluating whether the functional requirements from the Specification phase have been appropriately integrated and the system is operating as intended, as well as an assessment of the non-functional requirements. For this assessment user evaluation will be used, indicating the satisfaction of the stakeholders. The Evaluation phase will also asses the project's success and provide help answering the research question, ”How to develop a non-disruptive logistical data collection system for vehicles used for water-based maintenance tasks by Onderhoud Enschede BV?”.

Chapter 4 – Ideation

An important part of the Creative Technology Design process is the Ideation phase, during which a variety of concepts and approaches are investigated to work towards developing a non-disruptive logistical data collection system for vehicles used for water-based maintenance tasks by Onderhoud Enschede BV. Overall, this chapter describes the stakeholder participation, ideation sessions, draft designs, and requirements that helped to refine the concepts into a feasible prototype concept on a vehicle used for watering trees and plant beds.

4.1 Stakeholders

To develop a feasible and functional prototype, the project started with identifying the relevant stakeholders and their needs and requirements, which are covered in this chapter.

4.1.1 Stakeholder Identification

Stakeholder identification is crucial in ensuring that all parties who can influence or are impacted by a project are considered. For this project, the following parties are involved (Table 1):

Nr	*Stakeholder*	*Description*	*Interest*
1	*Management Onderhoud Enschede BV*	The management of Onderhoud Enschede BV is responsible for the sustainability of the water-based maintenance tasks within Enschede, requesting measurement of their water use and potentially reducing the use of clean water.	Interested in gaining precise insights into water usage to meet sustainability goals and reduce CO_2 emissions.
2	*Employees Onderhoud Enschede BV*	Employees directly involved in daily operations, responsible for executing water-based tasks.	Aiming to enhance their workflow efficiency without disrupting current operations, by accessing detailed insights on water usage and optimizing routing.
3	**Bart Aarts (Me)**	Student conducting research for the graduation project by applying gained academic knowledge to a real-world sustainability issue.	Aims to complete the graduation project by developing a functional prototype that serves as a non-disruptive logistical data collection system, aligning with the project's objectives.
4	**Richard Bults**	Project supervisor guiding the graduation project's direction and evaluation.	Ensure the project meets academic standards and is completed successfully.
5	**Saskia Hidding**	Project supervisor guiding and evaluating the graduation project and assisting Onderhoud Enschede by creating a dashboard overview from the data collected through the implemented logistical data collection system.	Successful completion of the graduation project, meaning a data collection system that provides accurate, actionable insights on vehicle locations, times, and water usage is realized and can be used to create a dashboard.
6	**Vitens**	Water supply company that could be affected by the project's outcomes, particularly in terms of reduced demand for clean water.	Benefits from reduced demand for clean water, relieving pressure on water supplies.

Table 1, involved stakeholders of this project

4.1.2 Stakeholder Analysis

Naturally, every stakeholder has a specific interest and position of power within the project. Their degree of engagement with the project's results and their ability to influence decisions can be classified by making use of the power/interest paradigm (see Figure 17). This provides valuable insights into their responsibilities and significance to the project's outcome.

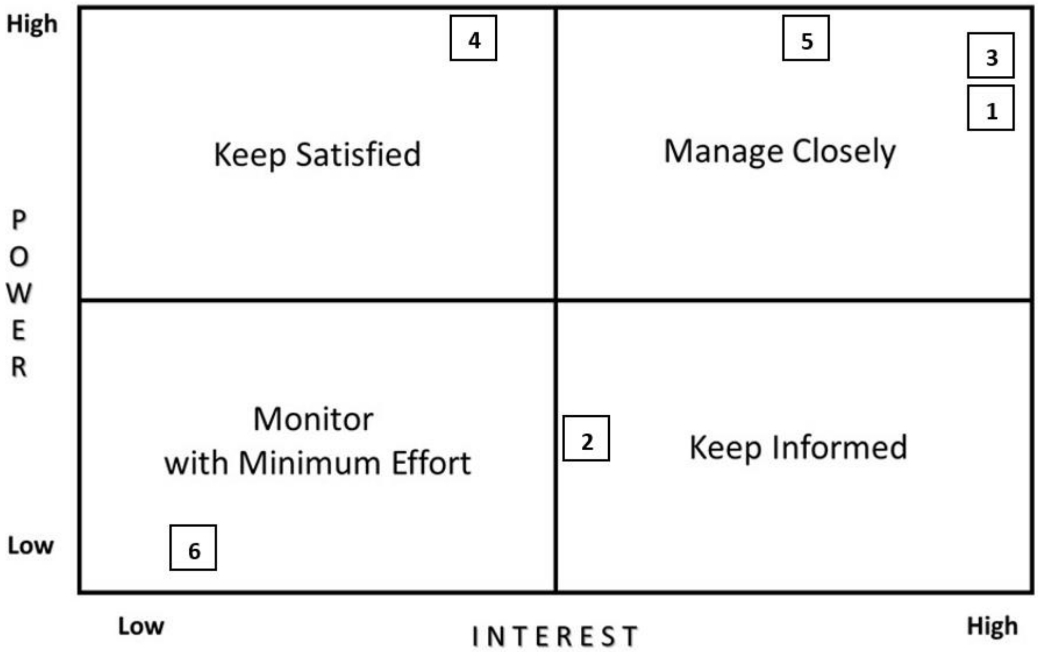


Figure 17, the power/interest paradigm categorizing stakeholders

The power/interest grid shows that Bart Aarts (Me) has a strong interest in the project, given that the project's outcome is of crucial relevance to my graduation. Besides this, I am the one designing the technology, resulting in a great amount of control over the project.

The supervisors Richard Bults and Saskia Hidding have more power over the project, as they have the responsibility of evaluating the project and certifying its compatibility with the Creative Technology curriculum. However, as Richard Bults will not be immediately impacted by the project's outcome, his interest in the project is considerably reduced.

Saskia Hidding does have more interest in the project, as she wants to ensure the operational functionality of the water distribution tracking system. Eventually, she is planning on using the collected data to create a dashboard for better water use insight.

Onderhoud Enschede BV is divided into two different stakeholders, as the management and the employees of Onderhoud Enschede BV do not exactly share similar interests.

As the management is requesting the water distribution instrumentation system, their interest is particularly intense because the project directly contributes to their sustainability goals. Moreover, they possess significant influence over the system's design due to their specific expectations and requirements. Therefore, the management holds both a very high level of interest and a high power of influence over the project.

Although the employees at Onderhoud Enschede did not initially request a water distribution tracking system on the water distribution and therefore do not have much influence in the development, they stand to benefit from its implementation. The system could enhance their operational efficiency by optimizing route planning, which would save time and streamline their workflow.

Finally, when Onderhoud Enschede BV can decrease their use of potable water, it will alleviate pressure on Vitens, making it more feasible for them to ensure a steady supply of clean water to all consumers. Successful completion of this project can therefore benefit Vitens in the long term.

4.1.3 Stakeholder Requirements

The requirements of the desired system emerged from the interest of the stakeholders. They were constructed by performing semi-structured interviews and observations of the machinery and locations of Onderhoud Enschede BV. To determine the main priorities of the system, the MoSCoW technique was applied. Meaning the requirements are divided into must, should and could categories (see Table 2). In the specification phase, these requirements will be more specified and divided into functional and non-functional requirements, which will eventually help evaluate the project's success

Category	Requirement
Must	The system must accurately measure and record water usage data from vehicles for watering young trees and plant beds.
	The system must combine the data on water use with the location and time.
Should	The system should strive for a modular design, so it can be implemented on all the vehicles for watering young trees and plant beds at Onderhoud Enschede BV.
	The system should not interrupt the current way of working of the employees at Onderhoud Enschede BV.
Could	The system could format the obtained data on water use, location and time in such a way it can be directly displayed on a dashboard.
	The system could provide the obtained data to be displayed on ArcGIS.

Table 2, stakeholder requirements based on the MoSCoW technique

4.2 Concepts Generation

First, the focus lay on generating potential solutions, where the aim was to obtain a broad spectrum of ideas without judgement or filtering, encouraging innovative methods to keep track of water volume inside of the water tank on vehicles for watering young trees and plant beds. From the brainstorming session, multiple concepts were generated and divided into the categories of flow rate measurement, water level measurement and weight measurement. These are briefly described and then an overview is created to examine the advantages and disadvantages.

4.2.1 Flow Rate Measurement

The first option involves keeping track of the water inflow and outflow rate. This will provide a change in volume as you can just add or subtract the incoming or outgoing water. Two ways to do this are on/off timing and water flow rate measurement. First, by implementing a timing mechanism of how long water is flowing in or out of the vehicle and by taking an estimation of a constant average flow rate, found in the specification manual of the pumps being used. In case of an unstable flow rate, this method is quite inaccurate. Then the second option would be to measure the flow rate more exactly by using a flow rate measurement device to determine water volume passing through a pipe. This is more accurate but requires some extra implementation effort.

4.2.2 Water Level Measurement

The second strategy is measuring the water level in the tank of vehicles used for watering young trees and plant beds, which can be converted into a volume of water in the tank.

Several approaches to tank water level measurement are already covered in Section 2.3, Sensor Technologies in Water Systems. The most feasible methods are examined in this section.

Starting with using ultrasonic waves to determine the water level from the top of the tank. This method may encounter difficulties when vehicles are in motion, impacting its accuracy and practicality. The next strategy involves mechanical water level indicators, as illustrated earlier in Figure 13. The vehicle used for watering trees and plant beds already has these indicators, and the water level can be calculated by measuring the angle of the float's axis. This strategy is only possible on vehicles with an external float mechanism and is therefore not a very modular solution. Building on the previous method, another approach involves using a float with magnetic tracking to provide direct water level observation. This method can be implemented in all vehicles with access to the tank. The last method involves using capacitance sensors, which measure variations in capacitance between probes to gauge the water level. However, their viability may be affected by tank materials, humidity, and temperature.

4.2.3 Weight Measurement

The last category makes use of the weight of water, one liter of water translates to approximately one kilogram. Therefore, by monitoring the weight of the vehicles or water tanks very accurate water volume measurement can be achieved. This solution is extremely adaptable and suitable for a wide range of configurations. The next method occurs inside the water tank, where the water pressure can be measured. Although accurate and modular, there might be some implementation difficulties due to different tank shapes and access inside the tanks.

4.2.4 Table Overview with Sensing Possibilities

A detailed comparison of potential solutions is performed based on the insights obtained in Chapter 2. This comparison considers various criteria such as goal, modularity, accuracy, feasibility, durability, and cost. The following table (Table 3) summarizes the findings:

The score in Table 3 is calculated according to the following assigned values.

Rating	Value	Description
+++	3	Very Good / Highly Suitable
++	2	Good / Suitable
+	1	Moderate / Acceptable
-	-1	Poor / Challenging
--	-2	Quite Poor / Significant Challenges
---	-3	Very Poor / Major Obstacles

Category	*Goal*	*Modularity*	*Accuracy*	*Feasibility*	*Durability*	*Score*
Flow rate (On/off timing)	Insight into water volume from outflow rate	+++	---	+	+++	4
Flow rate (Water meter)	Measures flow rate to determine water volume	++	++	+	+	6
Water level (Float axis)	Water level indication via float's axis angle	-	+	+++	+	4
Water level (Ultrasonic sensing)	Calculating the water level from the top of the tank by ultrasonic waves	+	-	-	-	-2
Weight (Load sensing)	Tracks weight difference to determine water volume	+++	+++	-	+	6
Weight (Pressure sensing)	Measures water pressure at the bottom of the tank to infer the water level	+++	+	--	--	0
Water level (Magnetic level gauging)	Direct observation of water level with magnetic tracking	+++	+	-	-	2
Water level (Capacitive sensing)	Measures the capacitance between probes which changes according to the water level	+++	++	-	--	2

Table 3, result of possible solutions after brainstorming

4.2.5 Top 4 Preliminary Concepts

Based on the score of Table 3, the four best preliminary concepts are selected and examined in this section. This includes the concepts of on/off timing (score 4), water flow meter (score 6), float axis (score 4) and weight scale (score 6).

