INSTITUTO SUPERIOR DE ENGENHARIA DO PORTO

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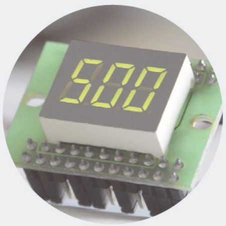

Automatic Fluid Sampler

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Automatic Fluid Sampler

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Abstract

The goal of this project is to build a new fluid sampler for the Centro de Estudo de Águas of ISEP. This is an independent lab that performs water analysis, including industrial waste waters. The fluid sampler has to work autonomously and be capable of collecting the specified fluid volumes at the configured frequency. The budget for building the prototype is 300 €.

This dissertation provides, first, an overview of similar fluid sampler devices currently available on the market as well as of the relevant guidelines and regulations regarding waste water sampling in Portugal. Then, it presents the platforms used and, finally, describes the complete development process of the fluid sampler.

The highlights of this project are the design and development of the fluid sensor and of the overall control system, the selection of universal materials and the simplicity of the water divider system. Together they create a low-cost, fully functional and easy to use and maintain automatic fluid sampler.

Table of Contents

List of Figures

List of Tables

List of Code Snippets

List of Equations

Glossary

Abbreviation	Description	Page
ISEP	Instituto Superior de Engenharia do Porto	iii
DO	Dissolved Oxygen	9
VOC	Volatile Organic Compounds	9
DNAPL	Light Non-Aqueous Phase Liquids	9
LNAPL	Dense Non-Aqueous Phase Liquids	9
PTFE	Polytetrafluoroethylene	8
pH	Power of Hydrogen	11
RF	Radio Frequency	11
IDE	Integrated development environment	18
DC	Direct Current	21
IC	Integrated Circuit	22
PCB	Printed Circuit Board	26
LED	Light-Emitting Diode	28
LCD	Liquid Crystal Display	28
RAM	Random Access Memory	35
PWM	Pulse Width Modulation	38
I2C	Inter-Integrated Circuit	38
GNSS	Global Navigation Satellite System	40
GPRS	General Packet Radio Service	40
SD	Secure Digital	40

Chapter 1

Introduction

The introduction chapter will describe the project and its objectives. It will also outline the structure of this dissertation.

1.1 Problem

Centro de Estudo de Águas do ISEP uses an ISCO-3700 water sampler to collect up to 24 samples from a water source. During this process, an operator is needed to take each individual sample. So if a water source has to be sampled 24 times with an 1 h interval between the samples the operator has to be available for 24 h.

To avoid this time consuming-process the Centro de Estudo de Águas do ISEP wants to develop an own automated fluid sampler that can be sold or leased to companies. This enables their clients to decide faster and easier when they want to perform a water analysis and this at a lower price point.

Figure 1.1: Centro de Estudo de Águas do ISEP current water sampler model

1.2 Objectives

The objective of the project is to develop a fully working prototype with the same capabilities as the currently owned commercial fluid sampler at a considerably lower price.

The fluid sampler will mainly be used in companies that have their own water treatment procedure for their waste water. These companies take water samples to see if their treatment is not failing and if it's capable of handling changes in their production chain (when the production line makes a different product the waste water is also affected).

Because the fluid sampler will be used in the industry for the analysis of waste water there are different aspects of water sampling that can be ignored. A more detailed explanation of water sampling standards, rules and the influence of automated sampling are discussed in Section 2.1.

1.2.1 Requirements

The desired functionality of the fluid sampler was explained during the initial meeting with Rosária Costa (Representative of the Centro de Estudo de Águas). After this meeting, a proposal with the following requirements was presented and accepted:

- Easy and friendly interface;
- Easy to clean and maintain;
- Portable and battery powered;
- Maximum number of 24 samples;
- Use sampling bottles of Centro de Estudo de Águas;
- Maximum sample acquisition depth of 7.5 m;
- Maximum sample volume of 1 l;
- Maximum sampling interval of 2 h;
- Minimum sampling accuracy of ±50 ml;
- Fully automated operation after set up.

1.2.2 Functional tests

A first test will evaluate the feasibility of theoretical concept of the fluid sensor and, if successful, will proceed with testing the operation of the sensor together with the microcontroller. These aspects are discussed in Section 4.2 and Subsection 5.1.1.

The second functional test will consist of testing the control of the pump operation. During this test, the samples will be collected in one central recipient and an evaluation of the dosage capabilities, with the developed fluid sensor, will be made. Depending on the results, it could be necessary to implement additional control during the second stage of the project.

The last test will check the proper working of the sample separation system. The key points to look for during this test are the volume of the samples, possible cross-contaminations and proper working of the sample divider system. Also, the mechanical structure will be evaluated for potential problems and weaknesses.

1.3 Plan

The design of the fluid sampler is divided into different parts (see Section 1.4). To make a timing schedule a Gantt chart is used (see Figure A.6). The Gantt chart lists all tasks that have to be done and the time frame in which they have to be finished.

1.4 Structure of the project

The project is divided into two stages. The first stage focuses on the pump and the controller for it. The second stage of the project will add a system for separating the samples into different bottles.

For the first stage, the samples will be collected and stored in one central recipient. To perform this a choice has to be made about the type of pump that will be used. The differences between the possible type of pumps are discussed in Subsection 2.2.3. The hardware to control the pump and the way the pump will be used are explained in Section 4.1.

The controller for the device should be designed keeping in mind the second stage in the project (enough I/O pins for controlling the sample distribution system, extra interface capabilities, etc.). The selection of the used platform is discussed in Section 3.1 and the development of the control electronics in Section 4.6. Figure 1.2 shows the basic system architecture that is realized in the first stage.

The fluid sampler will have the option to select the size of the samples (from 200 ml to 1000 ml). Therefore the controller will need a way to measure the amount of liquid being pumped up. The design of this system is explained in Section 4.2.

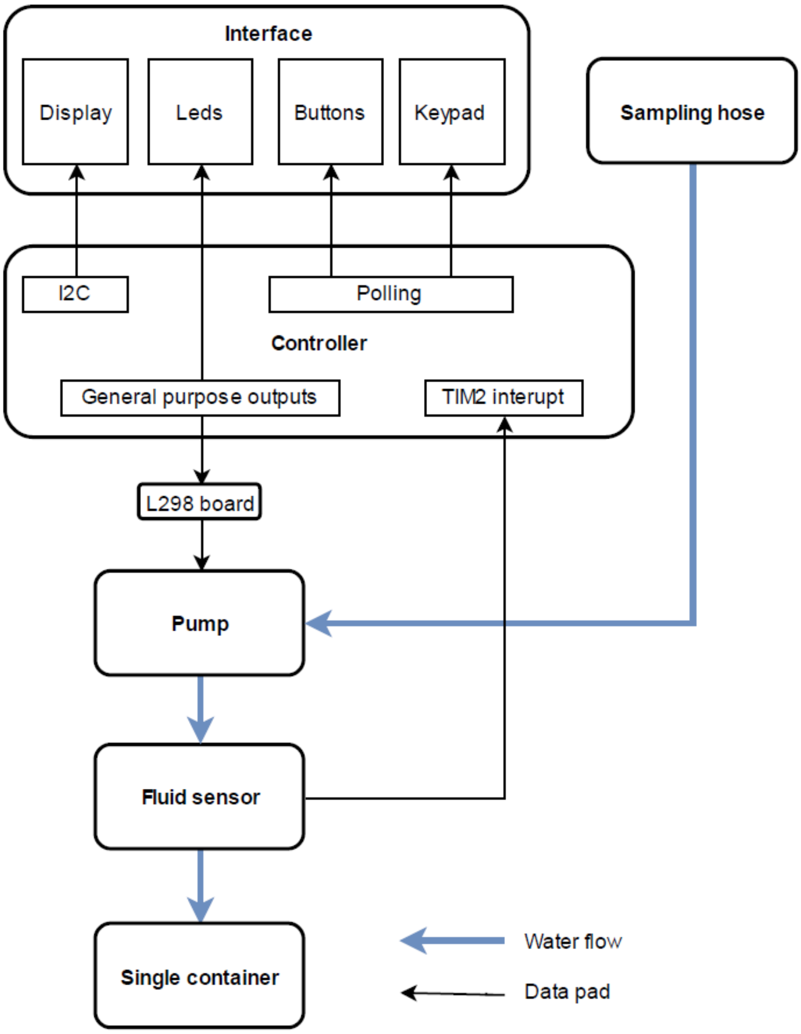

Figure 1.2: The basic system architecture

The second stage of the project will implement a mechanism to store the different samples in separate bottles. It will also investigate possible additions, such as options to add different types of interfaces (Wi-Fi, Bluetooth, radio frequency), extra types of control and measurement (flow rate, temperature). All these aspects are treated in Section 4.5 and Section 4.8. Figure 1.3 shows the final system architecture.

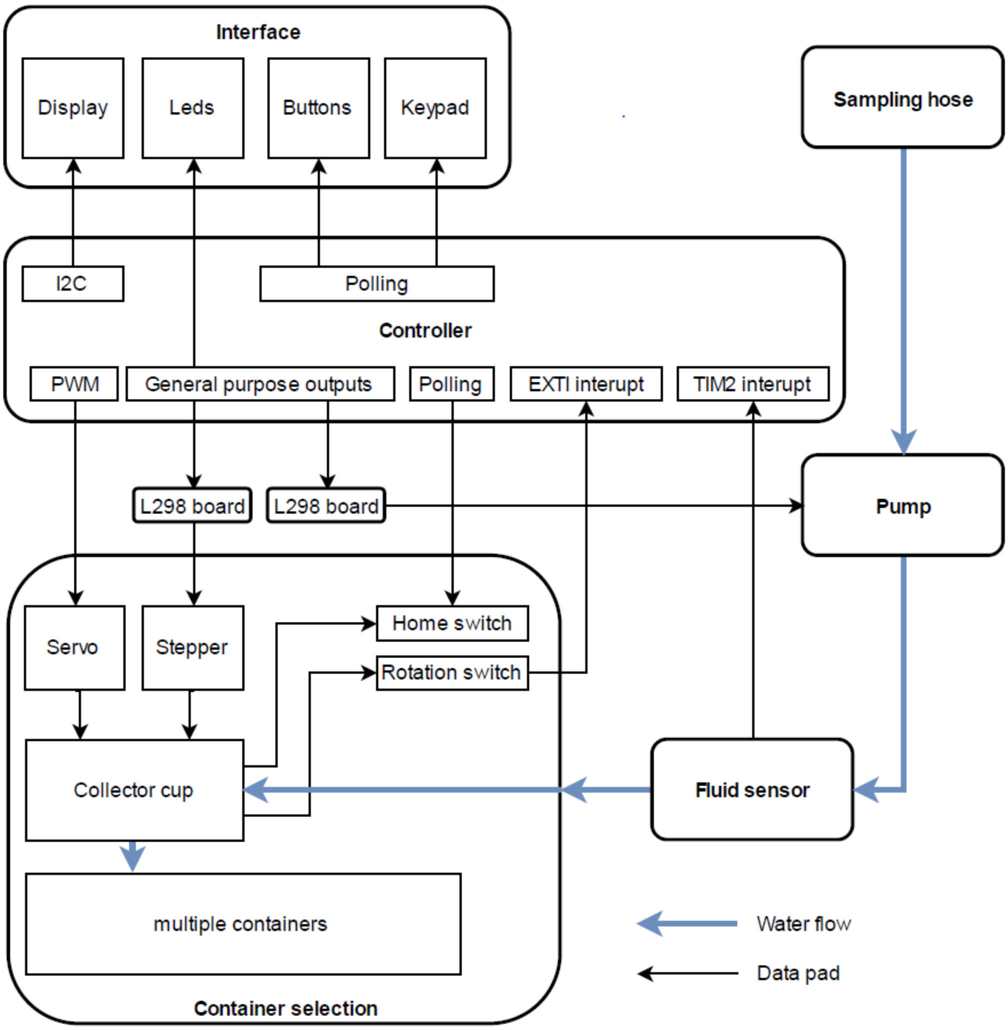

Figure 1.3: The final system structure

Chapter 2

State of The Art

In the State of The Art chapter, there will be a limited overview of water sampling and the guidelines, legislations and regulations about it. After this, an analysis will be made of the currently available fluid samplers and the different type of pumps.

2.1 Water sampling

Before analysing the currently existing systems and discussing the development of the fluid-sampler, it is important to situate the differences between sampling methods and discuss the influence of a peristaltic pump on the water samples. It is also important to point out that there are very detailed guidelines for water sampling and that waste water sampling has less strict norms.

2.1.1 Differences between sampling methods

The most common ways to obtain a water sample are by using a bailer, a single container or an automated fluid sampler. When sampling a water source it is important to keep in mind what are the analyses that will be performed and the type of water source. For example, when sampling drinking water all the used equipment has to be sterile; this is however not needed when a waste water stream is sampled. Also, certain types of analyses require different sampling techniques. For example, when analysing the water source for oil and greases a single 1 l sample should be taken manually. Laboratories performing water analyses should use standards and guidelines to ensure proper samples are obtained (see Subsection 2.1.2 for the most important guidelines in Portugal).

The goal of this project is to develop an automated fluid sampler for waste water sampling so the next part will focus on the properties, limitations and guidelines for an automated waste water sampler.

2.1.2 Guidelines, regulations and legislations for water sampling

To guide laboratories which perform water analyses there are specific guidelines available. There is one main guideline available from Rice et al. [11] and this could be complemented with the ISO5667 guidelines [1]. The ISO5667 consists of multiple parts and in each part one particular aspect of water sampling is discussed. Part 10 of the ISO5667 norm addresses the sampling of waste waters. The most important information of both guidelines around the sampling of waste waters is listed below.

