INSTITUTO POLITÉCNICO DE BRAGANÇA
Escola Superior de Tecnologia e Gestão

Development of an IoT solution for detergent supervision in industrial washing machines

Gustavo Gonçalves Coelho - 39502

Dissertation submitted to the School of Technology and Management of Bragança to obtain the Master Degree in Industrial Engineering

Scientific supervision:
Prof. Dr. João Paulo Coelho
Prof. Dr. André Luiz Regis Monteiro

Bragança
2018-2019

Development of an IoT solution for detergent supervision in industrial washing machines

Gustavo Gonçalves Coelho - 39502

Dissertation submitted to the School of Technology and Management of Bragança to obtain the Master Degree in Industrial Engineering

Scientific upervision:

Prof. Dr. João Paulo Coelho

Prof. Dr. André Luiz Regis Monteiro

Bragança

2018-2019

Dedication

I dedicate this work to my mother, Adriana Maura Gonçalves, who helped me to be in the position where I am today, without her none of this would be possible. I am forever grateful for all the support you have provided and continue providing for me to realize my dreams, and there are no words to describe it.

Acknowledgment

Hereby I would like to thank everyone who in a certain way contributed, directly or indirectly, to the development of this work.

Firstly, to my supervisor at Polytechnic Institute of Bragança (IPB), Professor Dr. João Paulo Coelho, for all the support, guidance and advice during the course of this work. I am very grateful for all the experience I had, my eternal thanks!

To my supervisor at the Federal University of Paraná (UTFPR), professor Dr. André Luiz Regis Monteiro, for the support, transmitted knowledge and good talks, especially when I was still in Brazil.

To my home university, UTFPR, for the opportunity to participate in the Dual Diplomacy program. I would never have had the opportunity to meet such nice people from all over the world without it.

To my family and friends, especially to my mother and grandparents, who were always encouraging and motivating. Nothing could be done without them.

Finally, a special thanks to Eric and Ighor, who for sure will be at my wedding one day... My eternal thanks for all the moments "gained" together.

Abstract

Automation of industrial activities aim to improve the efficiency of the productive processes while reducing costs and increasing safety. In industrial laundries, the detergent level measurement is a key element for asset management, mainly due to the necessity of maintaining a continuous flow of washing processes. Therefore, this work presents a solution implemented in the industrial laundry reservoirs of Santa Casa da Misericórdia de Bragança, in Portugal, using an Internet of Things (IoT) approach, which integrates a Wi-Fi based measurement system, capable of monitoring and recording the detergent liquid level from reservoirs in real-time. Thereby, a microcontrolled system was developed to perform level measurements using an ultrasonic sensor, in which data is sent to a database and, through a web based platform, the client can remotely access the measurement results. In order to facilitate the physical installation of the developed hardware in the existent setup, a custom-made enclosure was designed and 3D printed.

Keywords: Internet of Things; Database; Web Development; Ultrasonic Liquid Level Measurement;

Resumo

A automação das atividades industriais tem como objetivo melhorar a eficiência de processos produtivos, reduzindo custos e aumentando a segurança. Em lavanderias industriais, a medição de nível de detergente líquido é um elemento fundamental para o gerenciamento de ativos, principalmente devido à necessidade de manter um fluxo contínuo dos processos de lavagem. Dessa forma, o trabalho apresenta uma solução implementada nos reservatórios da lavanderia industrial da Santa Casa da Misericórdia de Bragança, em Portugal, usando uma abordagem de internet das coisas, na qual integra um sistema de medição com conexão Wi-Fi, capaz de monitorar e registrar o nível de detergente líquido dos reservatórios em tempo real. Com isso, foi desenvolvido um sistema microcontrolado responsável por realizar as medições de nível ulilizando sensor ultrasônico, na qual os dados são enviados para um banco de dados e, através de uma plataforma web, o cliente consiga acessar de forma remota o resultado das medições. Para facilitar a instalação do sistema nos reservatórios, um bujão foi desenhado sob medida e impresso em 3D.

Palavras-chave: Internet das Coisas; Banco de Dados; Desenvolvimento web; Sistema de Medição de Nível Ultrassônico;

Contents

List of Tables

List of Figures

Acronyms

AJAX Asynchronous JavaScript and XML.

API Application Programming Interface.

BLE Bluetooth.

BMS Battery Management System.

CSS Cascading Style Sheets.

DBMS Database Management System.

DC Direct Current.

DHTML Dynamic Hypertext Markup Language.

GPIO General Purpose Input/Output Interface.

HTML Hypertext Markup Language.

HTTP HyperText Transfer Protocol.

IDE Integrated Development Environment.

IoT Internet of Things.

IP Internet Protocol.

IPv6 Internet Protocol version 6.

JSON JavaScript Object Notation.

LED Light-Emitting Diode.