On/off Timing

The first solution includes a timer that automatically keeps track of how long the pump is running to measure water volume based on the duration of the outflow. This method can be applied to any vehicle equipped with a standardized water discharging mechanism. Therefore, this concept should be relatively easy to implement, as it does not require much additional hardware. This also makes the system durable, as no extra mechanical parts can wear and tear.

The downsides are that it does not gauge the water inflow and the accuracy depends on the flow rate. Measurement uncertainty is introduced when the flow is unstable and fast [56]. Also, the precision of the timing mechanism influences accuracy and water leakage can occur after turning off the pump. Since the flow rates for the water-involving vehicles typically revolve around high levels at Onderhoud Enschede BV and the collected data should be precise, this approach is most likely not considered to fulfil the accuracy requirement set by Onderhoud Enschede BV.

Water Flow Rate Measurement

A water flow meter offers versatility across various maintenance vehicle types and may be put in any vehicle with a plumbing system that can handle a flow meter. They are made to measure flow rates precisely, which are directly connected to volume. A downside of flow meters is that they consist of mechanical elements that are prone to wear or malfunction due to debris present in the water.

Float Axis

The third concept utilizes the mechanical float gauge, which is already present in the water tanks of the vehicles watering trees and plant beds, to monitor water levels. These float gauges provide an external view of the water level inside the tank. This approach leverages existing equipment, making it relatively straightforward to implement. Since the floats are already integrated into the tanks, there is minimal need for additional hardware, reducing the potential for mechanical failures.

However, this method may be less accurate if the float mechanisms are imprecise or not properly maintained. Ensuring regular maintenance and calibration is essential to maintain the accuracy of this system.

Weight Scale

The fourth concept involves using scale mechanisms to track the weight differences of the vehicles, which allows for the calculation of water volume. This system is highly accurate, as the only variable affecting the weight is the operator of the vehicle. By measuring the change in weight before and after water extraction or release, the system can provide precise data on water usage.

4.3 Final Concept

The most simple and accurate method to keep track of the water volume inside the tanks of the vehicles used for watering trees and plant beds would be using a static vehicle scale. However, this requires the vehicles to drive to the scale every time water is added or removed and is not the most efficient method. A better approach to achieving real-time weight monitoring involves tracking the weights of just the water tanks inside the vehicle. This will provide data on where and how much water a vehicle has extracted or released, without having to drive to a scale each time. This method works well for weed and pesticide control equipment, as their water tanks are not integrated into the vehicles. However, for vehicles used for watering plants and trees and street cleaning, the tanks can not be weighted separately from the vehicle. There is a method often used in regular lorry trucks, which involves a load sensor in the vehicle's suspension system[68]. This implementation is rather complex and beyond the scope of this project.

Considering the principle of tracking water inflow and outflow, using on/off timing or installing a water flow meter are potential options. Due to the requirement of 100 litres accuracy per tree, on/off timing is not preferred.

Using a water meter is also not optimal, as there are multiple spots on the vehicle used for water release, meaning multiple flow meters would be required. Additionally, debris from surface water could accumulate in the flow meter, affecting its functionality, as discussed in section 2.3.6.

Given the aforementioned factors and the project's time constraints, the Water level (Float axis) proposal is the most suitable, as indicated by its high feasibility score in Table 3. In the final design, the mechanical float axis' rotation angle (Figure 18) will be converted to a digital format. It will then be converted to a digital format and then translated to water volume.

Figure 18, mechanical float mechanism indicating the water level inside the tank

Chapter 5 – Specification

This chapter details the specifications of the water distribution tracking system designed for Onderhoud Enschede BV. This will begin with a detailed interaction scenario of the system. Then, all the functional and non-functional requirements are covered and last an overview of the functionalities of the system will be displayed.

5.1 Persona and Interaction Scenario

Although the water distribution monitoring system should be non-disruptive, it will involve some interactions. First, a fictional use case of a vehicle mechanic interacting with the physical device will be provided. Afterwards, a fictional scenario of an urban greenery manager will explain how he interacts with the data obtained from the system.

5.1.1 Persona One

Name: Henk de Jong
Job: Vehicle Mechanic at Onderhoud Enschede BV
Responsibility: Ensuring proper functioning of the vehicles of the fleet at Onderhoud Enschede BV
Goal: Implementing and fixing the data collection system

5.1.2 Use Case Scenario

At Onderhoud Enschede BV, Henk de Jong is in charge of vehicle maintenance. This means Henk has to identify and resolve problems with the vehicles as soon as possible to save downtime and guarantee that the maintenance employees can carry out their duties without disruption. Among his responsibilities include fixing lights and tyres, but also making sure that the water distribution monitoring system remains functional.

One day Henk discovers a vehicle that has been operating without providing any GPS data. This indicates that there is a problem with the water distribution monitoring system. He reads the data by simply connecting his computer to the physical sensors. When he finds no valid GPS data is available, he first checks if there is enough battery left in the power bank. Then, he starts inspecting the hardware. Upon noticing a loose wire, he reconnects it and runs tests to make sure the GPS data is being sent to the database again.

Next, Henk accesses the database to verify that the water distribution monitoring system is receiving and displaying data. Satisfied that the issue is resolved and the system is fully operational, he informs the management team that the vehicle is back in service.

5.1.3 Persona Two

Name: Tim Bakker
Job: Urban greenery manager at Onderhoud Enschede BV
Responsibility: Ensuring that the plants and trees throughout the city of Enschede remain healthy.
Goal: Obtaining data to instruct vehicle operators and reduce accountability towards the municipality of Enschede.

5.1.4 Use Case Scenario

Tim Bakker is in charge of managing the maintenance of Enschede's urban vegetation. When creating watering schedules, he makes decisions based on the water distribution monitoring system.

Tim starts his day by reviewing the previous day's data on water usage from the monitoring system. He checks that the trees receive an adequate supply of water. Using the ArcGIS program, which Onderhoud Enschede BV uses to monitor the watering of plants and trees, he marks regions that need more watering and those that have had enough. He ensures that the operators are aware of the exact volumes needed for each location, preventing over- or under-watering.

At the end of the day, Tim checks the water usage, location, and time data to ensure the right amount of water has been provided to the indicated location instructed at the start of the day.
If he finds any differences or locations that were overlooked, he gets in touch with the drivers of the vehicles to make any necessary adjustments.

Tim uses the information gathered to create a report after each week. The amount of water that the plants and trees have received is detailed in this report. This decreases the accountability Onderhoud Enschede has to the municipality of Enschede when trees or plant beds are perishing, while the right amount of water is received.

5.2 System Requirements

The system requirements are organized using the MoSCoW method, separating them into functional and non-functional categories based on the stakeholder needs derived from Chapter 4.1.3. The requirements are associated with a number that indicates whose stakeholder's need they belong to.

1. Onderhoud Enschede management
2. Onderhoud Enschede employees
3. Saskia Hidding
4. Richard Bults
5. Bart Aarts

Functional Requirements	Non-functional requirements
Must	
The system must keep track of the water volume, location, and time of the vehicles watering the trees and plant beds during operation (1)	The system must not interrupt the current way of working of the employees at Onderhoud Enschede BV (2)
The system should operate autonomously, requiring no user input except for battery replacement and occasional maintenance (2)	
The system must send the collected data to a database every second (5)	
The system must convert the rotation angle of the float’s axis changes in water volume with a maximum deviation of 100 litres, which equals the approximated water volume given to a single tree (3)(4)(5)	
The system must indicate how much water is used during a single trip with a maximum deviation of 100 litres (3)(4)(5)	
Should	
The system should include a modular design, enabling it to be applied to all the vehicles used for watering trees and plant beds (3)(4)	The system should be easy to install and maintain

The system should include a turn-on and turn-off button to stop data transmission to the database when the vehicle is not in operation (5)	The system should be placed in an operation-safe area on the vehicles of Onderhoud Enschede BV.
Data should be received at least every 5 seconds in the database (5)	The system should contain a battery, enabling operation for at least 8 hours without recharge (1)(2)(5)
	The system should be waterproof with an IP rating of at least IPX7 (5)
	The system's data transfer to the database should be reliable and secure, filtering incorrect data formats (i.e. incomplete GPS information) (5)
Could	
The system could add the functionality of integrating the obtained data with the ArcGIS application, currently used by Onderhoud Enschede BV to keep track of watering plants and trees (3)	
The system could include a physical indicator for the vehicle operators, which displays the water volume inside the tanks (5)	

Table 4, functional and non-functional requirements categorized using the MoSCoW technique

5.3 Flowchart

To understand how the water distribution tracking system operates, a flowchart (See Figure 19) illustrates the process from water extraction or release to data transmission and storage. The flowchart outlines the following sequence of actions:

- Start
- Read the rotation angle of the float mechanism's axle every second using the potentiometer.
- Convert the rotation angle to water volume using the pre-calibrated conversion function.
- Read the GPS data every second (location and time).
- Combine the water volume data with the GPS data.
- Format the combined data for transmission.
- Check if the mobile network connection is active.
- Transmit the combined data to the remote database via the mobile network.

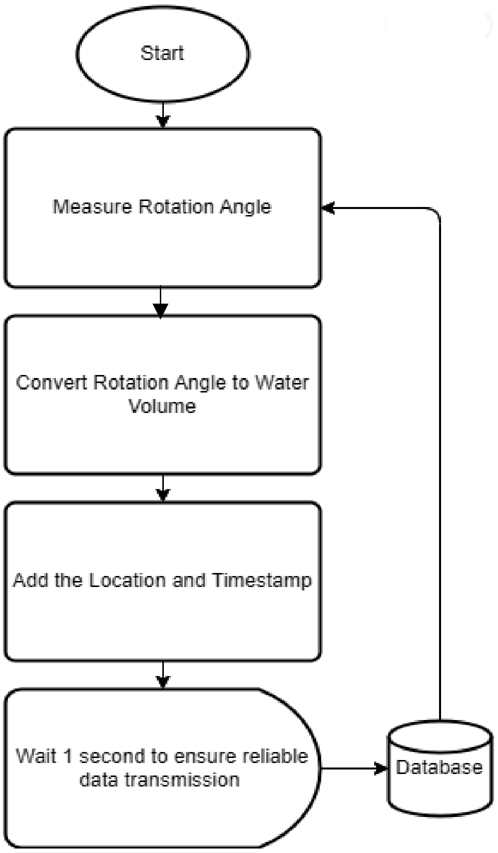


Figure 19, flowchart showing the system's processes

5.4 Functional architecture

The goal of the functional system architecture is to provide a clear overview of how the water distribution tracking system will function, as well as to clarify and define system interconnections and functions. Level 0: System Overview is the first level in the functional system architecture hierarchy. Then Level 1: System Decomposition will provide more detail of the system functioning.

5.4.1 Level 0 System Overview

This part displays a general overview of the water distribution tracking system (see Figure 20). When water is extracted or released from the tanks of the maintenance vehicles used for watering trees and plant beds it will be combined with the GPS data and then sent to the database.

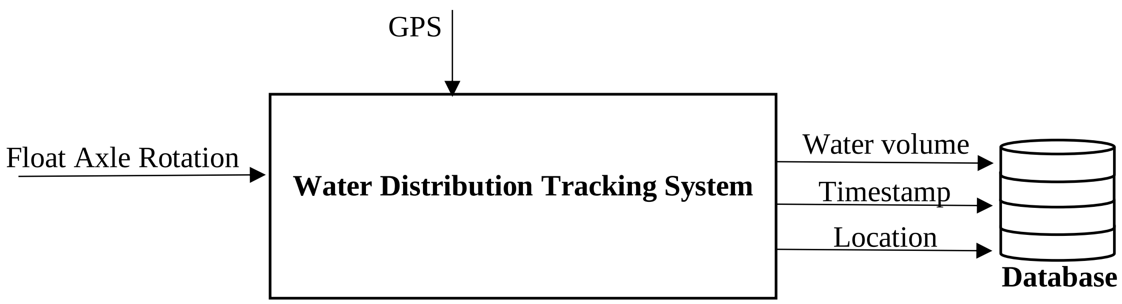


Figure 20, Level 0 System overview

5.4.2 Level 1 Decomposition

This section examines the role of the water distribution tracking system in greater depth (see Figure 21). The changing water level inside the tank influences the rotation angle of the float's axis, which is then translated into a change in water volume. The relevant GPS data will subsequently be sent online along with it. The GPS data and the volume change time will be compared, and the results will be stored in the database.