According to Rice et al. [11], the most important guidelines for sampling waste waters are the following:

- Collecting of multiple grab-samples with a 5 min to 1 h interval between samples.
- Using polytetrafluoroethylene (PTFE) containers to collect the samples.
- Taking 1 l samples.
- Storing the samples below 6 °C and avoiding to use dry ice to keep the samples at this temperature.

If a specific analysis has to be performed, in order to detect a certain chemical compound, Table 1060:1 of Rice et al. [11] provides the specific recommendations for the sample collection and preservation.

According to the ISO5667 norm [1], the most important guidelines for sampling waste waters are the following:

- Using plastic containers to store the samples.
- A minimum of parts should be introduced into the fluid stream.
- The sampling hose should have a minimum internal diameter of 9 mm.
- A minimum intake velocity of $0.5\,\mathrm{m\,s^{-1}}$.
- Purging the lines before every sampling cycle.
- A minimum volume accuracy of 5 %.
- A sample interval of 5 min to 1 h.
- Storing the samples between 0 °C and 4 °C.

- Taking samples between 200 ml and 300 ml and never less than 50 ml.
- Using time-weighted sampling.

Furthermore, the Portuguese law specifies how to collect and preserve water samples of all kinds. In particular, “Decreto-Lei n.º 236/98”, published on 01/08/1998 [4], addresses waste-water sampling. The most important part of this decree is Table XVIII, on pages 3717–3718, which lists the absolute maximum values allowed off the relevant chemical compounds in waste-water.

2.1.3 Influence of a peristaltic pump on samples

When using an automated sampler with a peristaltic pump there are two properties that are heavily affected.

The first property is the amount of dissolved oxygen (DO) in the water. Because of the turbulence created in the water-flow and the filling of the sample-containers from the top there is extra oxygen introduced into the fluid. This increases the amount of dissolved oxygen. Tests reported in Lee William E. [10] indicate that an automated sampler with a peristaltic pump introduces around 45 % extra DO when compared to a bailer (which introduces between 25 % and 50 % extra DO).

The second property is the volatile organic compounds (VOC). According to Lee William E. [10] the most important volatile organic compounds for water sampling are the following: *“The VOC of common interest normally include BTEX compounds (benzene, toluene, ethylbenzene and xylenes) and halogenated methanes, ethanes and ethenes (for example, trichloroethylene)”.* Tests show that a peristaltic pump causes a loss of VOC up to 43 %. This is mainly caused by the negative pressure which is generated by the pump. For a detailed description about the influences of an automated sampler with a peristaltic pump on VOC see Jingtao et al. [9].

An automated sampler using any type of pump will need a hose to sample the water source. This hose will be submerged into the fluid source. For proper operation, the end of the hose will be between the bottom and top of the water surface. This means that light non-aqueous phase liquids (LNAPL) and dense non-aqueous phase liquids (DNAPL) cannot be sampled.

2.1.4 Conclusion

An automated sampler with a peristaltic pump is, by definition, unsuitable for:

- Taking samples to analyse the water quality of drinking water.

- Taking samples to perform an analysis on the amount of VOC or DO. Also any analysis that is influenced by the amount of VOC or DO in the water should be avoided.
- Taking samples for the analysis of LNAPL or DNAPL.

These limitations are also confirmed by Rice et al. [11]. They describe how oils, grease and drinking water should be sampled and these methods always require a separate sample that was taken manually. Therefore excluding the usage of an automated fluid sampler.

The properties set forward in Section 1.2 also match the guidelines provided in [11, 1]. The biggest difference is that Centro de Estudo de Águas do ISEP doesn't require that the samples are stored refrigerated, and the internal diameter of the sampling hose can be smaller than 9 mm. These two aspects can be neglected because of the following.

There is no need to cool the samples below 6 °C because the sampled fluid is waste water. Not cooling the samples can degrade a chemical compound but this change is insignificant compared to the maximum allowed values presented on Table XVIII [4]. In the unlikely event that a higher accuracy is required, or extremely high temperatures are predicted, the possibility exists to use cooling elements to keep the sample cool. Also when the samples arrive at the lab (typical in 48 h after the first sample was taken) the most critical analysis are performed directly and the remainder of the samples are preserved refrigerated.

The reason that the intake hose diameter is allowed to be smaller than 9 mm is because there are no large solid particles in the wastewater. All big solid particles will be at the bottom of the water source and will not get sucked up because the hose is too far from the bottom and the flow rate is very low.

2.2 Comparison of commercial available fluid samplers

In this section will be made an overview and analysis of the currently available commercial fluid samplers. This overview will only list the different fluid samplers that are capable of performing the same objectives as outlined in Section 1.2.

The most active companies in this field are Campbellsci [3], WaterSam [16], Hach [7], Aquamatic [2] and Teledyne Isco [8]. They all offer very similar fluid samplers that in essence difference very little. The biggest differences are the shape of the mechanical structure (see Subsection 2.2.1), the options of the control electronics (see Subsection 2.2.2) and the type of pump being used (see Subsection 2.2.3).

Next to these differences, most manufacturers offer the option to keep the samples at a fixed temperature. This is performed either by placing the bottles that contain the samples in a temperature controlled chamber or by providing a space to deposit ice cubes that, in turn, keep the temperature low.

2.2.1 Mechanical structure

The mechanical design of the water samplers can be divided into two general categories: round taper-shaped and cube-shaped.

The round taper-shaped is a configuration where the bottles are placed next to each other in a circular pattern. To place the different samples into the bottles a rotational arm is used. The main benefit of the taper-shaped construction is that it allows easy passing through man-sized access points.

The cube-shaped containers are easier to build and store, but need to be placed near the water source, i.e., are inappropriate for placement inside wells or other man-sized holes.

2.2.2 Control electronics

The control part of the water samplers always have the same basic properties. They contain a simple keyboard and screen as interface to select the desired time between samples, the volume of the samples and the number of samples. On top of these basics the manufacturers provide different extras, such as logging of extra parameters (temperature, pH, flow rate, location, time and date), wireless monitoring and control (Wi-Fi, Bluetooth, RF, Cellular) or a trigger input to start sampling depending on certain events.

2.2.3 Pumps

For pumping the liquid up and depositing it in the appropriate container, there are two types of pumps used. The first type is a peristaltic pump and the second one a vacuum pump. Both pumps have a different basic working principle and, therefore, different benefits and drawbacks, being these differences discussed below.

Centrifugal pumps are not used in commercial available portable sampling systems. This is because they have some big downsides when compared to peristaltic or vacuum pumps. These downsides are pointed out in Subsection 2.2.3.3.

2.2.3.1 Vacuum pump

Vacuum pumps work by sucking out the air of a sampling chamber and creating a vacuum in this chamber. The vacuum chamber is connected through tubing with the water source. Because the water source is surrounded by atmospheric pressure, the liquid is pushed into the vacuum chamber. This working principle limits the theoretical vertical lift in a tubing with a cross Section of 1 cm^2 to 10.3 m.

Once the sampling chamber is filled with the desired volume the pumping is stopped. The sample is then deposited in the desired container and a purge cycle is initiated. The purge cycle cleans the sampling chamber and tubing by introducing high pressure in the chamber and pushing all the liquid out. Figure 2.1 shows the basic design for a fluid sampler using a vacuum pump.

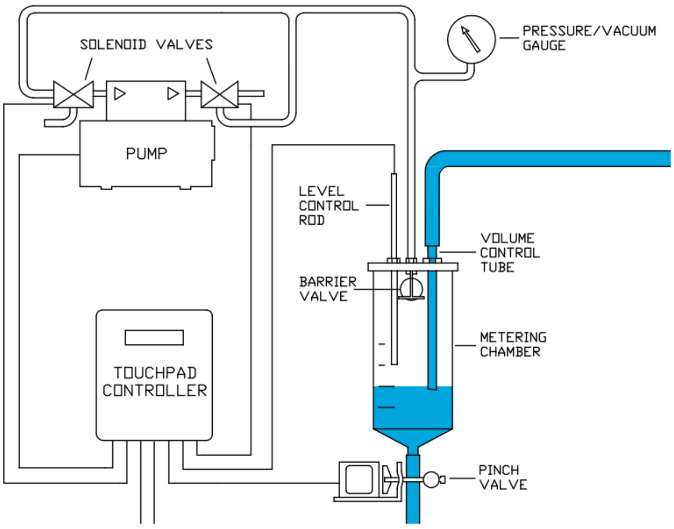

Figure 2.1: Basic working principle of a water sampler with a vacuum pump [6]

The main benefits of using a vacuum pump in a water sampler are:

- Capable of self-priming.
- Precise volume and repeatability.
- Big diameters of intake tubing are possible. Therefore liquids with bigger solids can be handled better.
- The sampling velocity is bigger, this keeps the particles in the fluid more representative.
- Purging happens under great pressure so cross contamination is less likely.

The biggest downsides of using a vacuum pumps are:

- Vacuum pumps require more energy and this decreases mobility.

- The vacuum chamber requires space, so the overall device will be bigger.
- The liquid comes in contact with more than the inside of the tubing alone.

2.2.3.2 Peristaltic pump

A peristaltic pump works by trapping a part of the liquid in the tubing and moving this upwards. The trapping is done by pinching the tube with two or more rollers that turn around (see Figure 2.2). Pinching the tubing harder has a positive impact on the output pressure and the maximum vertical suction height but negatively impacts the power required, the wearing of the tubing and the output flow.

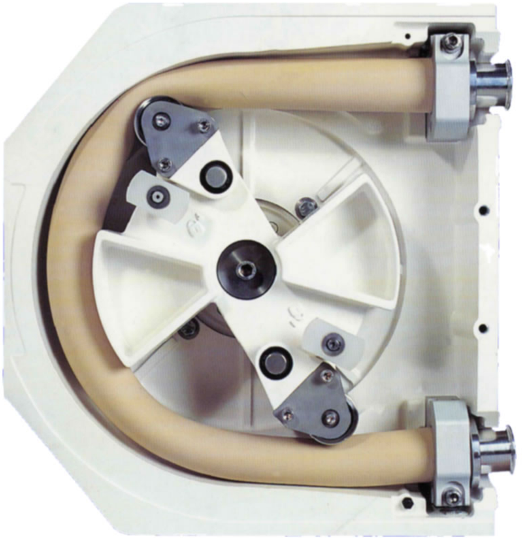

Figure 2.2: Basic work principle of a peristaltic pump [12]

The main benefits of using a peristaltic pump on a water sampler are:

- The pump is self-priming.
- The output is pulsed but has a constant flow.
- Able to dry-run without failure.
- It can handle high viscosity liquids.
- Low power requirements and small size.
- Lower initial cost than a vacuum pump.

The biggest downsides of peristaltic pumps in these applications are:

- The constant flow output needs an output safety valve if the possibility of pressure build-up exists.
- Slower output flow.
- Maintenance is required because of the tube wearing.
- Wearing of the tubing could affect the sample volume size slightly.

2.2.3.3 Centrifugal pump

The centrifugal pump is not used in any of the commercial available devices and this is because of its main downsides.

A centrifugal pump has to be lowered into the water source. This means that next to the pumping hose also an electrical cable has to go from the water source to the collecting vessel. Next to this, the pump is fully submerged in the water source and this makes cleaning more complicated and time-consuming. Furthermore it is impossible to perform a purging cycle between samples, and it also lacks the possibility to dry-run (if a centrifugal pump is dry-running for too long it will break down). The basic working of a centrifugal pump can be seen in Figure 2.3.

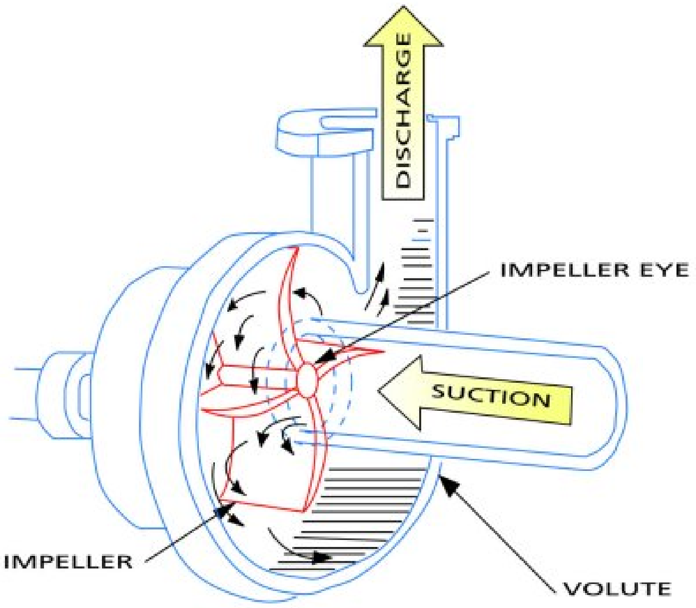

Figure 2.3: Basic work principle of a centrifugal pump [5]

All of these downsides do not add up to it very few benefits. The main benefit of a centrifugal pump is that it has a suction height higher than 10.3 m.

2.2.4 Conclusion

In Table 2.1 is presented a comparison of the different pump properties. It also lists the centrifugal pump but, because of its main downside (see Subsection 2.2.3.3), this pump is not an option for developing a portable fluid sampler.

Table 2.1: Comparison of the different types of pumps

Characteristic	**Peristaltic pump**	**Vacuum pump**	**Centrifugal pump**
Initial cost	low	high	low
Maintenance	high	low	medium
Maximum suction height	10.3 m	10.3 m	>10.3 m
Cross contamination	medium	low	medium
Size	small	medium	small
Self priming	yes	yes	no
Repeatability	low	high	medium
Cleaning	easy	medium	hard
Handling liquids with solids	bad	medium	good

The project will use a peristaltic pump to develop the fluid sampler because it is smaller and requires fewer components to integrate (no sampling chamber is needed). On top of this, it requires less energy and it has a lower initial cost. The better repeatability, higher sampling flow rate and low maintenance of the vacuum pump are unimportant benefits for this project and therefore a vacuum pump is not an option.

Chapter 3

Development Technologies and Platforms

This chapter will discuss the platforms and technologies used for integrating a microcontroller in the control electronics.

3.1 Platforms

The requirements for the microcontroller platform are:

- A large amount of available I/O.
- A hardware timer capable of running on at least 10 MHz.
- A small amount of non volatile memory.
- Decent libraries and support.
- Low price point.

These requirements are met by multiple platforms. Considering that the device has to be made at the lowest price possible the deciding parameter will be the cost of the board. All of these requirements make that the STM32L100 Discovery Kit from STMicroelectronics was selected. It provides an on-board programmer and debugger, great sample code and libraries, support software for code generation and support for multiple development environments. And it delivers all of this for 8 €. Other platforms worth considering are the LaunchPad from Texas Instruments, other STM or Nucleo boards and Arduino boards. But compared to the STM32L100 Discovery Kit they deliver less powerful processors at a higher price.

3.2 Languages

The program required for the control of the fluid sampler is not complex nor extensive. There is, however, a certain need for low-level control of the hardware to implement the fluid sensor. This eliminates any high-level programming languages such as C#, Java, etc.

The remaining main stream options are C, C++, BASIC, Pascal or Assembler. The selected board is from STMicroelectronics, which provides code samples and libraries written in C. Consequently, the fluid sampler software was developed in C.

3.3 Development environments

The selection of the integrated development environment (IDE) was based on the following criteria: (i) be open source; (ii) have an active software support; (iii) be an all-in-one tool for easy plug and play installation; (iv) minimal number of pre-written libraries and code to allow low-level access to the hardware; and (v) include a built-in debugging tool.

The following five platforms were analysed in terms of the above criteria: TrueStudio by Atollic, CooCox, ChibiStudio on the ChibiOS, ARMmbed and GNU ARM Eclipse. In the end, TrueStudio by Atollic proofed most promising and this IDE was selected to develop the software. The other platforms were rejected because of the following reasons.:

- CooCox looked very promising, but the developer lacks software maintainance and support.

- ChibiStudio is not a standard IDE. It runs on a specific operating system (ChibiOS) and has extensive software layers as a basis to program, which disables many low-level programming capabilities.

- ARMmbed was probably the closest competitor for TrueStudio. It features a very good support, is extremely easy to start on (the software runs online) and has good code samples. The only thing it lacks is an easy debug tool.

- GNU ARM Eclipse is a free and all-in-one IDE with debugging capabilities that runs on Eclipse. The biggest difference with TrueStudio is that it fails to provide an easy installation. To install GNU ARM Eclipse several components have to be installed separately and this only increases the chances of non-compatibility for future development and changes.

Table 3.1 shows a comparison of all the considered platforms.

Table 3.1: Comparison of IDE software suites

	Free	**Active**	**All in one**	**Low level**	**Debugging**
TrueStudio	yes	yes	yes	yes	yes
CooCox	yes	no	yes	yes	yes
ChibiStudio	yes	yes	no	no	no
ARMmbed	yes	yes	no	yes	no
GNU ARM Eclipse	yes	yes	yes	yes	yes

3.4 Conclusion

The selection of the development technology and platform is mainly focused on the low-cost of the hardware. After selecting a microcontroller board from STMicroelectronics, the options for the programming language and the development environment became more limited. For the programming language the only reasonable option was C. For the development environment there were multiple options, but the most complete and free IDE was TrueStudio from Atollic.

Chapter 4

System Development

This chapter is devoted to the description of the development process of the fluid sampler.

4.1 Pump control

The pump is driven by a 24 V DC-motor that draws 0.5 A on average. Because the pump has to suck the fluid up and also perform a purging cycle, a H-bridge will be needed to control the pump. The used H-bridge is an L298-board that will be interfaced with the developed PCB (see Section 4.6).

The pump is connected to the sampling hose and fluid sensor by a taper shaped tubing connector (see Figure 4.1).

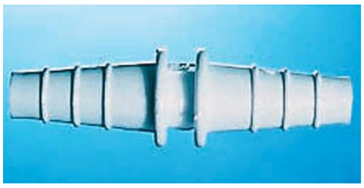

Figure 4.1: Taper shaped tubing connector

4.2 Fluid sensor

The system requires a fluid sensor because the fluid sampler has the option to select the desired sample volume, i.e., the fluid flow has to be measured. The easiest way to do this is by using a flow sensor that outputs a variable voltage, or pulse, depending on the flow of the fluid. However, this method has some downsides. First of all, it introduces an extra part in the fluid stream and this is not beneficial for maintenance and possible clogging. Secondly, the price of fluid sensor ranges between 30 € and 60 €, which is too expensive when compared to the total budget of the fluid sampler.

4.2.1 Sensor design and development

Various options were contemplated during brainstorming sessions. In the end, the best option was to develop a dedicated low-cost sensor to detect when the fluid is flowing through the hose and combining this with a time measurement to determine the sample volume. A time measurement can be used because the peristaltic pump runs at a fixed rotational speed and therefore has a predictable flow output. The reason that the flow of fluid has to be detected is because the amount of air that has to be removed out of the tubing depends on the depth of the water source. The moment that the fluid stream is detected a time measurement can be started because the distance from the sensor to the sample bottles is known.

The design of the sensor is in essence very simple. The base consists of an NE555 IC that generates a square wave as output. The NE555 requires 2 resistors and 1 capacitor to set the duty cycle and period of the square wave. Instead of using a normal capacitor, 2 copper plates are used with the sampling hose between them (see Figure 5.1 and Figure 5.2). When the fluid is inside of the tubing, the capacitor dielectric raises and the period of the square wave increases. This change in frequency of the square wave can be detected by the microcontroller. To verify this theory a test was made to determine the frequency difference between the air filled hose and the fluid filled hose – see Subsection 5.1.1 for the test results.

4.2.2 Detection in the microcontroller

The NE555 produces a square wave between 52.63 kHz and 66 kHz (see Subsection 5.1.1 for the measurements). To determine this change in frequency, a timer of the microprocessor will be used. To obtain the highest accuracy the timer should run on the maximum frequency possible. For the STM32L100 microcontroller this is 32 MHz (see Figure 4.2). Timer 2 of the STM32L100 is configured as follows:

- The clock of the timer is the internal clock that is configured to 32 MHz.
- The auto-reload mode is enabled with the timer counting up and the interrupt event enabled.

- The slave mode is enabled and configured in reset mode with external input (`PA5`).
- The input capture mode is activated on channel 1 and configured for external input (`PA5`) with its interrupt event enabled.
- The external signal of the fluid sensor is divided by 8 using the internal pre-scaler of `TIM2`.
- The update request source bit of the timer is set, ensuring that only an overload triggers the `HAL_TIM_PeriodElapsedCallback()` method. The `HAL_TIM_IC_CaptureCallback()` method is called whenever an input is detected.

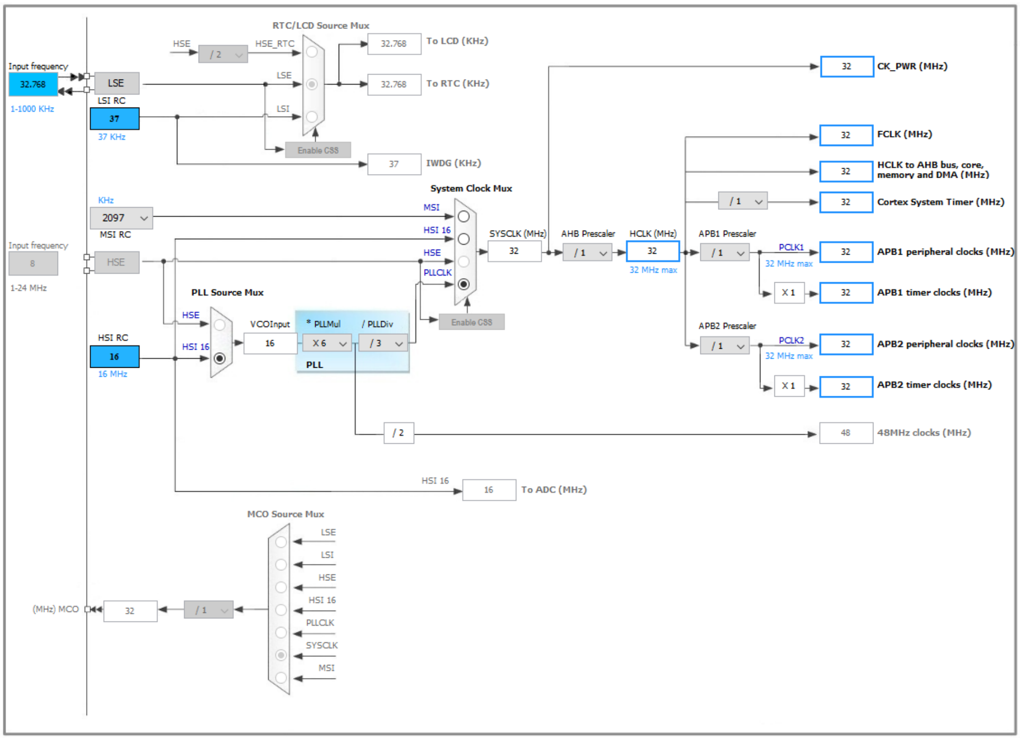

Figure 4.2: Clock configuration [13]

The configuration of the external input trigger is shown as the green path in Figure 4.3. Figure 4.4 illustrates the slave mode configuration as the blue path, the input capture configuration as the red path and the counter configuration as the brown path. Code Snippet 4.1 displays the timer initialisation code, Code Snippet 4.2 the auto-reload interrupt handler and Code Snippet 4.3 the input-capture interrupt handler.

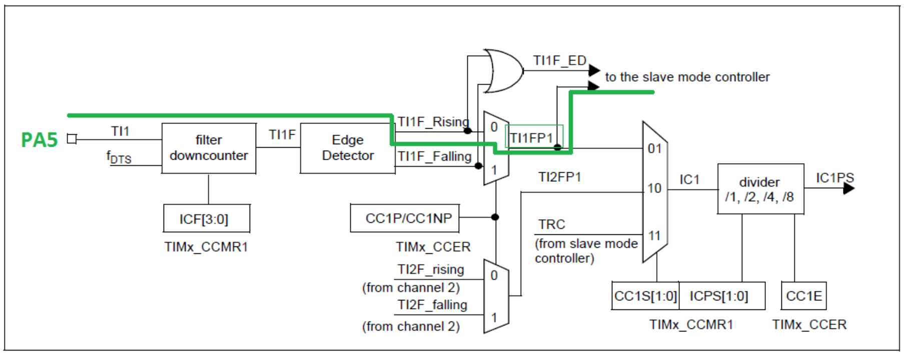

Figure 4.3: Input path external trigger pin [14]

Code Snippets 4.1 Timer initialisation

```c
/* TIM2 init function */
void MX_TIM2_Init(int period, int filter) {
  TIM_ClockConfigTypeDef sClockSourceConfig;
  TIM_SlaveConfigTypeDef sSlaveConfig;
  TIM_IC_InitTypeDef sConfigIC;
  // Configure the basics of the timer
  htim2.Instance = TIM2;
  htim2.Init.Prescaler = 0;
  htim2.Init.CounterMode = TIM_COUNTERMODE_UP;
  htim2.Init.Period = period;
  htim2.Init.ClockDivision = TIM_CLOCKDIVISION_DIV1;
  HAL_TIM_Base_Init(&htim2);
  // Clock source for timer
  sClockSourceConfig.ClockSource = TIM_CLOCKSOURCE_INTERNAL;
  HAL_TIM_ConfigClockSource(&htim2, &sClockSourceConfig);
  HAL_TIM_IC_Init(&htim2);
  // Slave mode configuration
  sSlaveConfig.SlaveMode = TIM_SLAVEMODE_RESET;
  sSlaveConfig.InputTrigger = TIM_TS_TI1FP1;
  sSlaveConfig.TriggerFilter = filter;
  sSlaveConfig.TriggerPrescaler = TIM_ETRPRESCALER_DIV8;
  HAL_TIM_SlaveConfigSynchronization(&htim2, &sSlaveConfig);
  // Input capture configuration
  sConfigIC.ICPolarity = TIM_INPUTCHANNELPOLARITY_RISING;
  sConfigIC.ICSelection = TIM_ICSELECTION_DIRECTTI;
  sConfigIC.ICPrescaler = TIM_ICPSC_DIV8;
  sConfigIC.ICFilter = filter;
  HAL_TIM_IC_ConfigChannel(&htim2, &sConfigIC, TIM_CHANNEL_1);
  // Set Update request source bit (URS).
  // Only a counter overflow triggers HAL_TIM_PeriodElapsedCallback
  htim2.Instance->CR1 |= (0x1 << 2);
  // Interrupt configuration
  HAL_NVIC_SetPriority(TIM2_IRQn, 0, 0);
  HAL_NVIC_EnableIRQ(TIM2_IRQn);
}
```

Code Snippets 4.2 Timer auto reload interrupt handler

```c
/* Interrupt handler a Period Elapsed Callback of any timer */
void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim) {
  if(htim->Instance == TIM2) // Make sure the interrupt is from TIM2
  {
  }
}
```

Code Snippets 4.3 Timer input capture interrupt handler

```c
/* Interrupt handler an Input Capture Callback of any timer */
void HAL_TIM_IC_CaptureCallback (TIM_HandleTypeDef *htim) {
  if(htim->Instance == TIM2) // Make sure the interrupt is from TIM2
  {
  }
}
```