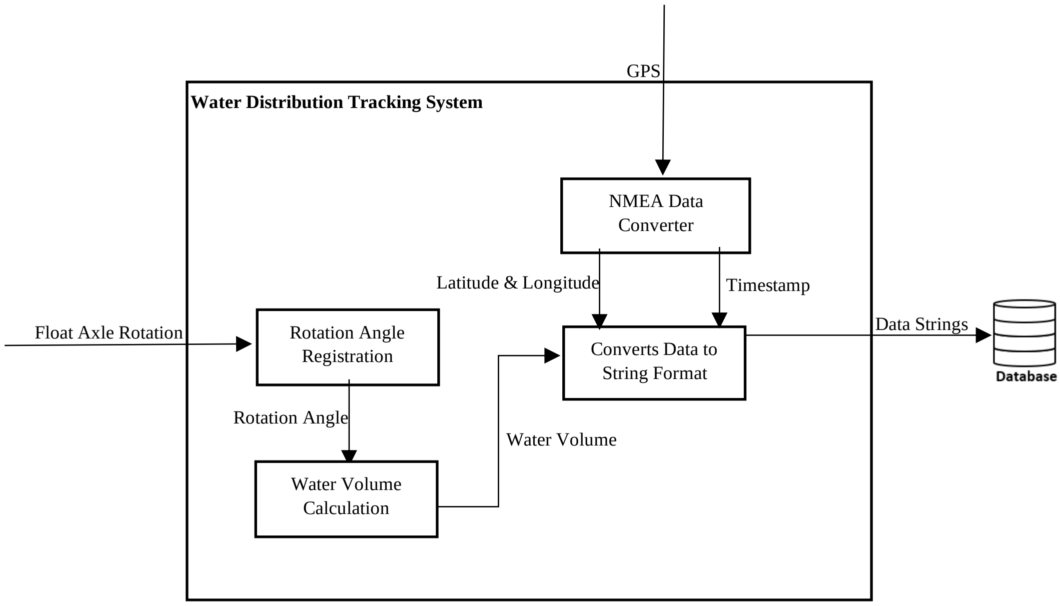


Figure 21, Level 1: System decomposition

Chapter 6 – Realisation

This chapter details the development of the functional prototype for the selected concept, focusing on measuring the rotation of the external float axis.

6.1 Main Construction

Initially, three 3D models were made in SolidWorks for the creation of the prototype's primary structure and housing for the potentiometer. After that, these models were 3D printed and came in the following parts:

Static clamps

Two static parts get locked around the vehicle's tank float axis and are tightened with 4 bolts and nuts. Additionally, the structure is further secured by an ingenious design where a screw emerging from the float's axis fits precisely into a cavity, preventing any rotation (Figure 22).

Figure 22, parts functioning as pipe clamp

Rotating clamp
A round clamp part around the end of the turning part of the float’s axis makes the potentiometer rotate (Figure 23). As the inside diameter narrows towards the crossbar, the clamp gets tighter around the axis.

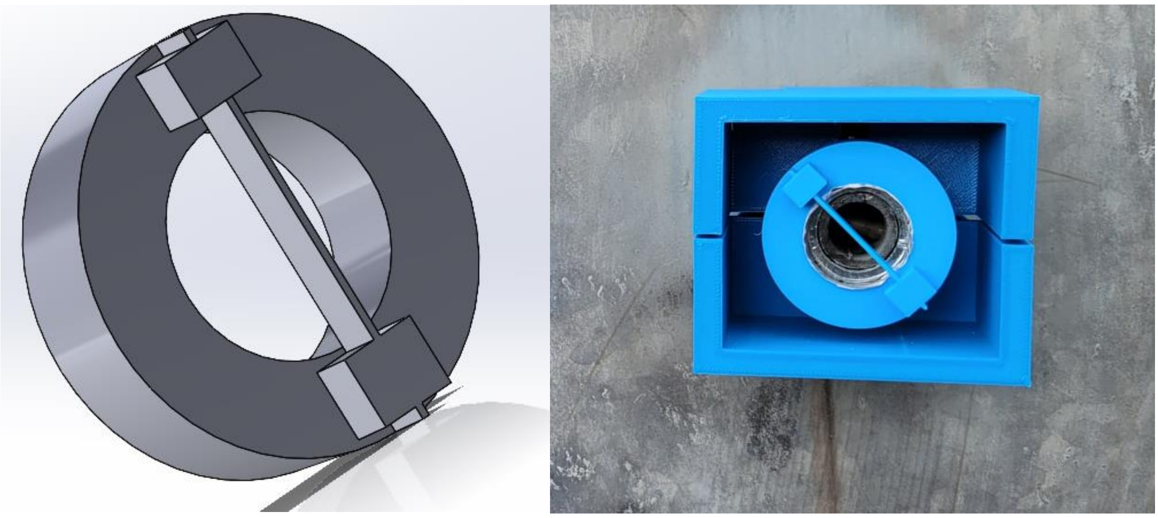


Figure 23, part which provides rotation to the potentiometer

The crossbar of the circle fits into the head of the potentiometer (see Figure 24), which rotates based on the axis of the float mechanism as the water level in the tank rises or falls.

Figure 24, a potentiometer with a slot used for rotation

Structure cover
A cover part securing the potentiometer in place to track the angle of the turning float axis. It also protects the potentiometer from water (Figure 25). There is still a small gap between the two clamp parts where water could pass through. However, this can be resolved by adding isolation tape.

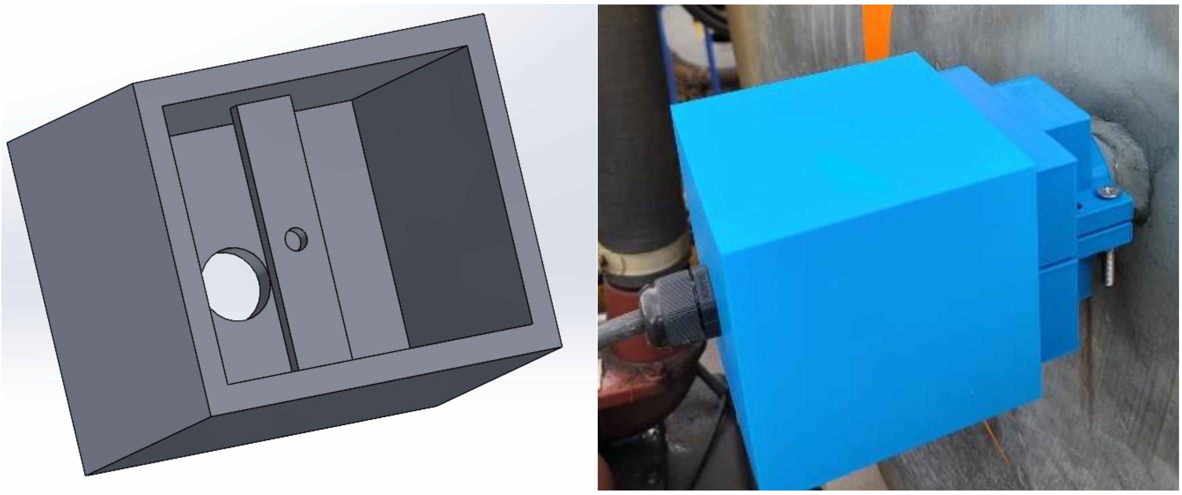


Figure 25, the cover which holds the static part of the potentiometer

As seen in the picture in Figure 25, there is a thick-black electrical cable connected to the cover part with a cable gland. This gland prevents the potentiometer from moving to ensure accurate measurements and also makes the design more waterproof. The cable transfers the potentiometer readings to an ESP32 microprocessor, which is found in a waterproof box that also contains a red button, an Arduino with a GPS shield and a power bank (see Figure 26). The Arduino obtains GPS data and transfers this to the ESP32, which formats and sends the data to the database. This sending of data can be activated and deactivated by pressing the button. Finally, the power bank indicates how much battery is left, ensuring you know when to recharge it. A detailed explanation of the system's functionality process is provided in the following sections.

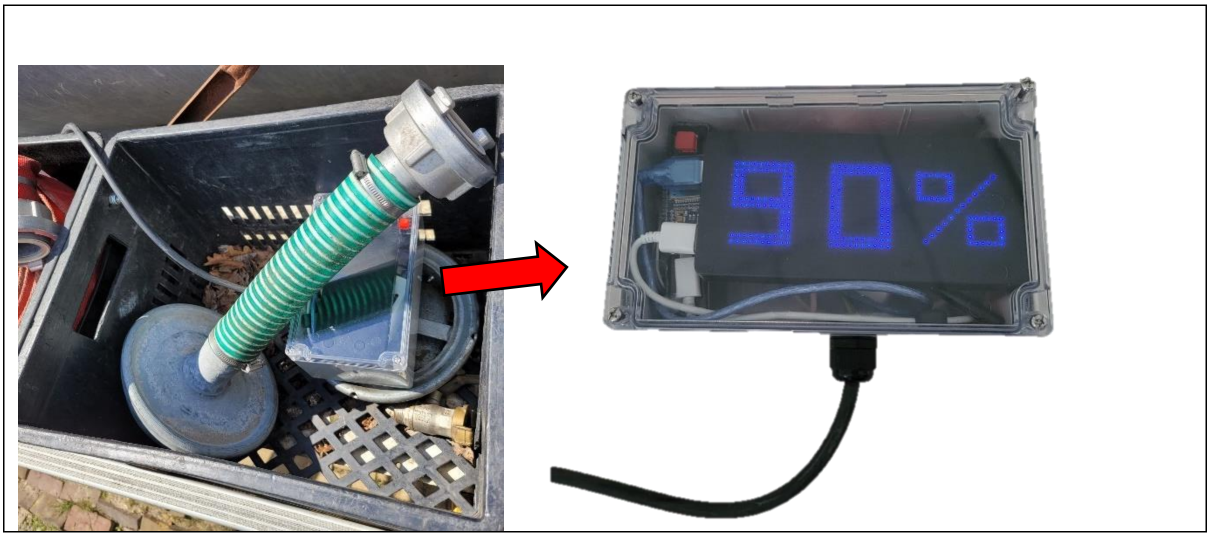


Figure 26, waterproof box containing the power bank, ESP32, Arduino with GPS shield and a red button

6.2 Electronics

A potentiometer is connected to the vehicle's external tank float mechanism’s axle, which rotates in response to changes in the water level inside the tank. The rotation of the potentiometer can then be translated into the corresponding volume change of water in the tank.

The potentiometer functions by adjusting a sliding or rotating contact, called the wiper, across a resistive element (see Figure 27). This changes the resistance and divides the input voltage proportionally between the output terminals, allowing for variable voltage output. Based on the wiper's location on the resistive track, the ESP32 microcontroller retrieves the maximum digital output of a 12-bit ADC, or 4095, which corresponds to the highest detected analogue input voltage. Take note that the listed maximum possible rotation angle of the type of potentiometer used is 270 degrees and in this range, 4096 different voltage levels are measured. These voltage levels will then be converted to water volume, this is covered in more depth in the next section.

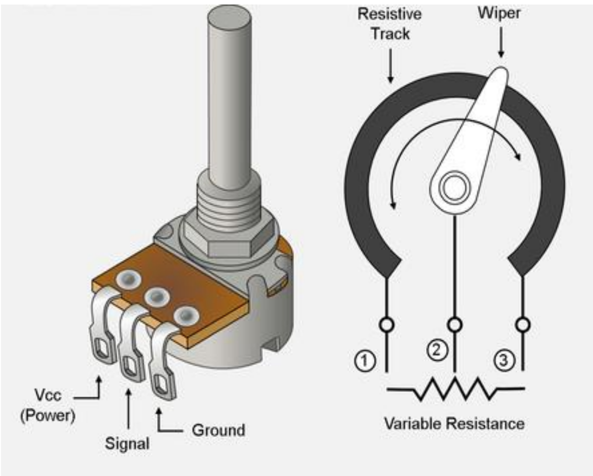


Figure 27, working principle of a potentiometer

To add the location and time to the volume measurements, an Arduino equipped with a GPS shield is connected to the ESP32. This allows the transfer of data including latitude, longitude, and Coordinated Universal Time (UTC).

Additionally, a button is incorporated into the system to control the data transmission to the database. This button can be used to enable or disable data transfer as needed, such as during periods when data logging is not required. For detailed wiring instructions for all hardware components, please refer to Appendix C.

6.3 Data Transfer and Saving

The ESP32 obtains the change in water volume from the rotation of the potentiometer. Connected to the ESP32 is an Arduino equipped with a GPS shield, which sends the time, longitude, and latitude via the Universal Asynchronous Receiver / Transmitter (UART) protocol. This data altogether is then transmitted via a mobile network from the ESP32 to the database, where it gets stored. The database has the following table structure (see Table 5):

Column	Type	Null	Default
id	int(11)	No	
water_volume	float	Yes	NULL
latitude	double	Yes	NULL
longitude	double	Yes	NULL
pot_angle	float	Yes	NULL
utctime	time	Yes	NULL
datetime	datetime	Yes	current_timestamp()

Table 5, table structure within the database

6.4 Data Conversion

As mentioned in section 6.2, the raw measurements from the potentiometer can be converted to a rotation angle. However, the more complex task is to determine the water volume based on the measured angle. Currently, the rotation angle indicates an unknown change in the water level within the tank. This change can be translated into water volume through a theoretical calculation, where the volume V of a liquid in a horizontal cylindrical tank can be calculated using the formula for the volume of a cylindrical segment[69]:

$$V_t = \mathrm{L}(R^2 cos^{-1}\left(\frac{R-h}{R}\right) - (R-h)\sqrt{2Rh-h^2})$$

Definitions:

- R: Radius of the cylinder
- L: Length of the cylinder
- h: Depth of the water
- V_t: Volume of the tank

For the vehicle where the prototype will be tested the measured dimensions approximate the following values:
L = 390 cm
R = 70 cm
Table 6, a hypothetical conversion table, may be created using these variables. This illustrates the relationship between the water volume in the tank—up to a maximum capacity of 6000 litres—and the matching water depth.

h (depth of water in cm)	Vt (expected volume of liquid in $\boldsymbol{m^3}$)	Vt (expected volume of liquid in litres)
0	0.000	0
5	0.068	68
10	0.190	190
15	0.345	345
20	0.526	526
25	0.726	726
30	0.943	943
35	1.173	1173
40	1.415	1415
45	1.666	1666
50	1.924	1924
55	2.189	2189
60	2.457	2457
65	2.729	2729
70	3.001	3001
75	3.274	3274
80	3.545	3545
85	3.814	3814
90	4.078	4078
95	4.337	4337
100	4.588	4588
105	4.829	4829
110	5.060	5060
115	5.277	5277
120	5.477	5477
125	5.657	5657
130	5.813	5813
135	5.935	5935
140	6.003	6003

Table 6, hypothetical conversion table to water volume

When converting the data from this table into a graph, we obtain the following result:

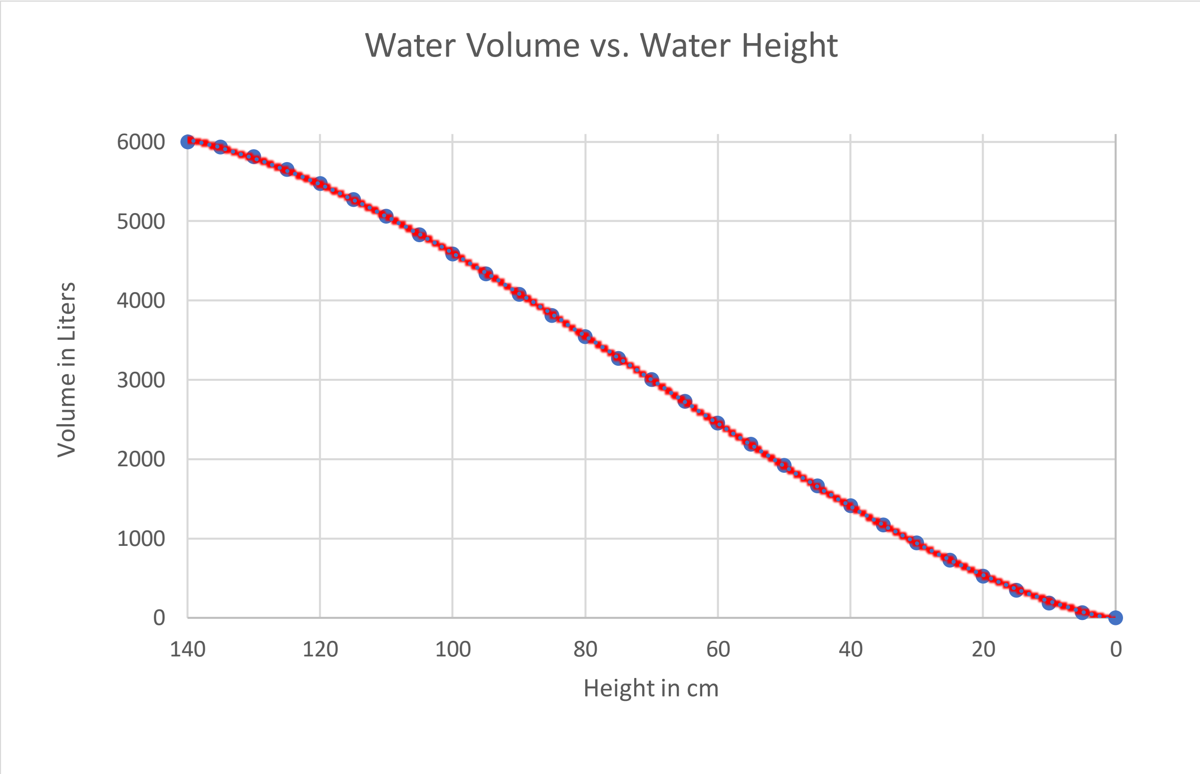


Figure 28, predicted relation between the water volume in the tank and the water height

6.5 Test Method

To establish a more precise conversion function between the rotation angle of the external float mechanism and the water volume inside the tank, a calibration test was conducted. During this test, the vehicle was driven onto a weighbridge, and water was gradually discharged from the tank. The weight loss of the vehicle was recorded alongside the rotation angle measured by the potentiometer.

This data, including the corresponding UTC time, was sent to a database for further analysis. By comparing the measured rotation angle with the weight of the vehicle at various intervals, the potentiometer is calibrated to accurately reflect the actual water volume in the tank. Since the relationship between weight and volume is directly related (with one kilogram of water equaling one litre). Consequently, the rotation angle also correlates with the water level, since the volume and level of water in the tank are intrinsically linked as seen in the previous section. The detailed results and comparison with the prediction of this calibration test will be discussed in the next chapter.

Chapter 7 – Evaluation

This chapter details the testing process of the system when applied to a vehicle used for watering plants and trees. The initial test aims to derive a conversion function that correlates the rotation angle of the float's axis with the water volume inside the tank. After establishing this conversion function, the system is tested in a real-world scenario. Since the system does not involve any users, the evaluation of the test results will focus solely on whether the functional requirements have been met.

7.1 Calibration Test

First, a calibration test was conducted to convert the potentiometer's rotation angle into water volume. The test involved driving the vehicle and water tank onto a weighbridge and recording the weight while completely draining the tank. Simultaneously, the potentiometer's rotation angle was measured throughout the process. See Figure 29 for the setup.

Figure 29, the setup for the calibration test

In total, the calibration process took approximately 35 minutes and the initial combined weight of the vehicle and the full water tank was 15,620 kg. After draining, the empty vehicle weighed 10,000 kg. Thus, the weight of the water was 5,620 kg, equivalent to 5,620 litres.

Data was transmitted every second, conditional on the availability of valid GPS data, resulting in an average interval of five seconds. The weight measurements were taken in steps of 20 kg, as this was the limit of the weight bridge. First, the collected data is presented in two graphs: a time vs. water volume graph (see Figure 30) and a time vs. rotation angle graph (see Figure 31).