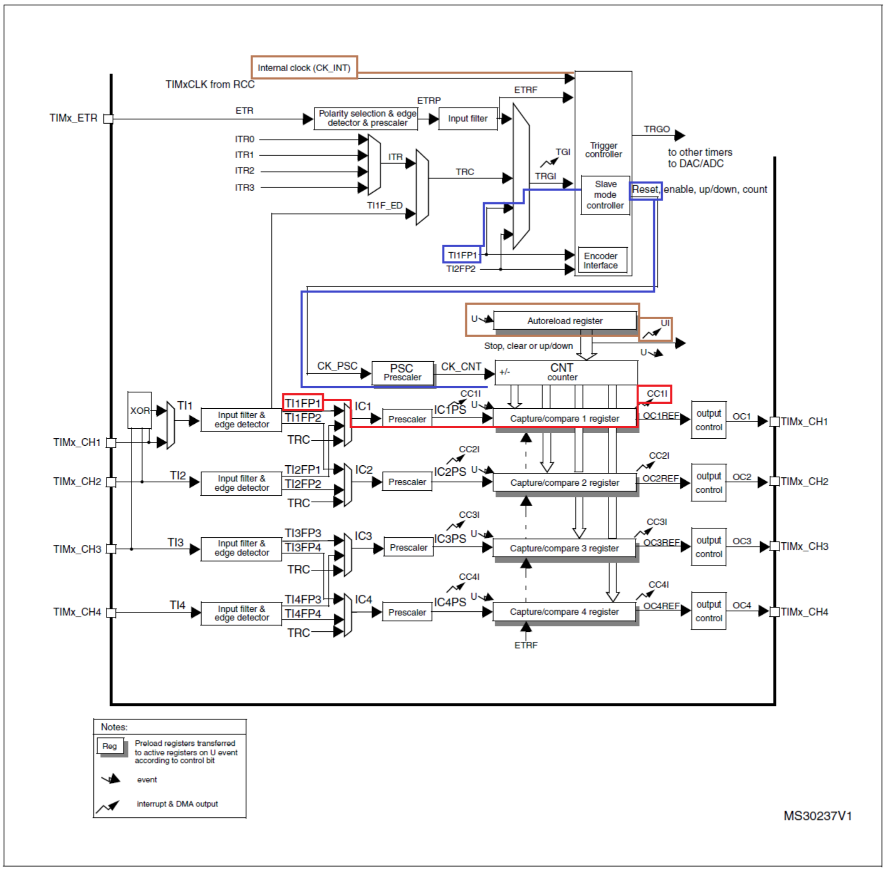

Figure 4.4: Timer configuration [14]

The combination of these setting allows using the timer to detect the frequency change of the fluid sensor. Figure 4.5 provides the flowchart with the steps that have to be performed each time the fluid stream has to be detected.

1. When the microcontroller is initialised the auto-reload value is configured to a high value. This is done to make sure that the timer never auto-reloads before the input capture happens.
2. When the software has to detect the fluid stream it starts the input capture mode on channel 1 with the interrupt enabled. This is done by calling the

`HAL_TIM_IC_Start_IT()` method. In the interrupt handler of the input-capture mode the following steps are completed.

  a) The first 10 captured values are stored in an array.
  b) After storing 10 values the input capture interrupt is disabled by calling the `HAL_TIM_IC_Stop_IT()` method.
  c) The average of the last 8 values is increased with 20 % and stored as the new auto-reload value of the timer.
  d) The pump is activated.
  e) The timer is activated in the auto-reload mode with the interrupt enabled. This is done by calling the `HAL_TIM_Base_Start_IT()` method.

3. Because the auto-reload cycle is 20 % larger than the frequency of the fluid sensor, which triggers the reset of the timer, the auto-reload value is never reached. When fluid is flowing through the tubing that is between the plates of the sensor the signal of the sensor increases 23 % and the timer will reach its auto-reload value and the interrupt will be triggered.

4. A flag is raised indicating that fluid has been detected, the auto-reload value is configured on a high value again and the timer interrupt is disabled by calling `HAL_TIM_Base_Stop_IT()` method.

5. From this point on the pump is kept activated for a certain amount of time depending on the desired volume.

Every time that the fluid has to be detected steps 2 until 5 are repeated. This method always determines a new and accurate value for the tubing without fluid inside. This allows the software to compensate for all possible factors that have an influence on the capacitor value created by the two copper plates, such as humidity or rusting of the copper.

Due to the simplicity of the sensor design, it is possible to place the electronics on the same copper plate that is used to construct the capacitor. The generated pulse has a frequency of 60 kHz and will be in close proximity of a DC, servo and stepper motor. It would be possible to transport the signal by normal wires but to avoid any interference and obtain a clear measurement, a 50 Ω coax cable will be used to transport the signal from the sensor to the main PCB. The schematics of the PCB can be seen in Figure 4.6 and the layout in Figure 4.7.

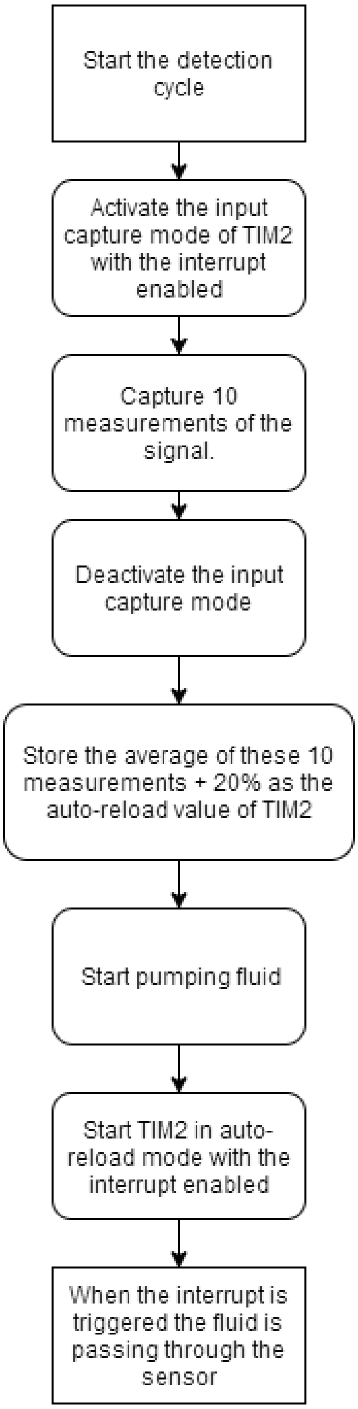

Figure 4.5: Fluid detection flowchart

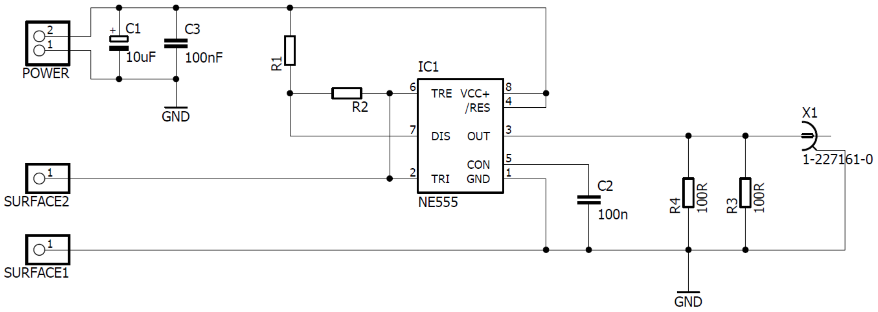

Figure 4.6: Fluid sensor schematic

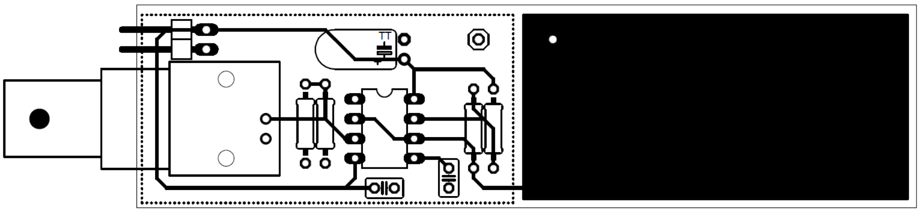

Figure 4.7: Fluid sensor board layout

4.3 Interface

One of the main requirements, mentioned in Subsection 1.2.1, is that the interface of the fluid sampler needs to be as simple as possible. To get a better understanding of the required functionalities for the interface and the possible interactions with it, use cases were made (see Section 4.4).

A 12-key hex-keypad in combination with 4 separate buttons (Stop, Enter, Cancel and Status) are the only way for the user to provide input. An LCD, red LED, orange LED and green LED will provide the necessary feedback to the user. See Figure 4.8 for the full interface.

The LED will provide quick feedback to the user about the current state of the machine. Table 4.1 lists the meaning of all possible LED-indications. The LCD will be used to provide more detailed information about the status or ask the user for specific input. By default, the screen will turn off after 30 s of inactivity.

The hex-keypad enables the user to enter the desired amount of samples, the time between samples and the size of the samples, using the buttons 0 to 9. The 2 extra buttons (* and #) do not have a function and are reserved for future extensions.

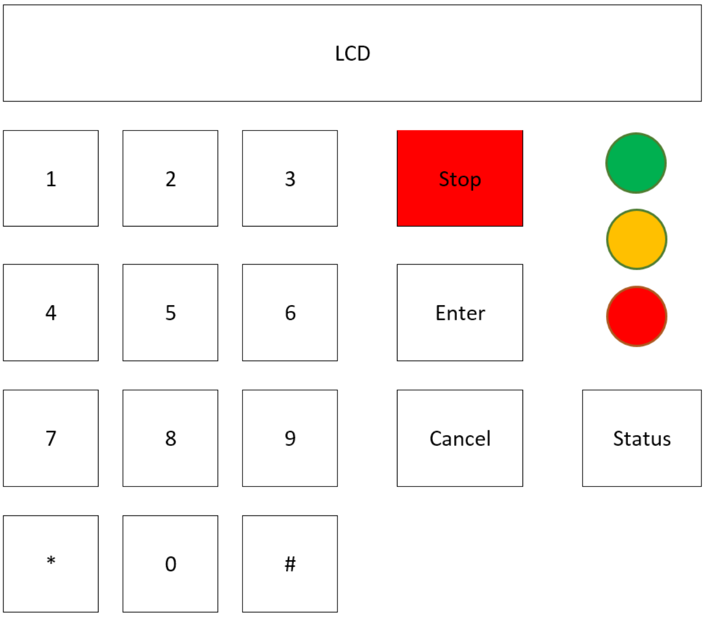

Figure 4.8: Overview of the interface

Table 4.1: Status LED indications

LED status	**State**	**Description**
Green blinking	Active	The sampling cycle is active
Green burning	Finished	The sampling cycle is finished
Orange blinking	Battery	The battery level is too low to perform a 24 h sampling cycle
Orange burning	Fault	A fault was detected
Red blinking	-	-
Red burning	Stop	The machine is in Stop mode

The stop button is used as an emergency button. Pressing it will place the fluid sampler in a full stop-state. In this state the motors and pump are disabled immediately.

The Enter and Cancel buttons are used to confirm and reject settings or input. The Status button is used to wake up the screen when it is turned off. When the fluid sampler is in the stop-state the user can use the Cancel or Enter button to restart or stop the current sampling cycle (see Subsection 4.4.4 for the description of this functionality).

4.4 Use cases

4.4.1 Deploying the fluid sampler

Summary:
Procedure to deploy and initialise the sampler for autonomous working.
Actor:
Company employee.
Precondition:
The fluid sampler is placed close to the fluid source with the sampling hose lowered in the source. It is placed steady on a flat surface and it is powered off.
Main sequence:

1. The user activates the fluid sampler by flipping the power button.
2. The fluid sampler will show the default parameters (200 ml, 60 min, 24 samples) and ask if the user wants to use these.
3. The user confirms by pressing Enter.
4. The fluid sampler will start the sampling operation, this is indicated by a flashing green light. The screen will be turned off after 30 s.

Alternative sequence:

3. The user presses the Cancel button to change the parameters.
4. The fluid sampler will ask to enter the desired volume of the samples.
5. The user enters the volume in ml and confirms with Enter.
6. The fluid sampler will ask to enter the desired time between samples.
7. The user enters the time in minutes and confirms with Enter.
8. The fluid sampler will ask to enter the desired number of samples.
9. The user enters the number of samples and confirms with Enter.
10. The fluid sampler will show an overview with the entered parameters and will ask if the user want to use these.
11. The users confirms with Enter (pressing Cancel will start the alternative sequence again).
12. The fluid sampler will start the sampling operation, this is indicated by a flashing green light. The screen will be turned off after 30 s.

4.4.2 Status check

Summary:
The procedure to check the current status of the fluid sampler.
Actor:
Company employee.
Precondition:
The machine is currently in one of the following states:

- It is performing a sampling cycle (flashing green light).
- It has finished has sampling cycle (burning green light).

Main sequence:

1. The user presses the Status button.
2. The fluid sampler will present the battery level and amount of samples taken.
3. After 30 s the screen is disabled to save energy.

4.4.3 Retrieve the samples

Summary:
The Procedure to extract the samples from the fluid sampler for analysis.
Actor:
Company employee.
Precondition:
The fluid sampler indicates that it has finished the sampling sequence with a burning green light. Alternatively the sampler indicates that it is still performing a sampling cycle with a blinking green light.
Main sequence:

1. The employee turns the power off.
2. The machine is opened by using the hinge-locks.
3. The sampling bottles are removed from the fluid sampler.

Alternative sequence:

1. The users presses the stop button.
2. The machine will stop all actions and indicate the stop-state with a burning red light and a message on the display.

3. The user holds down the Enter button for 3 s.
4. The fluid sampler ends the sampling cycle (this is indicated with a burning green light).
5. The employee turns the power off.
6. The machine is opened by using the hinge-locks.
7. The sampling bottles are removed from the fluid sampler.

4.4.4 Stop the sampling operation

Summary:
The procedure to stop the current sampling cycle.
Actor:
Company employee
Precondition:
The machine is currently performing a sampling cycle (this is indicated by a flashing green light).
Main sequence:

1. The user presses the stop button.
2. The machine will stop all actions and indicate the stop-state with a burning red light and a message on the display.
3. The user holds down the Enter button for 3 s.
4. The fluid sampler ends the sampling cycle (this is indicated with a burning green light).