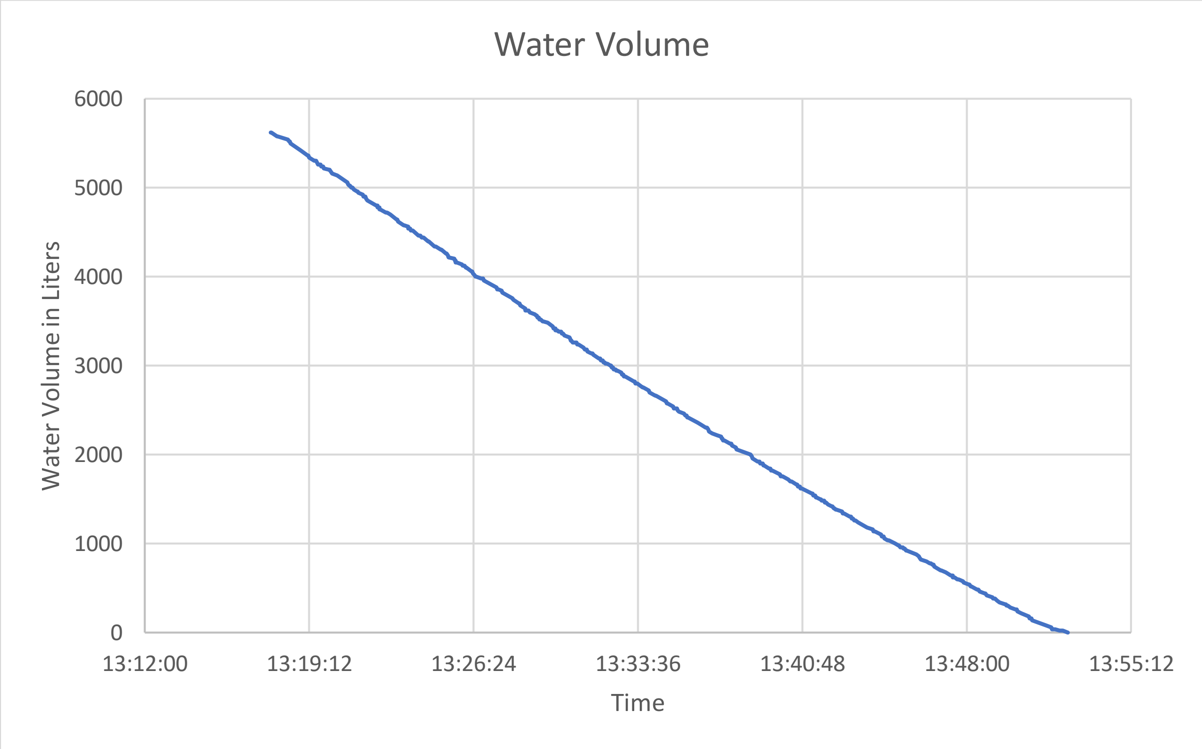


Figure 30, time vs. water volume graph

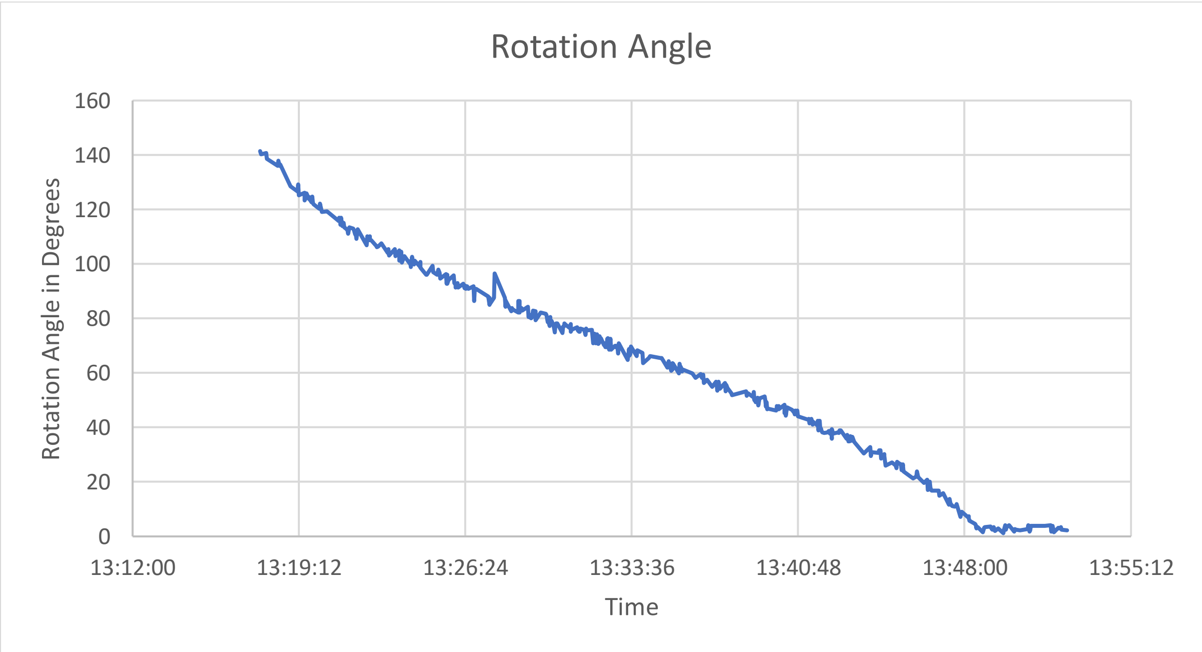


Figure 31, time vs. rotation angle graph

Now that an overview of the behavior over time is obtained, the water volume can be compared to the rotation angle to derive a conversion function. This comparison is illustrated in Figure 32. Here the extreme values are marked indicating the operational window of the system. The maximum volume is 5580 litres with a corresponding rotation angle of 138.59 degrees, and the minimum water volume is

440 litres with a minimum rotation angle of 1.45 degrees.

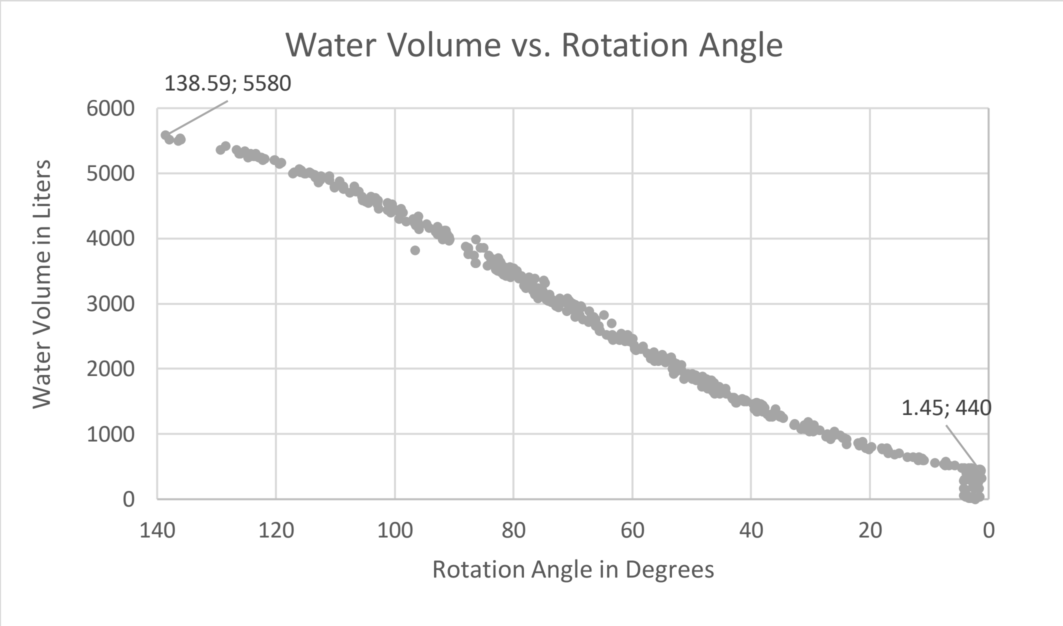


Figure 32, the water volume vs. the rotation angle

7.2 Calibration Test Analysis

Before creating a conversion function from the rotation angle to water volume, the behaviour of the graph should be analyzed to identify any abnormalities and to determine if they are consistent with predictions.

7.2.1 Water Volume Analysis

First, starting with the water volume, the graphical behaviour observed is as expected. The rate of water outflow is proportional to the volume of water present resulting in a close to linear graph.
But the force causing the outflow—in this example, pressure—also decreases as the water volume drops. This leads to a slower rate of outflow over time, which could be explained by Torricelli's Law (see Figure 33) [70].

Even though this phenomenon is only proven for vertical cylindrical tanks, it might also explain the slightly nonlinear decrease in water volume observed in the graph. In the latter part, the slope becomes less steep, indicating a reduction in the rate at which the water volume flows out of the tank.

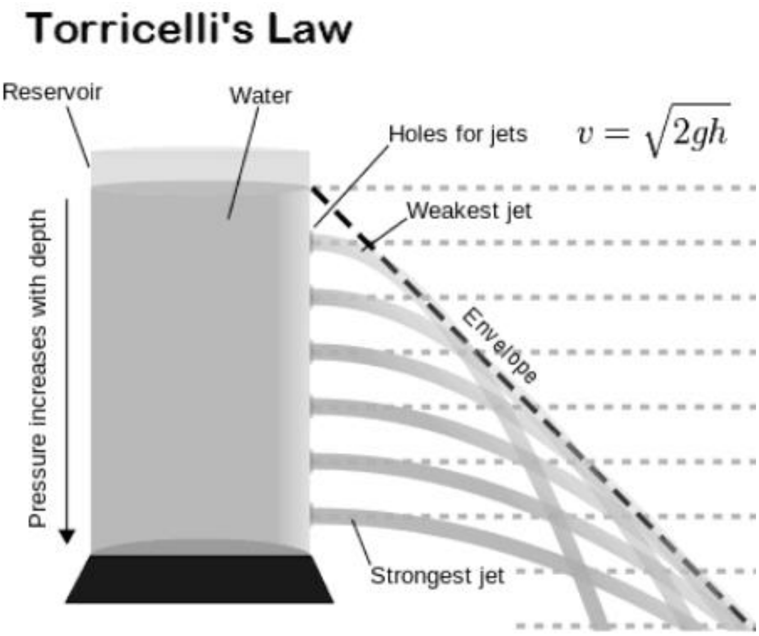


Figure 33, visual explanation of Torricelli's law

7.2.2 Rotation Angle Analysis

A clear difference between the behaviour of the rotation angle and the water volume is that the rotation angle does not follow the water volume's linearity, as the slope is steeper in the initial and final parts (see Figure 32). However, this non-linear relationship matches the theoretical formula for translating water level to water volume in a horizontal cylindrical tank and is therefore no abnormality.

As observed in Figure 32, there is a notable deviation starting from 440 litres of water volume. At this point, the graph indicates that the lowest angle degree has been reached, while the graph in Figure 32 shows that the weight continues to drop. This implies that the potentiometer is unable to register the last approximately 440 litres of water in the tank accurately. This phenomenon can be partially attributed to the design of the float mechanism as well as vehicle tilt.

To begin with, the float mechanism in the tank operates as illustrated in Figure 34. The float mechanism consists of a floating ball that rises and falls with the water level. This motion causes the connected lever to move, rotating the axis to which the potentiometer is attached. The float mechanism is located at the front of the tank, which raises an issue. When the tank is slightly tilted due to its connection with the tractor, the front of the tank is elevated, causing the float to reach its lowest position prematurely, even though there is still water in the rear of the tank (see Figure 35).

This misalignment due to the tilt means that the float mechanism stops registering the actual water level accurately once the water level drops below a certain point.

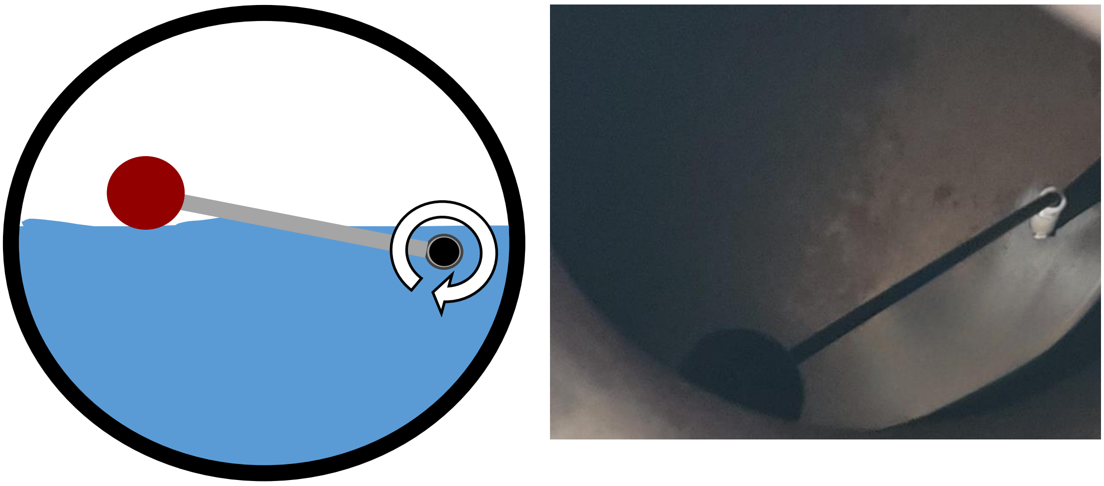


Figure 34, the working of the mechanical float system inside the tank

Figure 35, side view showing how the tilt impacts the float measurement ability

The above-mentioned issue can be solved by removing the data from 440 litres onwards, this results in the graphs seen in Figures 36 and 37.

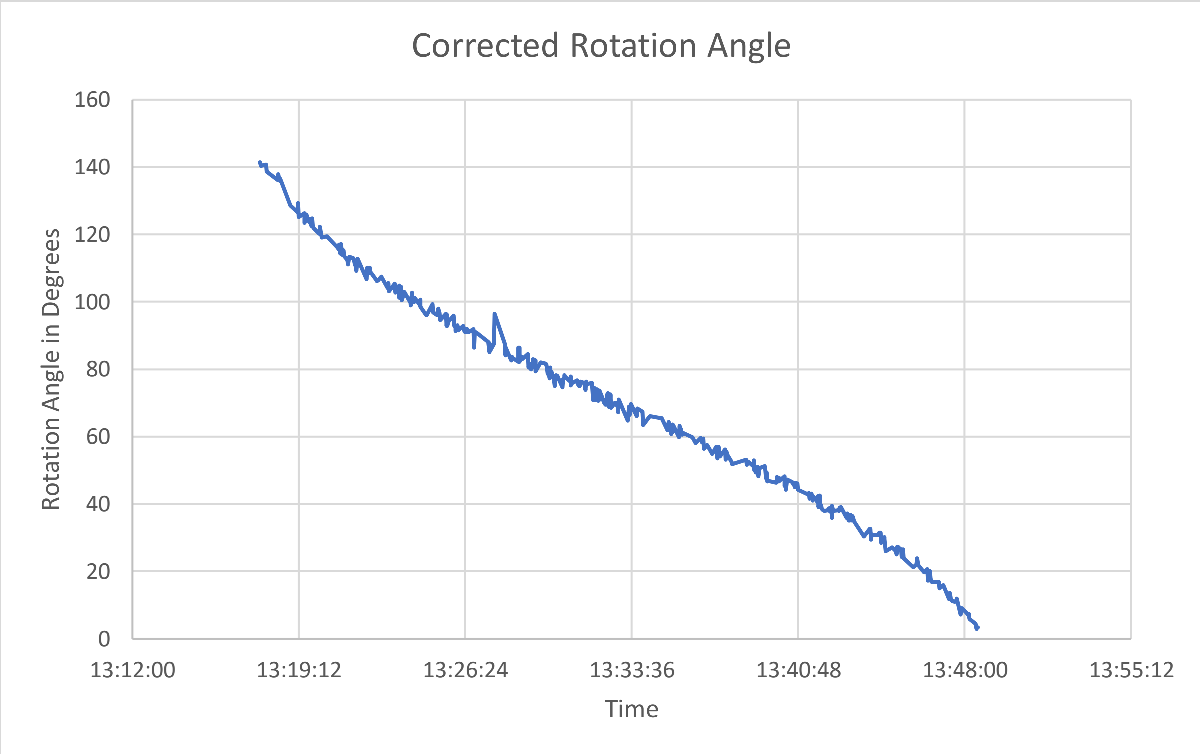


Figure 36, improved rotation angle vs. time graph

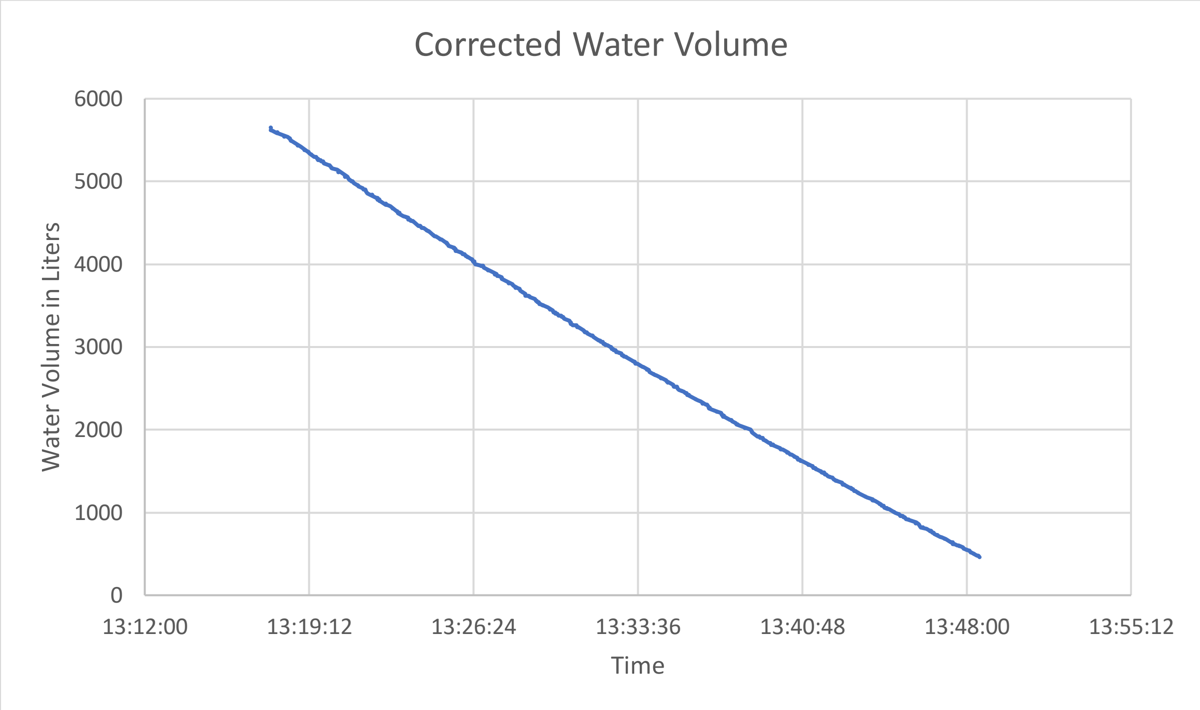


Figure 37, improved water volume vs. time graph

Another aspect evident in the graph of the rotation angle in Figure 36 is the presence of noticeable spikes, indicating significant variations in the rotation angle relative to the water volume. This suggests that the water level is not smoothly dropping, there may be measurement errors in the potentiometer, or the float mechanism might be inaccurate due to an unstable water level.

First, the measurement accuracy of the potentiometer will be tested. This involves monitoring the rotation angle over a certain period while keeping the potentiometer in the same position. To perform this test, the prototype was placed on the desk while leaving the potentiometer untouched to isolate any possible measurement inaccuracies from the float mechanism. This test helps to determine whether the deviations in the rotation angle are due to measurement inaccuracies or other potential issues with the float mechanism or water level stability.

Below in Table 7, the portion containing the biggest deviations seen during the accuracy test is shown.

Id	Water_volume	Latitude	Longitude	Pot_angle	Utctime	Datetime
11067	1420.95	52.228279	6.869692	39.76	10:14:22	2024-06-19 12:14:25
11066	1388.35	52.228279	6.869692	38.97	10:14:20	2024-06-19 12:14:23
11065	1401.88	52.228279	6.869692	39.3	10:14:18	2024-06-19 12:14:21
11064	1410.04	52.228279	6.869692	39.49	10:14:16	2024-06-19 12:14:19
11063	1364.2	52.228279	6.869692	38.37	10:14:14	2024-06-19 12:14:17
11062	1420.95	52.228279	6.869692	39.76	10:14:12	2024-06-19 12:14:15
11061	1399.17	52.228279	6.869692	39.23	10:14:10	2024-06-19 12:14:13
11060	1374.9	52.228279	6.869692	38.64	10:14:07	2024-06-19 12:14:11
11059	1366.87	52.228279	6.869692	38.44	10:14:07	2024-06-19 12:14:10
11058	1410.04	52.228279	6.869692	39.49	10:14:05	2024-06-19 12:14:08

Table 7, static potentiometer accuracy test

As observed, when the potentiometer is kept static, there are possible fluctuations of about one degree in the rotation angle. While this may seem minor, it can lead to a difference of nearly 57 litres. However, this inaccuracy alone does not explain the earlier observed fluctuations, as calibration test records sometimes differed by a few degrees at the same weight. Therefore, potential inaccuracies with the float mechanism due to an uneven water level should also be considered. As water leaves the tank, it can create currents and turbulence causing temporary dips or rises in the water level. This means that the float might not always be positioned at the actual average water level, resulting in fluctuating readings. To mitigate this effect you could implement digital filtering techniques, such as a moving average filter. This smooths out the signal from the potentiometer and provides more consistent readings.

7.2.3 Predicted Volume vs. Actual Volume

Now that the uncertainties have been analyzed, the theory can be matched with the actual measurements (see Figure 38). It can be seen that a similar trend occurs when a trendline is drawn through the data points. However, the data does not reach the extreme highs and lows predicted by the theoretical model. This discrepancy results from the tank not being filled to its maximum capacity of 6000 litres, but to 5580 litres, coupled with the limitations of the float mechanism, which cannot register the final 440 litres of water. This results in an average deviation of approximately 200 litres between the predicted and actual data.

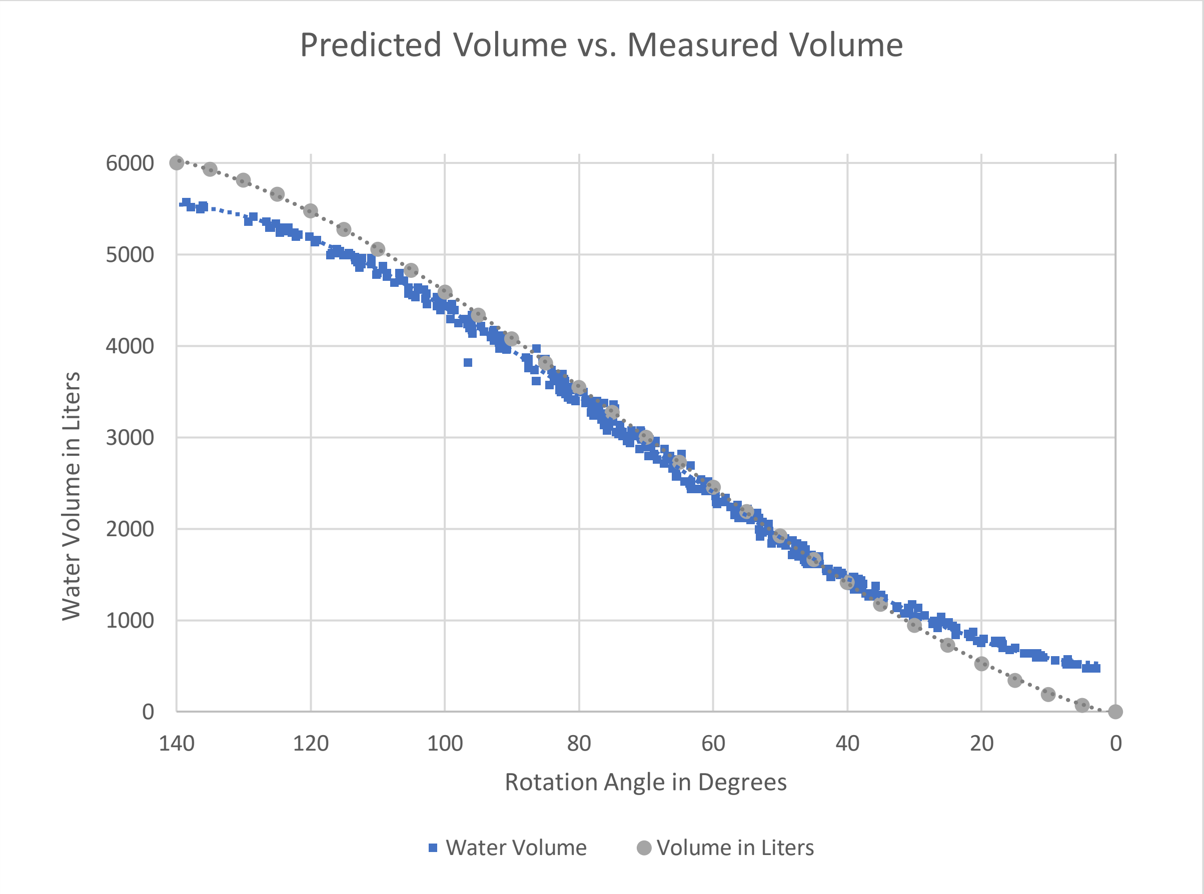


Figure 38, the predicted vs. the actual relation between the rotation angle

The graph in Figure 38 is created using Excel, which offers a function to add various types of trendlines to the data points. The line that fits the data points best is a third-order polynomial. When adding this trendline to our scatterplot of actual measured data (see Figure 39), the resulting third-order polynomial equation from the trendline provided by Excel is:

$$y = -0.00355x^3 + 0.774x^2 - 3.23x + 549$$

This function can be used to convert the rotation angle to water volume when the weight of the vehicle is unknown with an accuracy of up to 57 litres. Note that the conversion function is accurate when the vehicle is stationary with a maximum volume of 5580 litres and a corresponding rotation angle of 138.59 degrees, and a minimum water volume of 440 litres with a minimum rotation angle of 1.45 degrees.