Alternative sequence:

1. The user holds down the Cancel button for 3 s.
2. The machine will resume the sampling cycle (this is indicated by a flashing green light).

4.4.5 Maintenance

Summary:
The procedure to service the fluid sampler. All steps should be followed during maintenance. It is recommended to perform an scheduled maintenance every 6 months to ensure proper operation. The maintenance should be performed by a qualified technician.

Actor:
Technician
Precondition:
The fluid sampler is powered off.
Main sequence:

1. Check the sampling hose for clogging, wearing and general condition.
2. Check the peristaltic pump and pay special attention to the wearing of the tubing inside.
3. Check the water collector cup for clogging, cracks or damage.
4. Verify that there is no water in the bottom of the fluid sampler or indications of water overflows.
5. Inspect the mechanical structure for cracks or damage.

4.5 Sample separation

To collect 24 samples in separate bottles, a separation system had to be developed. One possibility is to place the bottles in a grid and attach the sampling hose to an XY motion system. The main disadvantage of this system is that such an approach requires two stepper motors, threaded rods and a strong mechanical support system. This makes that this solution is too expensive and inadequate for this project.

A more interesting separation system places the bottles in a circle, couples the sampling hose to a rotating arm to select and fill each bottle. Due to the simplicity of this system, it is robust and the cost relativity low. The sample separation is associated with two main requirements mentioned in Subsection 1.2.1: (*i*) the usage of standard bottles provided by Centro de Estudo de Águas; and the (*ii*) the portability of the fluid sampler. The provided bottles have a height of 200 mm, an external diameter of 92 mm and a volume of 1 l. Creating a circle of 24 bottles would result in a fluid sampler with a diameter of at least 900 mm, which is too large to easily carry and transport the fluid sampler. Placing the bottles in two concentric circles reduces the dimensions of the fluid sampler to an acceptable size, but complicates the separation system. See Figure A.4 for the comparison of different bottle placement layouts.

When designing an arm to route the samples to the bottles, which are placed into 2 concentric circles, the following aspects should be kept in mind.

- The friction between the sampling hose and the system should be kept minimal

- The system should be easy to disassemble for cleaning and maintenance.

Figure 4.9 displays the created solution, consisting of a collector-cup, divided in the middle, and two lateral round exits, one on each side of the division, for connecting extension-tubes. By placing a longer extension-tube on one side it is possible to deposit the sample either in the inner or outer bottle circle. This collector cup fits into a holder connected to a stepper motor, which revolves around the whole assembly. The bottom of the holder is fitted with notches every 8°, these will be used in combination with a switch to verify the current angle of the water separation system. This water separation system was built with a 3D printer. Figures A.1, A.2, A.3 provide the detailed schematics.

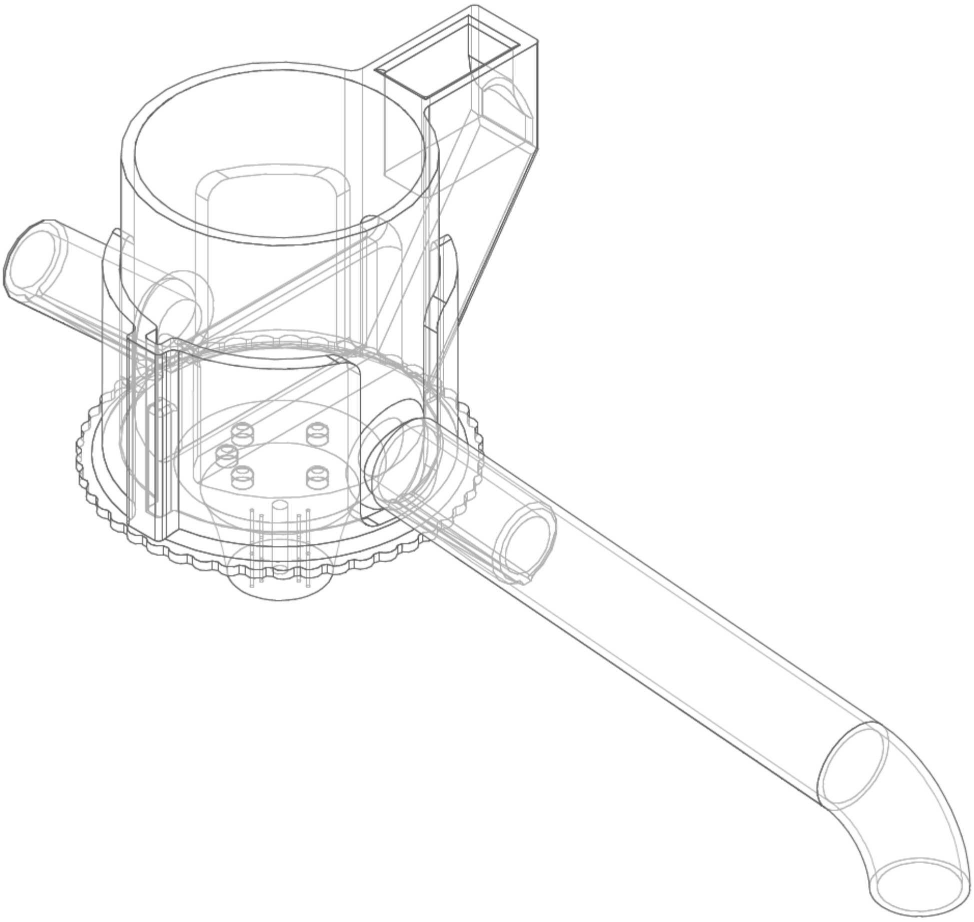

Figure 4.9: Water separation system

The servo motor, which is connected to the outer side of the collector-cup, places the tube above the intended half of the cup. Figure 4.10 illustrates how the servo motor interfaces with the tube. The tube fits inside the hole that hangs over the collector cup. To avoid wearing the tube, a 1 mm spacing is provided between the diameter of the tube and the hole.

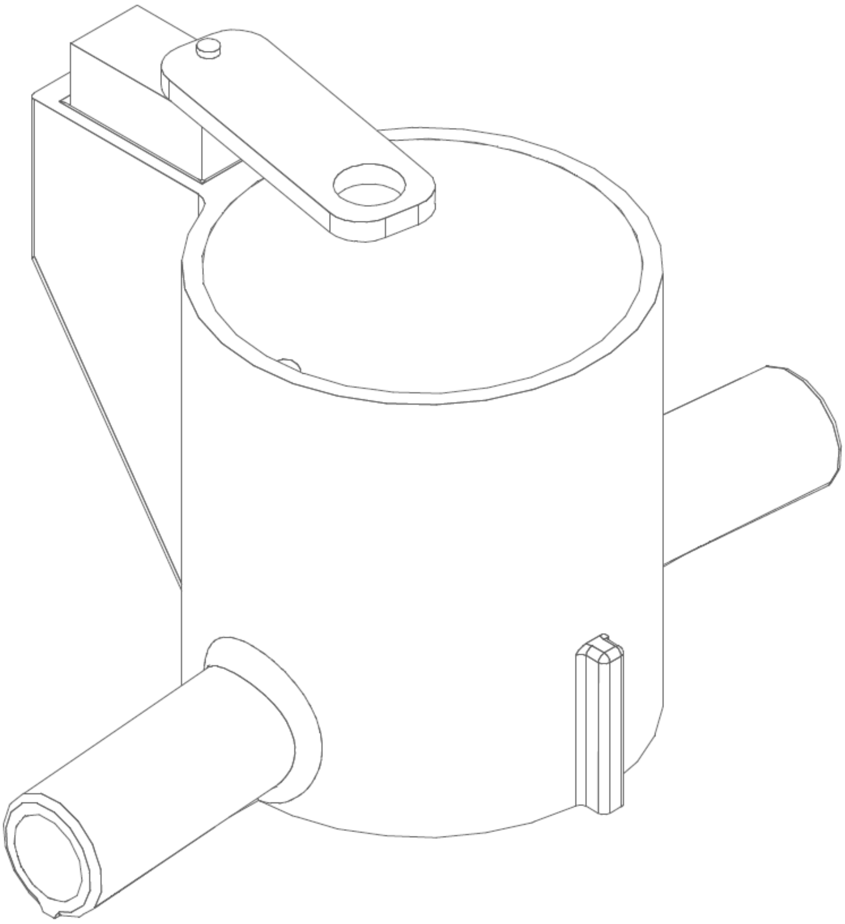

Figure 4.10: Interface servo motor and tubing

4.6 Control electronics

The fluid sampler is controlled by the STM32L100C-DISCO microcontroller board, containing a 32-bit Cortex M3 processor with 256 kB flash and 16 kB RAM as well as an on-board programmer and debugger. The STM32L100C-DISCO microcontroller board interfaces with all electronic components through a designed PCB (see Figure 4.11 for the architecture and Figure A.5 for the electronic schematic).

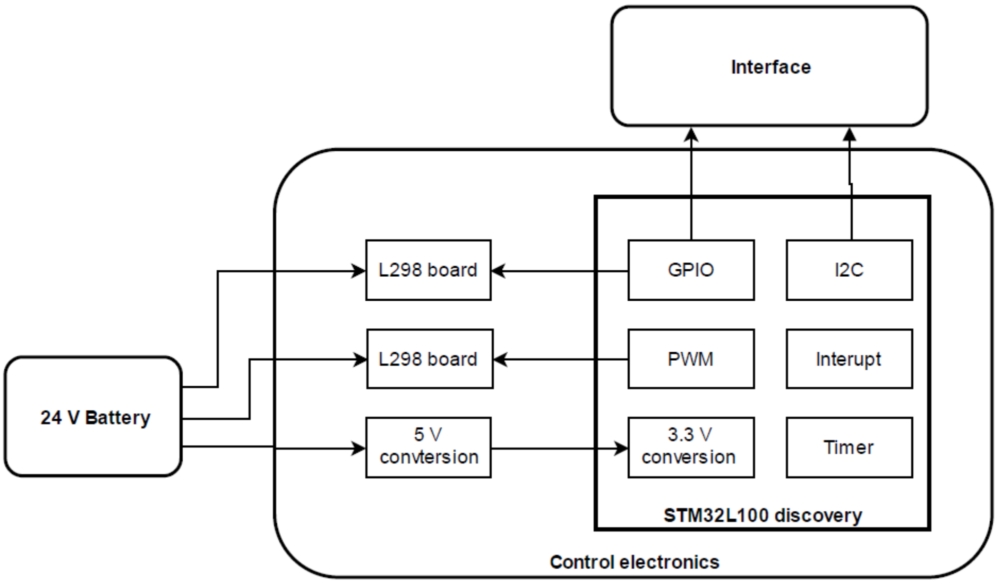

Figure 4.11: Architecture of the control electronics

4.6.1 Power conversion

The designed PCB features a power conversion section where a 7805 voltage regulator converts 24 V to 5 V. The generation of 3.3 V is done by the STM32L100C-DISCO, since it includes on-board an LD3985M33R voltage regulator capable of delivering up to 100 mA. Figure 4.12 depicts the on-board power conversion of the STM32L100C-DISCO.

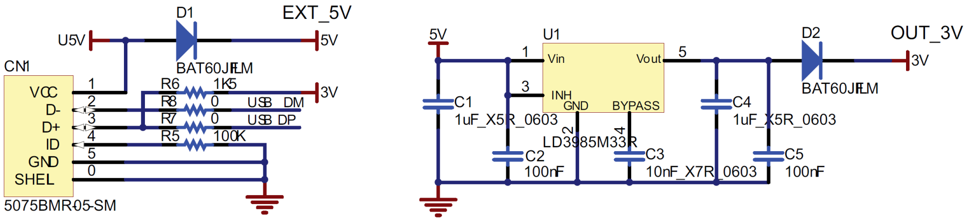

Figure 4.12: Power regulation STM board

Table 4.2 displays the current required by the various components powered through the 7805 voltage regulator.

Equation 4.1 represents the total power dissipation of the 7805 without the servo since the servo will only work for very short amounts of time. Equation

Table 4.2: Current driven by the 7805

Component	**Current** (mA)
STM-board	20.00
3 LED	30.00
LCD back light	32.00
LCD logic	0.18
NE555 sensor	5.00
Servo	200.00

4.2, which displays the calculation of the junction temperature when no heat sink is used, allows concluding that temperature is still under the maximum value (120 °C). However, when considering the servos operation and an ambient temperature of up to 50 °C, it is clear that a heat sink is needed.

Equation 4.1: 7805 dissipation without heatsink

$$(24\,\mathrm{V} - 5\,\mathrm{V}) \times (20\,\mathrm{mA} + 30\,\mathrm{mA} + 32\,\mathrm{mA} + 0.18\,\mathrm{mA} + 5\,\mathrm{mA}) = 1.66\,\mathrm{W} \tag{4.1}$$

Equation 4.2: 7805 temperature without heatsink

$$1.66\,\mathrm{W} \times 35\,^{\circ}\mathrm{C/W} = 58\,^{\circ}\mathrm{C} \tag{4.2}$$

The used heat sink has a thermal resistance of 7.1 °C/W. Using the thermal resistance from junction to case for a TO220 package (5 °C/W) and the thermal resistance from case to heat sink (0.5 °C/W), it is possible to calculate the temperature rise of the heat sink. As seen in Equation 4.3 this temperature rise is acceptable for a worst case calculation.

Equation 4.3: 7805 temperature with heatsink

$$1.66\,\mathrm{W} \times (5\,^{\circ}\mathrm{C/W} + 7.1\,^{\circ}\mathrm{C/W} + 0.5\,^{\circ}\mathrm{C/W}) = 20.9\,^{\circ}\mathrm{C} \tag{4.3}$$

4.6.2 DC-motor drivers, stepper and servo

The DC-motor of the pump and the stepper motor responsible for rotating the water collector cup are both driven by L298 boards (see Figure 4.13). The use of separate L298 boards makes maintenance and repairing easier.

The L298 board driving the DC-motor of the pump uses both H-bridges in parallel. This is done by connecting input pins 5 and 12 and interconnecting

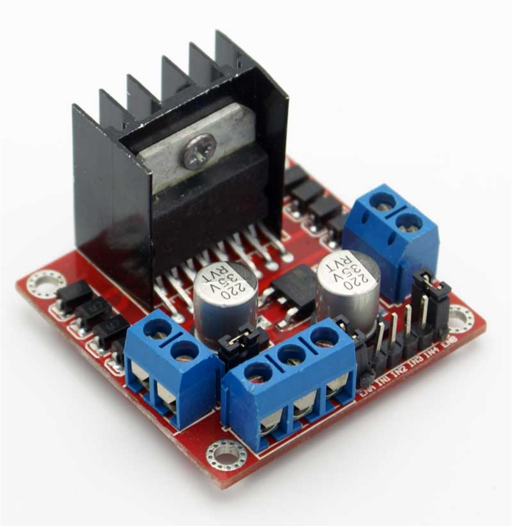

Figure 4.13: L298 board

input pins 7 and 10. For the output, pins 2 and 14 are connected and pins 3 and 13 are also interconnected. The L298 board is powered by 24 V and has its own internal 5 V conversion.

The other L298 board drives the stepper motor. The stepper motor is a PM55L-048 which was mounted in an old printer. It has 48 steps per revolution and works with 24 V. The motor can be used in uni-polar or bi-polar drive – see Figure 4.14 for the coil layout of the stepper. To increase the resolution and maximise the torque, the stepper will be used in bi-polar drive with half-stepping. With half-stepping the on rotation is divided in 96 steps instead of 48 steps, resulting in a 3.75° rotation for each electrical step.

The servo motor, which places the tube over the intended side of the collector cup, is driven by a PWM signal generated by the microcontroller and powered at 5 V by the 7805 voltage regulator. The servo motor is a MC1811 which is a low-cost model mainly used by hobbyist for controlling small toys. To extend the lifespan of the servo, the 5 V power supply is switched on through a relay only when the servo has to move and switched off in all other cases.

4.6.3 LCD interface

The LCD communicates with the microcontroller through the I2C bus and is mounted directly onto the PCB. This means that the PCB has to be mounted just under the top of the upper bucket (see Section 4.7 for the mechanical layout). The back light of the LCD is switched on or off by the microcontroller using a transistor.

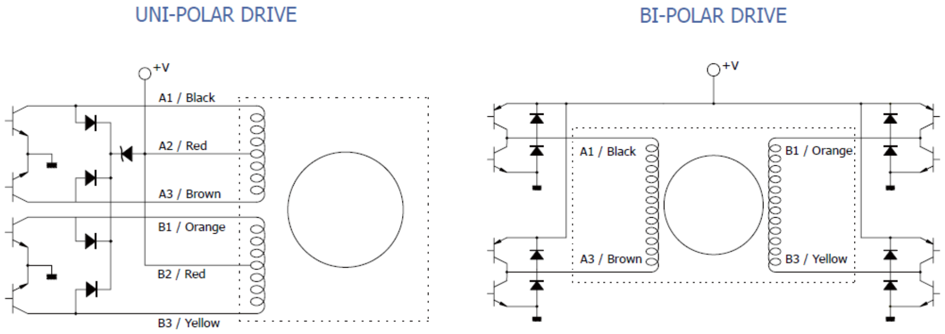

Figure 4.14: Stepper motor coil configurations

4.7 Mechanical structure

The mechanical structure holding the two concentric circles of bottles, the rotational arm to fill the bottles, the water separation system, the pump, hose, the control system and the user interface has a circular section. Due to the size of the bottles the minimum diameter of the structure is 640 mm (see Figure A.4). The majority of general-purpose plastic circular structures (buckets, cans or baskets) have a diameter smaller than 640 mm. However, in farm equipment stores it is possible to find large round plastic containers, up to 1 m diameter.

The mechanical structure is made with two large plastic buckets with a diameter of 71 cm and a height of 32 cm. They are mounted with their openings facing each other connected by two hinges to secure them together while providing easy access to the samples.

To fix the bottles in their position the base of the bottom container was filled with polyurethane and the position of the 24 bottles was imprinted. First, the bottles were placed in the desired layout, filled with water and covered with a thin plastic film. Then, the expandable polyurethane is inserted between the bottles and left to dry. Once it is dry, the bottles are taken out and the excess of expandable polyurethane is removed on the top using a knife.

The bottom of the top bucket is the top part of the mechanical structure. The buttons, keypad and power switch are mounted on this surface and a rectangular hole to fit the LCD. This hole is covered with perspex. Since the LCD display is mounted directly on the main PCB, the PCB is also attached to the bottom of the top bucket. This is done with 4 screws and spacers to provide enough space for the other parts on the PCB.

4.8 Possible additions

The main goal of this dissertation was to develop a robust and low budget fluid sampler. This also means that the fluid sampler includes no extra options. There are, however, a few useful upgrades that could be installed with a small cost.

The first would be to collect complementary information regarding the sampling conditions, e.g., acquire and store the temperature, the flow rate or the location, using a GNSS receiver, of the collected samples. These parameters could be used to keep a detailed log and have more information when abnormalities are detected.

A second feature would be to include an external data connection to get real-time status updates from a remote location. This could be achieved by implementing a Wi-Fi, GPRS or Ethernet connection between the microcontroller and a local network and running a Web server on the microcontroller.

Since communication links are power consuming and can be expensive, the device could, as an alternative, include a storage device (such as an SD-card or pen drive). The fluid sampler could then output more detailed information in the form of a log file on the storage device. This data could be transported with the samples and, in case of abnormalities, there would more parameters available to interpret the samples.

A last useful addition would be an external trigger input. This way the fluid sampler could take a sample when specific conditions are met. For example, a pH-probe could measure the pH and when a certain change is detected a sample could be taken. One way to implement this would be to add a generic trigger input on the device. Depending on the situation and need, a sensor could be developed to connect to the generic trigger input.

4.9 Conclusion

The development of a dedicated fluid sensor did not only reduce the cost of detecting the fluid stream, but it also reduced the number of parts placed in the fluid stream, diminishing the risk of clogging and the need to replace parts because of wearing.

The main PCB is designed to hold all electrical components. Furthermore, it is adaptable for future expansions or changes by the extra I/O pins provided and the separate motor controllers adopted. The main downside of the board is the use of a 7805 voltage regulator to generate the 5 V for the logic since it consumes 1.77 W. As a future extension, a step-down converter could be used to generate the 5 V and, thus, extend the battery life.

Chapter 5

Tests, Results and Validation

This chapter describes the functional tests and their results. The final functional test of the full device is provided in the form of a video that will be presented during the presentation of the work.

5.1 Tests

During the development of the project tree main tests were performed regarding the fluid sensor, the measured fluid volume and the bottle selection and filling.

The first test was to verify the feasibility of the fluid sensor idea. Once the concept was proven, the test was adapted to a real-size sensor and the required software was developed. The results of this test are provided in Subsection 5.1.1.

The second test analysed the pumping speed and the accuracy of the fluid sensor combined with a time measurement. The goal of the test was to determine the flow rate of the pump as well as the accuracy of the volume measured when conditions change.

The third test verified the operation of water divider system. This test was performed with the fully assembled device running in a sampling cycle of 24 bottles of 200 ml with a 1 min interval.

5.1.1 Fluid sensor

Before measuring the frequency change, the expected capacitance was estimated considering a capacitor with two parallel copper plates separated by a tube. This theoretical capacitance was determined using Equation 5.1, where κ is the dielectric constant of the material between the plates, d is the distance between the plates in mm, A is the surface area of the plates in mm^2 and 8.854×10^{-12} is the value of the vacuum permittivity expressed in F/m.

Equation 5.1: Capacitance of two copper plates

$$C = \frac{\kappa \times A \times 8.854 \times 10^{-12}}{d} \tag{5.1}$$

The dielectric constant of air is 1, water at 20 °C it is 80 and of polyvinylchloride is 3. The outer diameter of the tube is 9 mm and the surface of the copper plates is 7500 mm^2 (60 mm wide and 125 mm long). Equation 5.2 presents the theoretical capacitance of the copper plates for the three types of dielectric, which varies between 7.38 pF and 590 pF because the dielectric material is composed of air and Polyvinylchloride and depends on the fluid in the tube (air or water). F/m

Equation 5.2: Capacitance values with air, water and polyvinylchloride

$$\begin{gathered}
\frac{1 \times 7500\,\mathrm{mm}^2 \times 8.854 \times 10^{-12}\,\mathrm{F/m}}{9\,\mathrm{mm}} = 7.38\,\mathrm{pF} \\
\frac{3 \times 7500\,\mathrm{mm}^2 \times 8.854 \times 10^{-12}\,\mathrm{F/m}}{9\,\mathrm{mm}} = 22.1\,\mathrm{pF} \\
\frac{80 \times 7500\,\mathrm{mm}^2 \times 8.854 \times 10^{-12}\,\mathrm{F/m}}{9\,\mathrm{mm}} = 590\,\mathrm{pF}
\end{gathered} \tag{5.2}$$

The first test was made with copper plates of 7500 mm^2 and two tube sections between the plates. This resulted in a signal with a period of 20 µs and a 12.5 % difference when air or water flows through the tubing. To increase the frequency difference, four tube sections (see Figure 5.1) were placed between the plates, resulting in a 50 % difference between the air and water filled tube.

However, in terms of design, the best way to implement the sensor is to use plates with dimensions identical to the tubing. A second test was made to verify if the microcontroller was capable of detecting the difference in the signal produced by the smaller copper plates (see Figure 5.2). Using these smaller plates (115 mm long, 20 mm wide), the NE555 still produced a difference of 28 % in the period of the signal. This change is easily detected by the microcontroller (a 20 % increase is used as threshold).

Table 5.1 lists the measurements obtained with the fluid sensor. The capacitance was calculated through Equation 5.3, using the value of the measured frequency and of both resistors (R1 = 60.6 kΩ and R2 = 410 kΩ). Figure 5.3 and Figure 5.4 display the sensor measurements when water and air are flowing in the tube.

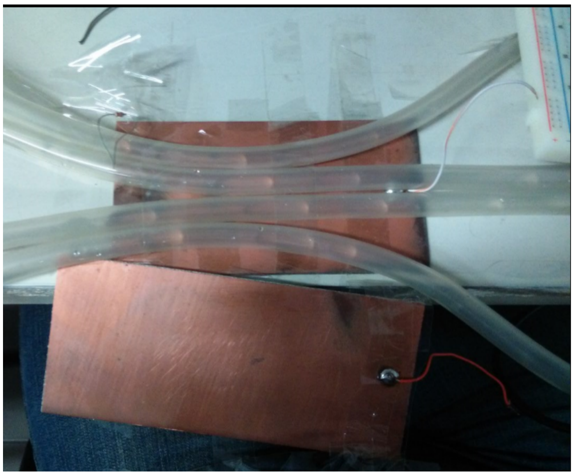

Figure 5.1: Fluid sensor with four tube sections between larger plates

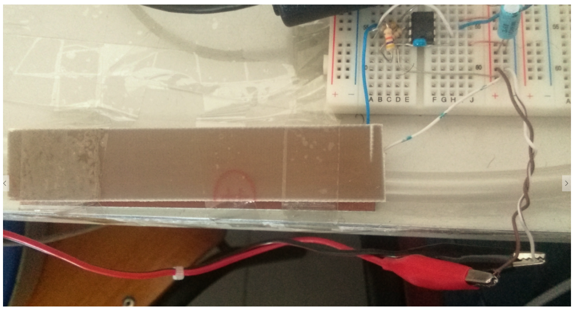

Figure 5.2: Fluid sensor with one tube section between smaller plates

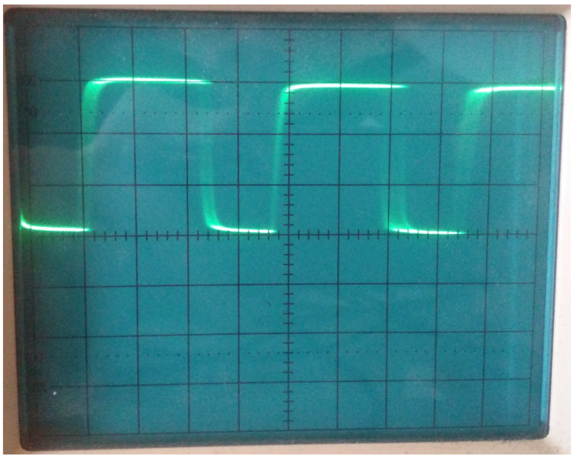

Figure 5.3: Pulse with water (5 µs/division; 1 V/division)

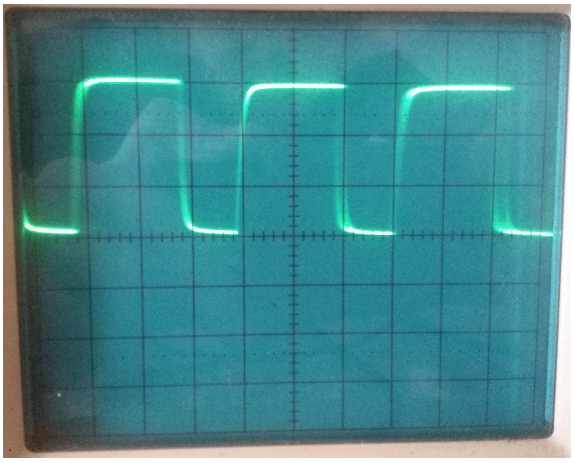

Figure 5.4: Pulse with air (5 µs/division; 1 V/division)

Table 5.1: Fluid sensor measurements

Period (µs)	**Capacitance** (pF)	**Difference** (%)	**Description**
20.0 22.5	32.7 36.8	+12.5	Big surface (7500 mm^2) plates with the tubing passing twice
16.0 24.0	26.2 39.3	+50.0	Big surface (7500 mm^2) plates with the tubing passing 4 times
14.0 18.0	22.9 29.5	+28.0	Small surface (2300 mm^2) plates with the tubing passing once

Equation 5.3: NE555 frequency calculation

$$f = \frac{1.44}{((R1 + 2 \times R2) \times C)} \tag{5.3}$$

5.1.2 Flow rate and sample volume

The goal of this test was to determine the flow rate of the pump and, consequently, the performance of the fluid sensor. The only parameter that can influence the flow rate significantly is the supply voltage of the motor. Table 5.2 displays, for different battery voltages, the determined flow rate.