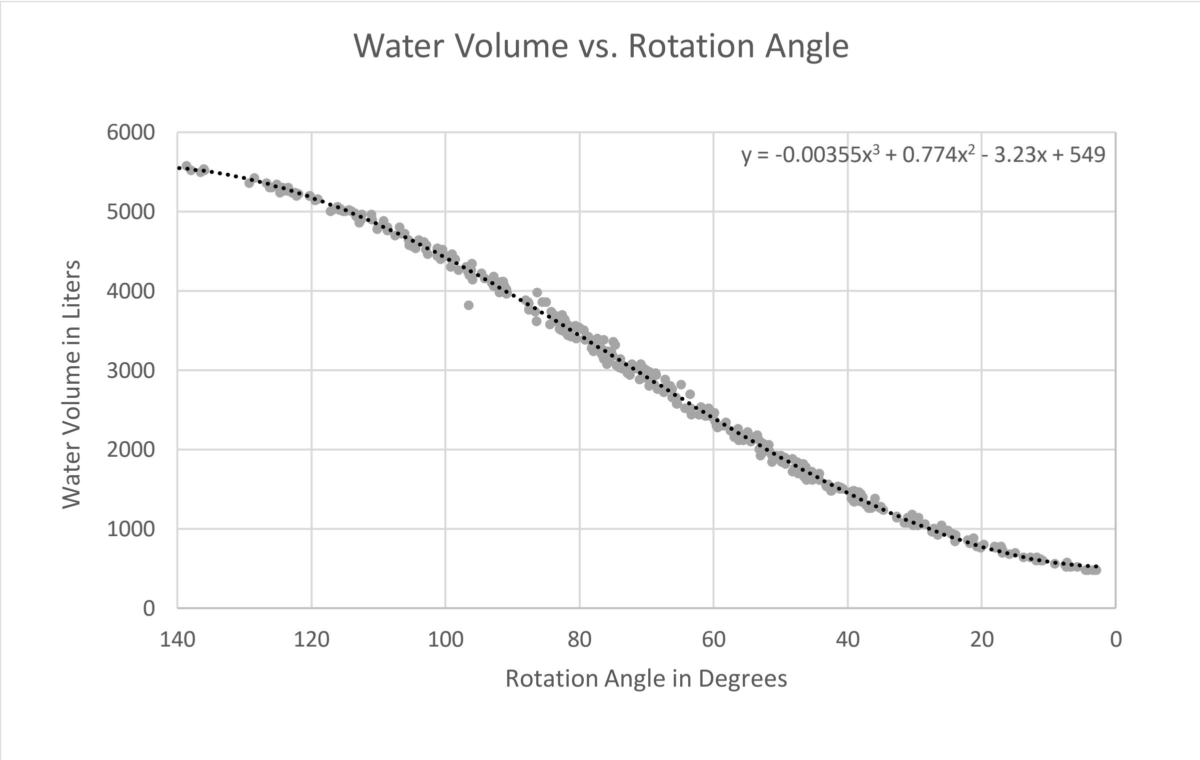


Figure 39, water volume vs. rotation angle graph

7.3 Real-World Test

After developing a functional prototype and a conversion function, it is time to evaluate the prototype in a real-world scenario. The system was installed on a vehicle used for watering plants and trees. Unfortunately, due to heavy rainfall, the vehicles were not operating full days as usual. However, for this research, a single test drive was conducted to mimic real-life conditions.

The route taken during the test drive is shown in Figure 40, with the data plotted in the ArcGIS application. The heat map indicates the locations where water was dispensed, as evidenced by concentrated points representing multiple GPS readings at the same locations. While traffic lights and other moments of the vehicle being stationary should be taken into account, these waiting times were significantly shorter than the time required to water the trees during the test drive.

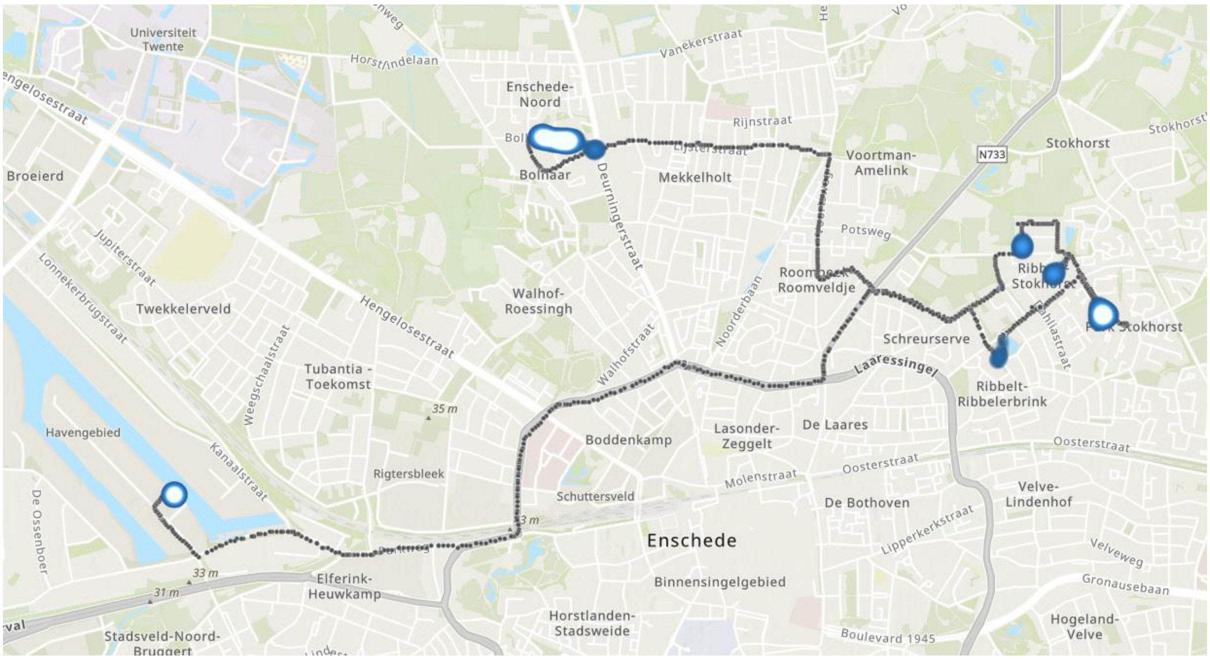


Figure 40, the driven route highlighting concentrated points indicating where water was released to the trees[71]

The test drive began with a full tank of approximately 5500 litres and concluded with 1100 litres remaining, after which the driver decided to refill the tank. He estimated that the remaining water was insufficient to supply the next locations. With the system in place, the driver would no longer have to estimate and can ensure the complete tank is emptied before refilling. This can result in more efficient route planning.

During the trip, a total of 34 trees were watered, with each tree receiving an average of approximately 130 litres. This amount is considerably higher than the earlier estimate of about 100 litres per tree, as mentioned in section 2.1.1. This could be explained by the current method used by the drivers, which involves filling each barrier around a tree to the edge (see Figure 41).

However, this method has several flaws. The barriers may vary in width, water is not always added precisely between the barriers, water can spill if the tap is turned off too late, and some barriers are not completely waterproof, leading to simultaneous water outflow during filling.

Figure 41, the process of watering a tree at which some visible spilling occurs

7.3.1 Real-world Test Analysis

In Figure 42, the water volume during the test drive is depicted, with several key points highlighted for clarity:

The blue line represents the water volume under ideal conditions, where each tree receives 100 liters of water. This provides a better overview of the special periods described down below.

The red circles indicate periods when a specific number of trees, represented by the corresponding numbers, were watered. During these times, water was released from the tank, resulting in a decrease in water volume. This decrease is more pronounced when a larger number of trees are watered, which is evident in the scatter plot. However, it seems that some trees have received significantly more water than others. This can be partly explained by the inaccurate watering method, where some barriers are leaking. Additionally, it indicates that the measurements themselves display some inaccuracies.

The yellow circle highlights a measurement flaw that occurred while the vehicle was stationary on a hill. This positioning caused the water volume inside the tank to appear lower than it was. Therefore the slight decrease in water volume is not correct as there was no water released during that time.

The blue circle highlights significant fluctuations in water volume during a period when the vehicle was in motion. These fluctuations are likely caused by the sloshing of water inside the tank, which affects the float mechanism. It is worth noting that there are other instances when the vehicle is in motion, but these occur later when the tank is less full. This reduced water mass could result in less sloshing, although this is not entirely certain. Finally, the green circle marks the point when the tank is refilled. Here, sloshing probably occurred as well when the vacuum pump was enabled, contributing to the observed fluctuations.

In conclusion, while large volumes of water released from the tank are detectable in the water volume differences, the system lacks the accuracy needed for individual tree watering. This inaccuracy is due to the sloshing effect and vehicle tilt impacting the float mechanism.

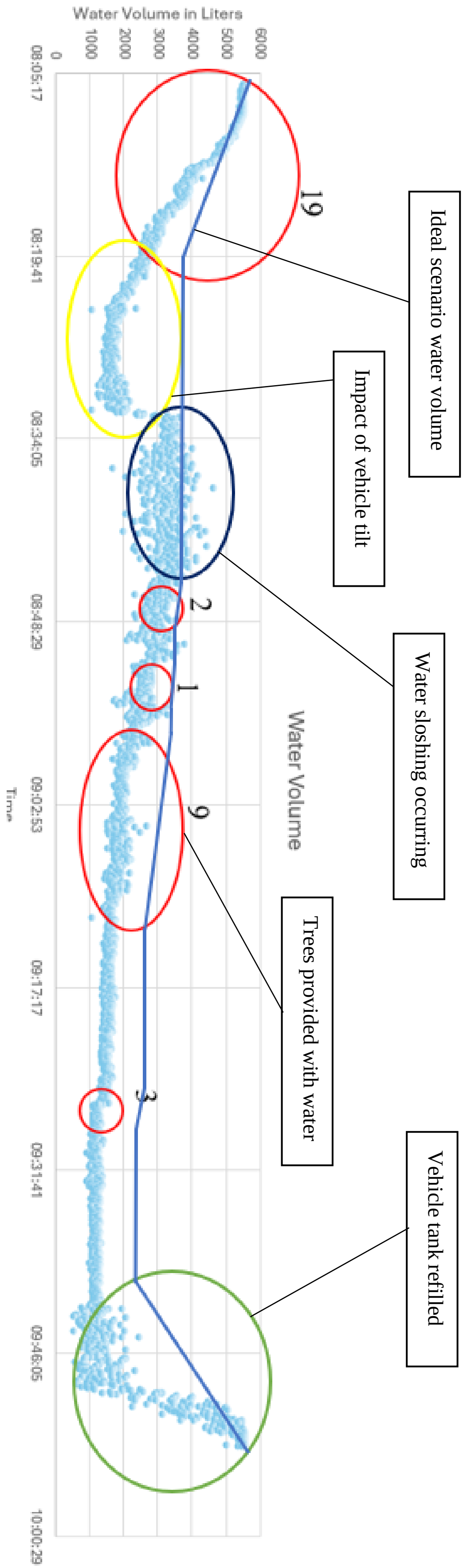


Figure 42, measured water volume during the test drive

7.4 System Evaluation

Using the results, the system can be evaluated to determine whether the functional requirements have been achieved (see Table 8).

Functional Requirements	Requirement met
The system must keep track of the water volume, location, and time of the vehicles during operation.	YES
The system should operate autonomously, requiring no user input except for battery replacement and occasional maintenance.	YES
The system must send the collected data to a database every second.	YES*
The system must convert the rotation angle of the float's axis changes in water volume with a maximum deviation of 100 litres, which equals the approximated water volume given to a single tree.	YES**
The system must indicate how much water is used during a single trip with a maximum deviation of 100 litres	UNKNOWN***
Should	
The system should include a modular design, enabling it to be applied to all the vehicles used for watering trees and plant beds	NO
The system should include a turn-on and turn-off button to stop data transmission to the database when the vehicle is not in operation	YES
Data should be received every 5 seconds in the database	YES
Could	
The system could add the functionality of integrating the obtained data with the ArcGIS application, currently used by Onderhoud Enschede BV to keep track of watering plants and trees.	NO****
The system could include a physical indicator for the vehicle operators, which displays the water volume inside the tanks.	NO

Table 8, evaluation of the functional requirements

* Depends on the condition that valid GPS data is available
**If the vehicle is stationary and unaffected by water sloshing or tilting, the conversion process has an inaccuracy of only 57 liters due to the potentiometer.
***Only a single test drive is performed and therefore accurate assessment is not possible
****The data can be directly loaded into ArcGIS but has to be done manually

Overall, the system meets most of the primary functional requirements but has areas in need of improvement, particularly in measurement accuracy which will be discussed in the next chapter.