Table 5.2: Water flow rate for different supply voltages

Voltage (V)	**Flow rate** (ml/s)
23.7	3.796
21.7	3.410
19.7	2.896

Two minimise the influence of the voltage supply in the flow rate determination, a compensation software algorithm was implemented based on this data. The algorithm increases the pumping time 7.77 % for each 1 V battery voltage drop. When the battery voltage remains constant at the nominal value, the accuracy of the samples is ±5 ml. This accuracy was determined by taking five different volume samples (see Table 5.3 for the results). This deviation is introduced by the number rounding, which occurs when multiplying the flow rate by the desired volume.

Table 5.3: Pumped volume accuracy at nominal supply voltage

Setpoint (ml)	**Sample volume** (ml)
100	105
200	205
300	300
400	400
500	495

The measured volume accuracy drops to ±20 ml when the applied voltage changes. This accuracy is determined by applying multiple voltages to the pump and taking multiple measurements (see Table 5.4). In this case the accuracy decreases because of the additional rounding errors introduced by the compensation algorithm.

Table 5.4: Pumped volume accuracy at variable supply voltage

Setpoint (ml)	**Voltage** (V)	**Sample volume** (ml)
100	25.0	105
100	24.0	100
100	22.5	105
100	20.0	105
200	25.0	200
200	24.0	210
200	22.5	205
200	20.0	205
300	25.0	300
300	24.0	301
300	22.5	310
300	20.0	305
400	25.0	400
400	24.0	405
400	22.5	410
400	20.0	405
500	25.0	495
500	24.0	505
500	22.5	520
500	20.0	515
1000	20.0	1010
1000	24.0	1020
1000	22.5	1040
1000	20.0	1040

5.1.3 Sample separation

The complete system is activated in order to test the sample separation system (see Figure 4.10). This test was performed with a sampling cycle of 24 bottles of 200 ml, with a 1 min interval and filmed. The video is available at the wiki-site of the project [15].

5.2 Debugging

The debugging of each part of the software was done with the support of the debugging functionalities of the TrueStudio environment. TrueStudio uses the ST-Link circuit debugger provided on the microcontroller board.

The debugging of the full software was performed by activating the fluid sampler and going through the different options and possible conditions: using default parameters, entering custom parameters, performing an emergency stop, simulating a low battery condition, sampling a dry water stream, stopping and continuing in the middle of a sampling cycle. The software passed all these tests and worked with the different settings.

5.3 Conclusion

The development of the fluid sensor was successful: it is low-cost when compared to any commercially solution available and, above all, it is non-intrusive, i.e., is not inserted in the fluid transportation system. However, since the output signal of the sensor is non standard, it required the development of custom-designed electronics.

The flow rate of the peristaltic pump is as predictable as assumed. The accuracy of the fluid sampler is only affected by the rounding errors introduced by the software. The first rounding occurs during the conversion of the sample volume in ml into a pumping time interval in ms and the second when the pumping time is compensated according to the battery voltage level. The result is a pumping accuracy of ±10 ml for samples smaller than 400 ml and an accuracy of ±40 ml for samples bigger than 400 ml, which is sufficient.

Chapter 6

Conclusions

This chapter summarises the project achievements and suggests potential improvements.

6.1 Outcomes

This project involved the development of the automatic fluid sampler control system, including a dedicated fluid sensor. The control system receives inputs through the user interface and operates the motor pump (to pump the water), the stepper motor (to rotate the intended bottle angle) and the servo motor (to select the desired bottle row) accordingly.

The different subsystems have been tested with success and, at this moment, the final assembling is undergoing. The final project outcomes will be written after the complete assembly, integration and test is accomplished on the 26th of July.

6.2 Suggestions

A list of possible extensions was already mentioned in Section 4.8 regarding the user interface and the acquisition and storage of complementary information about the water samples.

In terms of future developments, the product could improve its power efficiency, measured volume accuracy and mechanical structure.

The power regulation of the main PCB is done by a power consuming 7805 voltage regulator. To extend the battery life the 7805 could be replaced by a step-down converter that has improved power efficiency.

The accuracy of the sample volume could also be improved. The current software uses predetermined constants to calculate the pumping time interval depending on the desired sample volume and the current battery level, introducing rounding errors. This could be avoided if the software uses a lookup table containing the pumping intervals for each battery level and desired sample volume. This is not implemented because the required accuracy is only ±50 ml.

The current mechanical structure was built with the aim of creating a robust and functional case based on commercially available containers. The design and construction of custom-made plastic casing would allow reducing the dimensions of the automatic fluid sampler and improve the image of the product.

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Appendix A

Appendix

Table A.1: List of components

Description	**Supplier**	**Order number**	**Price (€)**
STM32L100C-DISCO	Farnell	2365203	7.30
Keypad	Farnell	1182236	8.60
12 V batteries (2)	Farnell	2475282	38.42
LCD	Farnell	2063205	8.65
Red button	Farnell	1634627	2.88
Peristaltic pump	Williamson pumps	810-090-024-187/2	126.02
Divider cup and holder	Media Markt	-	27.00
Plastic containers (2)	Saavedra	-	54.00
Servo and connectors	PT Robotics	-	26.23
Stepper motor	Recycled	-	-
LED (3)	-	-	-
PCB BNC connectors (2)	-	-	-
L298 boards	-	-	-
9 mm transparent tube (10 m)	-	-	-
Polyurethane foam	-	-	-
1 l sample bottles (24)	-	-	-
Total			**299.10**