Chapter 8 – Discussion & Future Work

This chapter addresses the implication of the results, evaluates the accuracy and related challenges of the system, and looks at future development and possible enhancements to achieve the sustainability goals of water distribution at Onderhoud Enschede BV.

8.1 Result Implications

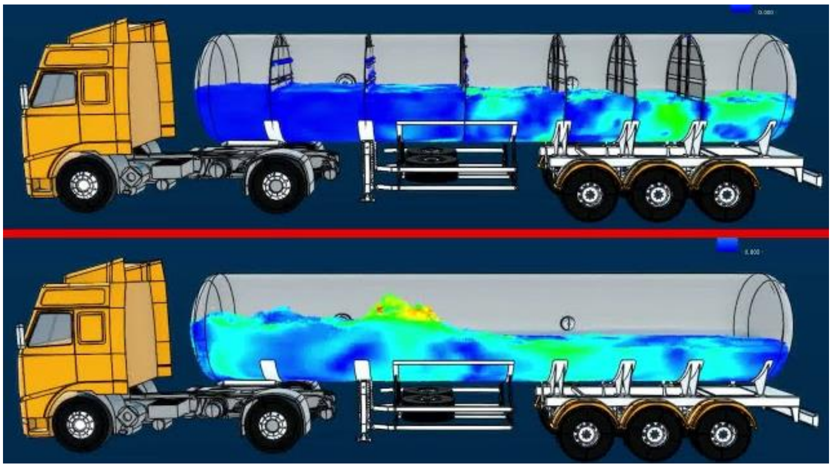
The obtained results demonstrate that it is possible to keep track of the water volume inside the tank of a maintenance vehicle, just by measuring the rotation of the external float axis. The obtained conversion function can convert the rotation angle to water volume when the weight of the vehicle is unknown with an accuracy of up to 57 litres. Note that the conversion function is accurate when the vehicle is stationary with a maximum volume of 5580 litres and a corresponding rotation angle of 138.59 degrees, and a minimum water volume of 440 litres with a minimum rotation angle of 1.45 degrees.

Even though the system provides insight into where water is released following the GPS data, its water volume accuracy during the trip is lacking. However, in the single test performed, the volume in the tank at the beginning and end was clearly visible. Therefore, conducting more tests could provide a more accurate average value. However, it is still not precise enough to determine the exact amount of water provided to each tree due to the challenges described in the next section.

8.2 Challenges Encountered

One of the primary issues encountered was the tilt of the vehicle. This problem was evident during calibration testing, where the last 440 litres of water accumulated in the back of the tank and could not be registered by the float mechanism located at the front. Additionally, tilt causes the water depth to be uneven throughout the tank, leading to inaccurate measurements. This issue was also observed during the real-world test, where the tank appeared less full than it was because the vehicle was stationary on a hill. To compensate for the tilt, one solution could be adding a gyroscope that indicates how much the vehicle is tilted and then corrects the measurement to obtain a more accurate water level.

Another measurement uncertainty is the fluctuations observed in the potentiometer readings, suggesting potential inaccuracies in the sensor. Testing the behaviour of the potentiometer at a fixed position showed a maximum deviation of about one degree. Therefore, the more significant graphical fluctuations of one degree at the same water volume level are likely caused by other factors, such as an unstable water level or a possible sloshing effect occurring in the tank. The unstable water level due to water outflow in the tank could potentially be reduced by implementing a moving average filter. What is seen during real-world testing is that measurements are even more fluctuating when the vehicle is in motion, therefore implying there is sloshing occurring in the tank. This effect is very hard to mitigate. The most common solution for lorry trucks carrying liquids is to add barriers inside the tank, preventing significant movement. Implementing such barriers could reduce water movement resulting in a more stable water level (see Figure 43) [72].


.
Figure 43, simulation how barriers can reduce water sloshing inside a tank

Lastly, valid GPS data was not always available, causing the measurement interval to occasionally be larger. This impacts the consistency of data collection but could be mitigated by sending the rotation angle to the database even when GPS data is not available. Then, by using the database's timestamp instead of relying on UTC more data points are obtained, which can increase the accuracy. Other options would be to consider using a better GPS sensor or improved sensor placement, to obtain a stronger signal.

8.3 Future Work

To develop a more accurate and reliable non-disruptive logistical data collection system, the following future work is recommended:

As mentioned in the discussion the impact of water sloshing and vehicle tilt should be mitigated to achieve better measurement accuracy or . Still, the sloshing effect will be hard to overcome due to restricted tank access. Therefore, even if implementation might be harder, reconsidering other preliminary concepts might be necessary. The concepts of keeping track of weight and using a water flow meter would be most suitable, as they are almost not affected by water sloshing and vehicle tilt.

Chapter 9 – Conclusion

Currently, only rough estimations are available on the water used for maintenance at Onderhoud Enschede BV. The development of a non-disruptive logistical data collection system for vehicles used in water-based maintenance tasks by Onderhoud Enschede BV enhances insights into their water consumption. By recording water usage, location, and time of vehicles watering trees and plant beds, data-driven decisions can be made to optimize their water distribution process. This advancement leads to more efficient and sustainable operations, potentially reducing (potable) water consumption and lowering CO2 emissions.

Therefore, the research question this study aims to answer is
"How to develop a non-disruptive logistical data collection system for vehicles used for water-based maintenance tasks by Onderhoud Enschede BV?"

The concept chosen for this project for tracking water usage was monitoring the rotation of the float axis, which indicates the water level in the tank. By integrating a GPS sensor, data on water outflow at specific locations and times could be obtained. A functional prototype has been developed and applied to a vehicle used for watering young trees and plants. The obtained results are listed below.

The resulting prototype fulfils most of the functional requirements:

- The system must keep track of the water volume, location, and time of the vehicles during operation.
- The system must convert the rotation angle of the float's axis changes in water volume with a maximum deviation of 100 litres, which equals the approximated water volume given to a single tree
- The system must send the collected data to a database every second.
- The system should operate autonomously, requiring no user input except for battery replacement and occasional maintenance.
- Data should be received every 5 seconds in the database
- The system should include a turn-on and turn-off button to stop data transmission to the database when the vehicle is not in operation.
- The system's data transfer to the database should be reliable and secure, filtering incorrect data formats (i.e. incomplete GPS information).

It fails the following requirements:

- The system should include a modular design, enabling it to be applied to different types of vehicles watering trees and plant beds
- The system could include a physical indicator for the vehicle operators, which displays the water volume inside the tanks.
- The system could add the functionality of integrating the obtained data with the ArcGIS application, currently used by Onderhoud Enschede BV to keep track of watering plants and trees.

In conclusion, the accuracy of the system has not met expectations. This is due to the restricted operational window of the float mechanism, which does not measure the last 440 liters, as well as the sloshing effect and vehicle tilt during operation.

Additionally, ensuring a more reliable GPS signal is crucial to meet the requirement of receiving data every second in the database. Therefore, while a functional prototype has been developed, several areas need improvement. Future efforts should focus on either enhancing the system's accuracy or exploring alternative concepts that may provide more reliable results.

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Appendix A: Component List

Component	Amount	Obtained at
ESP-WROOM-32	1	Stores [73]
Bolts and nuts M5	4	Praxis [74]
Potentiometer 10kOhm	1	Own stock
Button for Arduino	1	Own stock
3D printed construction	1	Designlab
Jumper wires (F>F)	6	Stores [73]
Waterproof box	1	SmartXP
Cable gland	2	SmartXP
10 mm electrical cable	1	SmartXP
Arduino GPS shield v1.0	1	SmartXP
Arduino Uno	1	SmartXP

Appendix B: Code Snippets

Arduino code for regulating the GPS parsing and communication to the ESP32:

ArduinoGPS

```
#include <SoftwareSerial.h>
#include <TinyGPS++.h>

SoftwareSerial SoftSerial(2, 3); // RX, TX
TinyGPSPlus gps;

void setup() {
    SoftSerial.begin(9600); // the SoftSerial baud rate
    Serial.begin(9600); // the Serial port of Arduino baud rate.
    Serial.println("GPS Module Testing");
}

void loop() {
    while (SoftSerial.available()) {
        char c = SoftSerial.read();
        if (gps.encode(c)) {
            sendGPSInfo();
        }
    }

    if (Serial.available()) {
        SoftSerial.write(Serial.read()); // Write it to the SoftSerial shield
    }
}

void sendGPSInfo() {
    if (gps.location.isValid() && gps.time.isValid()) {
        String gpsData = "LAT:" + String(gps.location.lat(), 6) +
                         ",LON:" + String(gps.location.lng(), 6) +
                         ",TIME:" + String(gps.time.hour()) + ":" +
                         String(gps.time.minute()) + ":" +
                         String(gps.time.second());
        Serial.println(gpsData);
    }
}
```

Arduino code which converts the rotation angle to water volume and correctly formats the GPS data:

```
// Continue the program only if it's running
if (programRunning) {
  // Read the analog value from the potentiometer
  float sensorValue = analogRead(potPin);

  // Map the sensor value to water volume and angle
  pot_angle = mapFloat(sensorValue, 0, 4095, 0, 270);
  //water_volume = 44.8 * pot_angle - 167;
  float water_volume = -3.55e-03 * pow(pot_angle, 3) + 7.74e-01 * pow(pot_angle, 2) - 3.23e+00 * pot_angle + 5.49e+02;

  // Variables to hold GPS data
  String latitude = "";
  String longitude = "";
  String utctime = "";

  // Read GPS data from Arduino
  while (SoftSerial.available()) {
    String gpsData = SoftSerial.readStringUntil('\n');

    // Check if the GPS data is correctly formatted
    int latIndex = gpsData.indexOf("LAT:");
    int lonIndex = gpsData.indexOf(",LON:");
    int timeIndex = gpsData.indexOf(",TIME:");

    if (latIndex != -1 && lonIndex != -1 && timeIndex != -1) {
      latitude = gpsData.substring(latIndex + 4, lonIndex);
      longitude = gpsData.substring(lonIndex + 5, timeIndex);
      utctime = gpsData.substring(timeIndex + 6);
```

PHP script connecting to the MySQL database, retrieving water volume and GPS data from a POST request, and inserts it into the "watervolume" table:

data_handler.php

```
<?php
// Database connection credentials
$hostname = "localhost";
$username = "root";
$password = "";
$database = "volume_db";

// Establishing the database connection
$conn = mysqli_connect($hostname, $username, $password, $database);

// Check if the connection was successful
if (!$conn) {
    die("Connection failed: " . mysqli_connect_error());
}

echo "Database connection is OK<br>";

// Retrieving POST data sent from the ESP32
$v = $_POST["water_volume"];
$a = $_POST["pot_angle"];
$lat = $_POST["latitude"];
$lon = $_POST["longitude"];
$utctime = $_POST["utctime"];

// SQL query to insert data into the watervolumeconversion table
$sql = "INSERT INTO watervolumeconversion (water_volume, pot_angle, latitude, longitude, utctime) VALUES ('$v', '$a', '$lat', '$lon', '$utctime')";

// Execute the query and check if it was successful
if (mysqli_query($conn, $sql)) {
    echo "New record created successfully";
} else {
    echo "Error: " . $sql . "<br>" . mysqli_error($conn);
}

// Close the database connection
mysqli_close($conn);
?>
```

Appendix C: Wiring of the Hardware