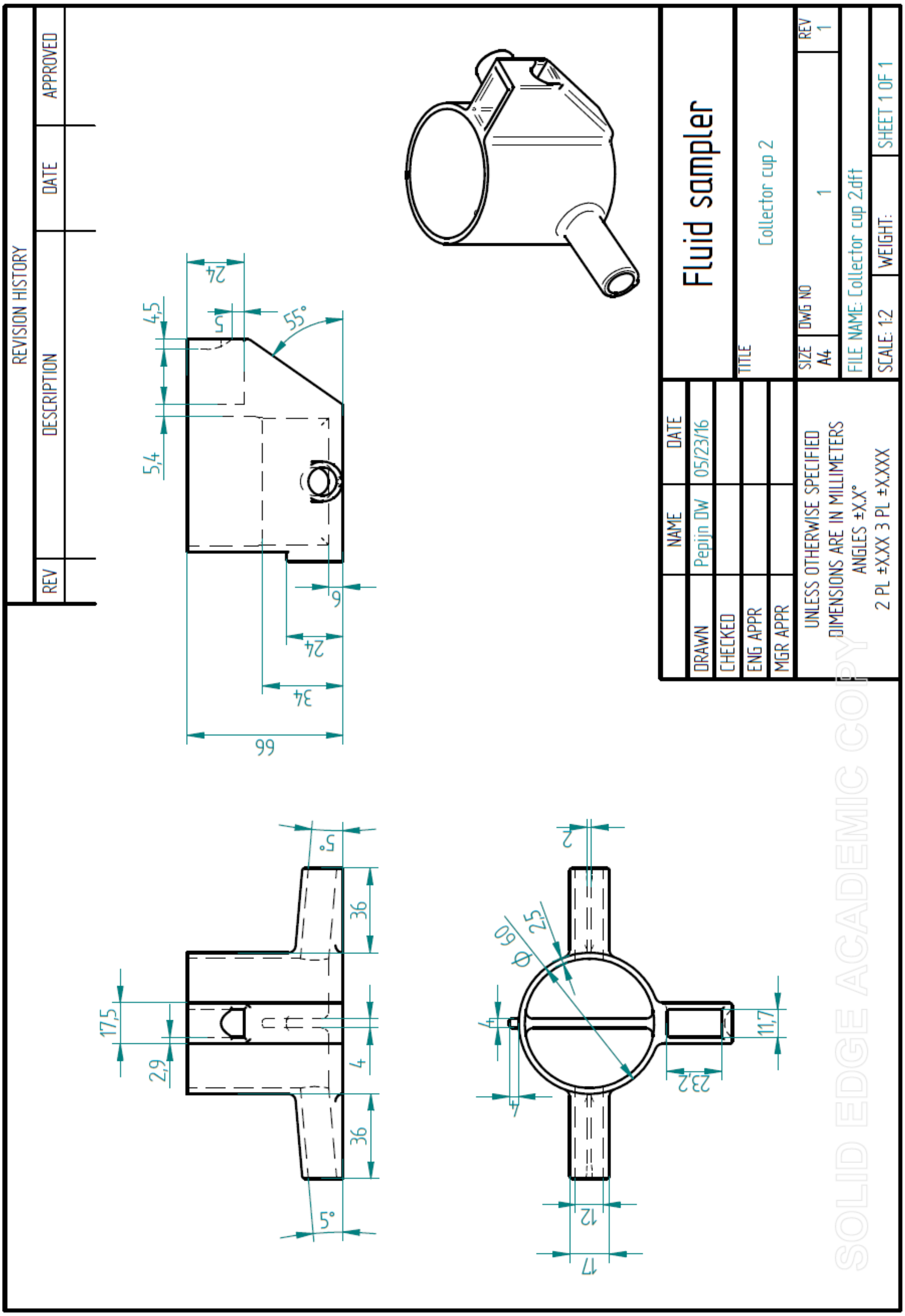


Figure A.1: Water collector cup

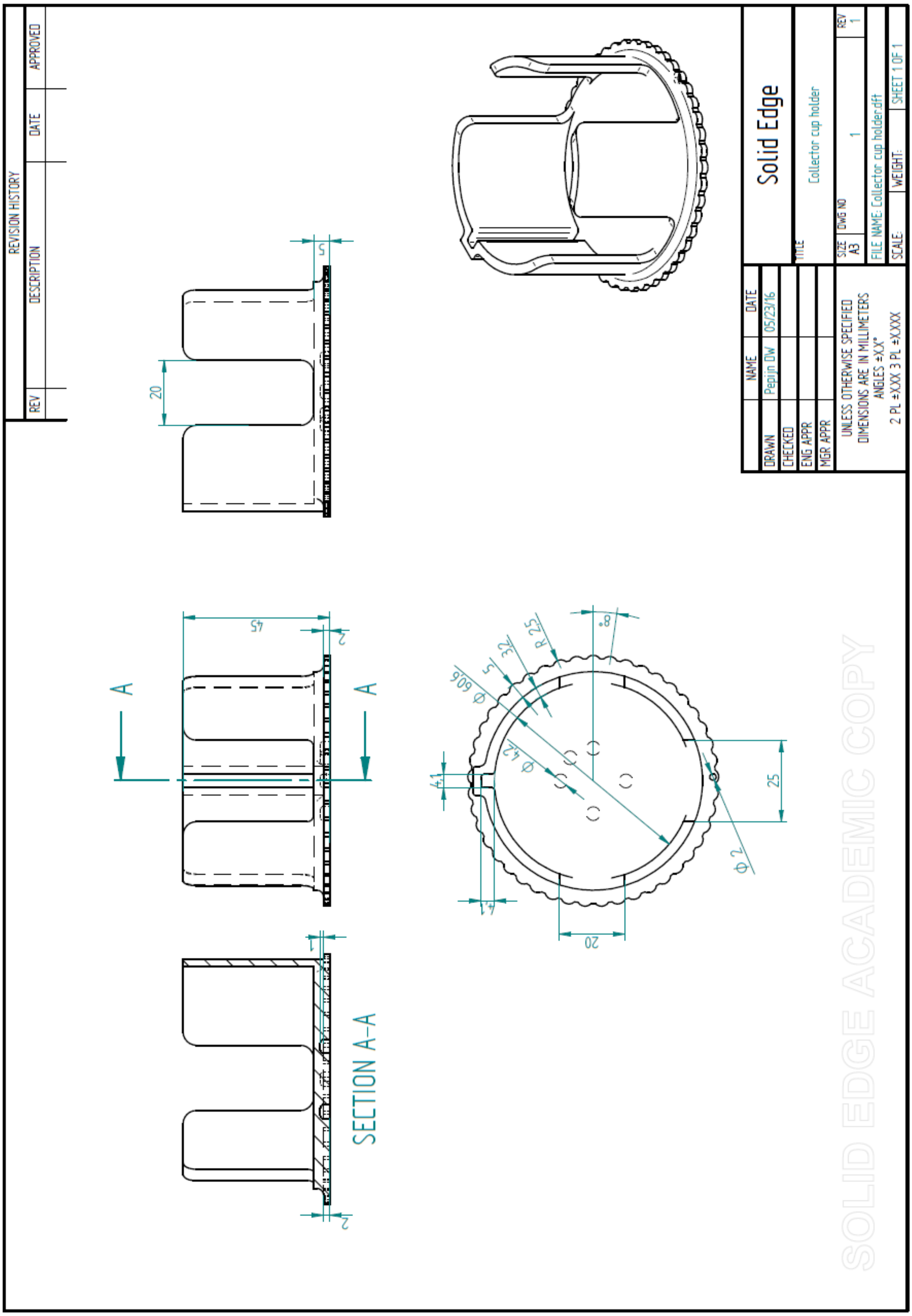


Figure A.2: Water collector cup holder

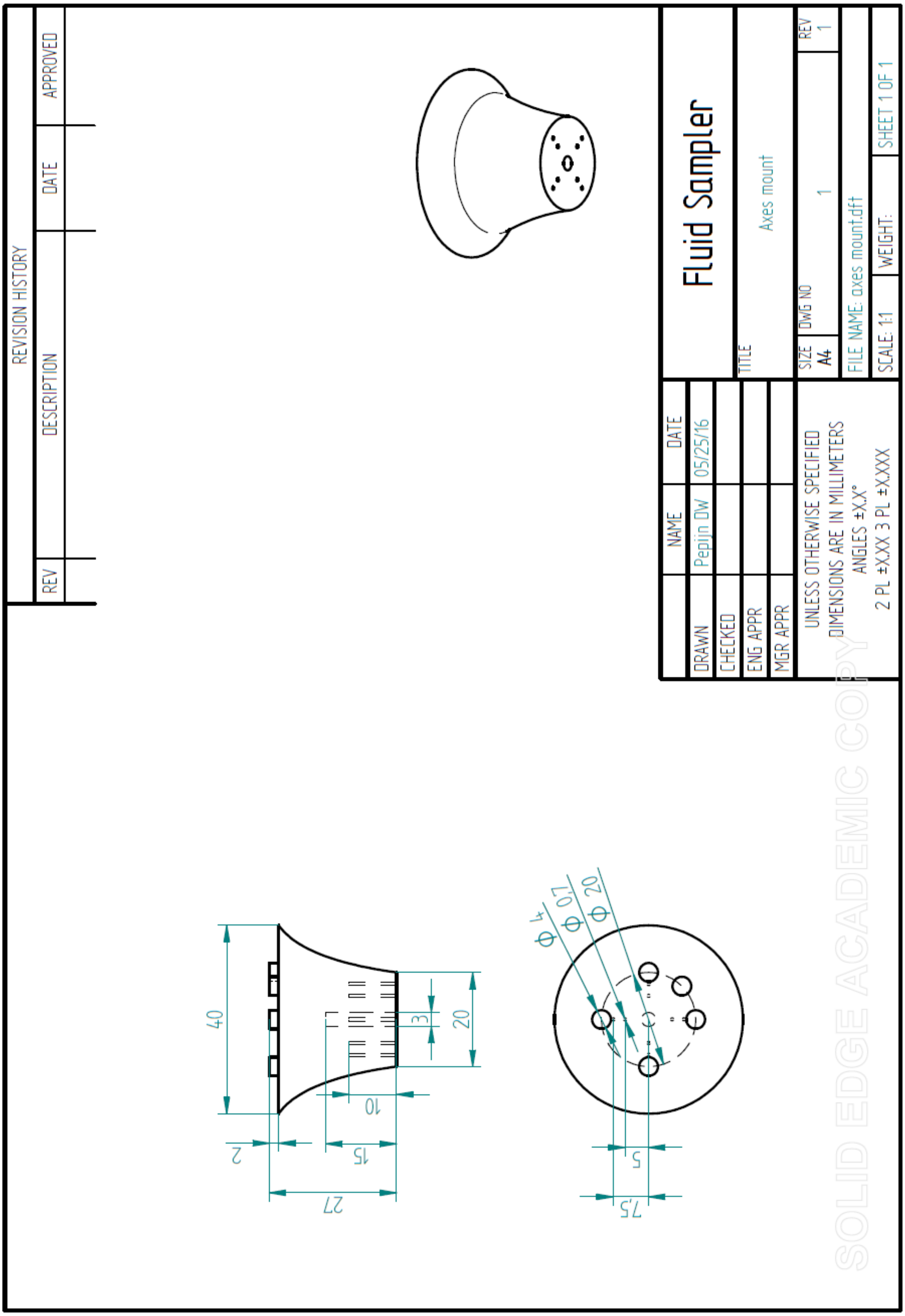


Figure A.3: Axes mount for cup holder

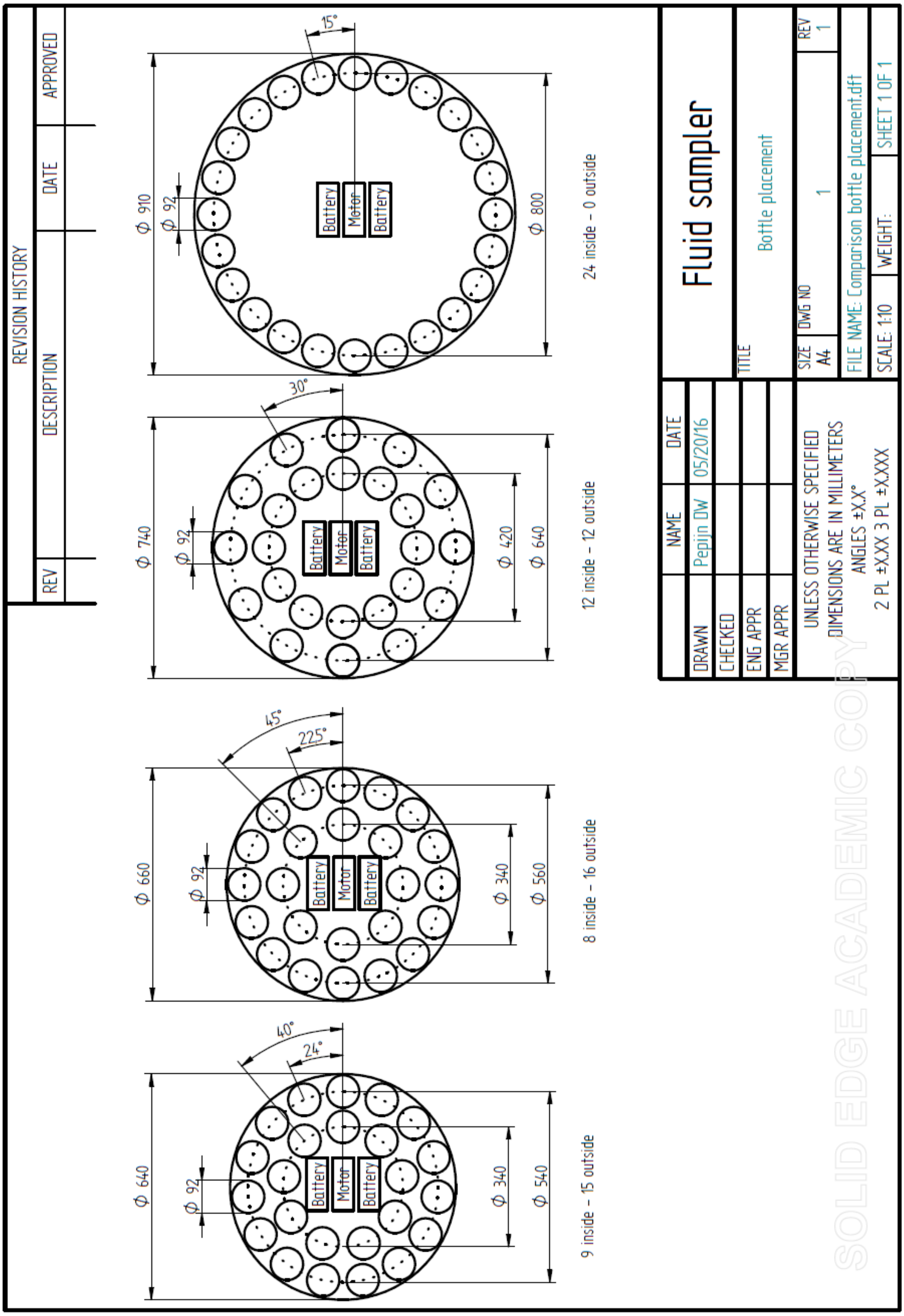


Figure A.4: Comparison of bottle placement layouts

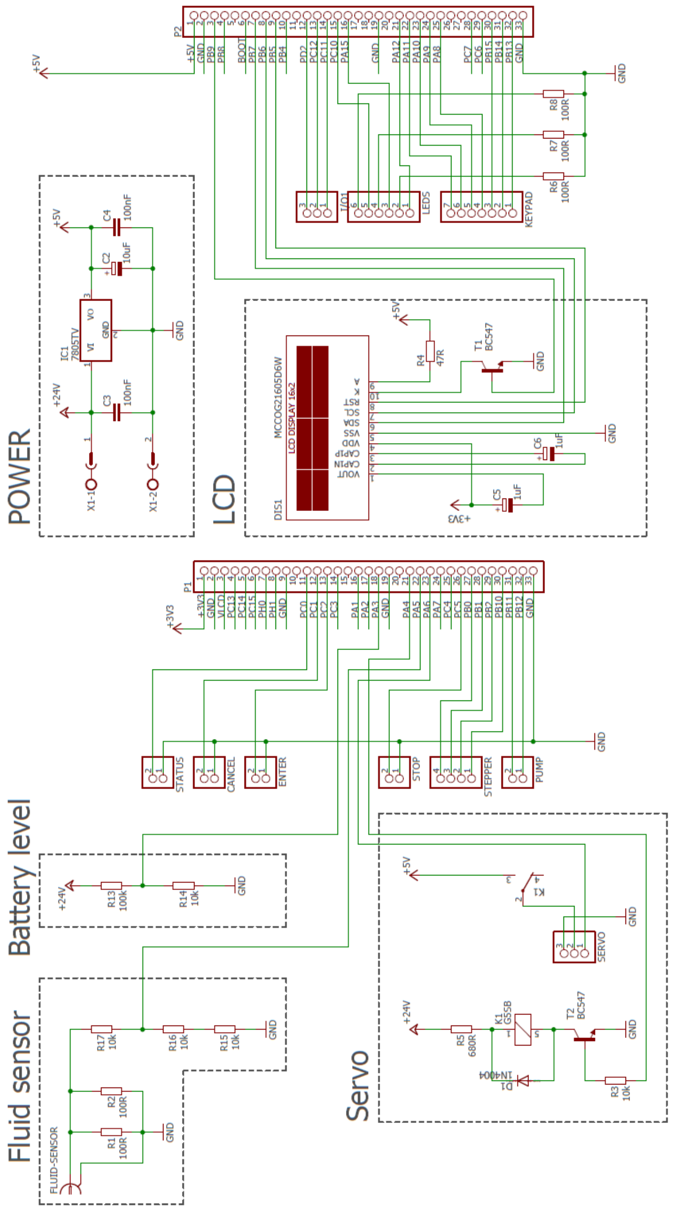
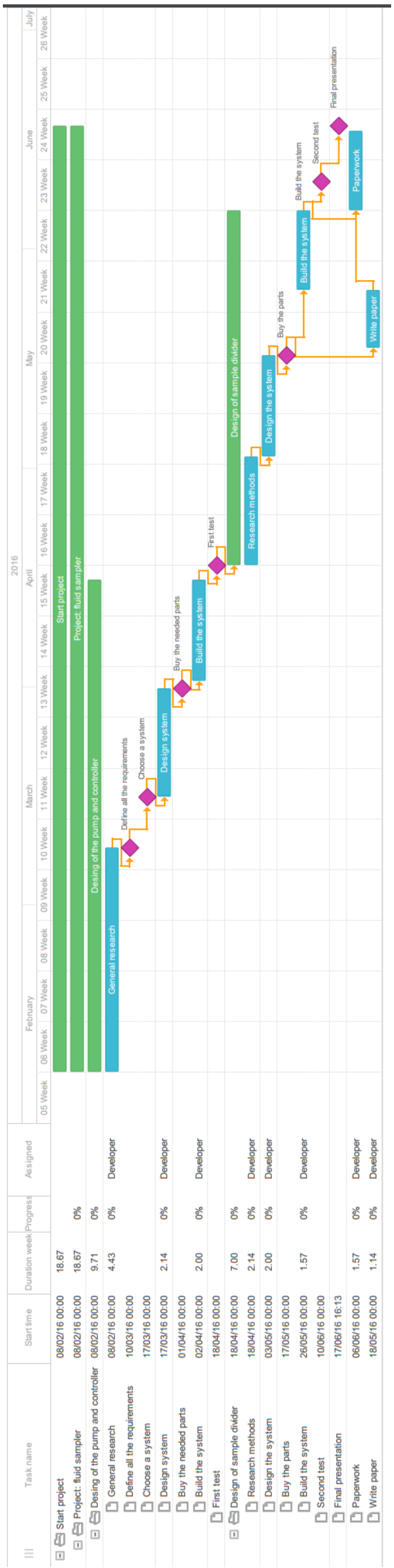


Figure A.5: Schematic of the control system



Task name	Start time	Duration week	Progress	Assigned
Start project	08/02/16 00:00	18.67		
Project: fluid sampler	08/02/16 00:00	18.67	0%	
Desing of the pump and controller	08/02/16 00:00	9.71	0%	
General research	08/02/16 00:00	4.43	0%	Developer
Define all the requirements	10/03/16 00:00			
Choose a system	17/03/16 00:00			
Design system	17/03/16 00:00	2.14	0%	Developer
Buy the needed parts	01/04/16 00:00			
Build the system	02/04/16 00:00	2.00	0%	Developer
First test	18/04/16 00:00			
Design of sample divider	18/04/16 00:00	7.00	0%	
Research methods	18/04/16 00:00	2.14	0%	Developer
Design the system	03/05/16 00:00	2.00	0%	Developer
Buy the parts	17/05/16 00:00			
Build the system	26/05/16 00:00	1.57	0%	Developer
Second test	10/06/16 00:00			
Final presentation	17/06/16 16:13			
Paperwork	06/06/16 00:00	1.57	0%	Developer
Write paper	18/05/16 00:00	1.14	0%	Developer

Figure A.6: Gantt chart