PHP Hypertext Preprocessor.

PWM Pulse Width Modulation.

RDBMS Relational Database Management System.

SCMB Santa Casa da Misericórdia de Bragança.

SDK Software Development Kit.

SQL Structured Query Language.

TCP Transmission Internet Protocol.

ToF Time of Flight.

URL Uniform Resource Locator.

Chapter 1

Introduction

This chapter presents the motivation of the work, objectives and the document structure adopted. It will introduces a quick overview about the concepts of the Industry 4.0 and some of its related technologies.

1.1 Overview

In the past few decades, the pressure for the companies to be competitive has been increasing. The recent necessity for customized products, alongside with the decreasing product life-cycles, is making the industry to change its production paradigm [1]. Recently, the term Industry 4.0 has emerged and pretend to represent the 4^{th} Generation Industrial Revolution. This new manufacturing model is leading into an industry transformation based on Cyber-Physical Systems (CPS) [2].

In order to make the production more flexible, the intention of the Industry 4.0 is to develop intelligent production processes, commonly called "smart manufacturing". The CPS is making it possible by adding physical objects with embedded software and computing power, a fusion of the physical and virtual worlds [3].

With all of these changes, the increase on the amount of data available from different types of sources, mostly based on IoT technologies, is a challenge for the actual manufacturing system to deal with, i.e., there are some issues with the rapid decision-making the companies are facing due the lack of smart analytic tools [2]. This is a common problem of the Big Data era, a term that is defined by the TechAmerica Foundation as: "(...) a term that describes large volumes of high velocity, complex and variable data that require advanced techniques and technologies to enable the capture, storage, distribution, management, and analysis of the information." [4, p. 10]

For productivity improvement, it becomes necessary to take advantage of the whole useful information in order to keep an innovation of industrial production. However, this large amount of data collected is useless if unreliable information is stored. So, ensuring reliability of measurements, knowing and understanding measurements uncertainty is very important in order to make wise decisions [5].

Each industry has its own specific challenges concerning its modernization process in this new industrial era. The laundry industry also benefits with the use of automated process. In order to ensure the quality and efficiency of the service, such as optimal wash results, low running cost and increasing reliability, the use of cutting edge technology is essential to maintain the competitive business environment.

Besides the use of modern technologies, effective logistics and proper resource management is at the heart of productivity and service quality. It will ensure that all the necessary resources will be at right place, at the right time, at the right quantity and at the right quality and cost. This supply chain is fundamental in order to keep a sequence of events flowing and adding value to the product and service itself [6].

Therefore, the use of state-of-the-art technologies, complemented by the addition of smart integrated systems of sensing and control, is the path required to meet the technical needs of development to improve productivity, product quality and cost reduction [7].

1.2 Motivation

The work presented in this thesis follows from a challenge proposed by the Santa Casa da Misericórdia de Bragança (SCMB) located in the city of Bragança, Portugal. The institution acts in concert, and in an integrated manner, to meet the needs of the community by providing resources that contribute to local development and protection of the most vulnerable social groups.

Through areas of social action, health, disability, childhood, culture and education, the institution develops its activity with the objective of providing the population with social services and answers, from a perspective of continuous improvement and innovation.

In the facilities of the SCMB, there is an industrial laundry which is responsible for washing all the clothes of the institution. Using a set of industrial washing machines, the storage to keep the laundry products used for the clothes cleaning is not done locally on each washing machine, but done centralized in a room where all the reservoirs are located. Each washing machine get the products from the storage reservoirs with 200 liters of volume trough a set of peristaltic pumps, as can be seen in Figure 1.1.

Figure 1.1: Set of peristaltic pumps and storage reservoirs.

To keep all the washing machines operating without scarcity of laundry product is a real logistic problem. The misuse of laundry products during a washing cycle, e.g., liquid detergent, bleach, fabric softener, etc, present a major challenge to the SCMB because of its direct impact on the quality of the service, waste water and electric energy and time reduction due the rerun of the washing machine cycle.

As approached by Cemernek, Gursch and Kern [8, p. 240], it is unpredictable to say that all industrial laundry facilities have the same problem due the heterogeneity of the systems involved, but at the laundry's facility of the SCMB concerns the logistic problem. The actual measurement system only detects when the reservoir is already empty, which may not be useful for the industrial laundry, as it may be necessary to rerun the washing cycle program in case the reservoirs are drain out in the middle of the process. Therefore, it can be solved trough the concepts of the new industrial era.

1.3 Objectives

This work proposes a problem solution for industrial laundry system which consist in the development of an integrated system that is capable of monitoring and recording the detergent level inside of the reservoirs in the facilities of the Santa Casa da Misericórdia de Bragança (SCMB).

The project must be able to measure the liquid level using a low-cost ultrasonic sensor and the data must be collected using an ESP32 Development Board. The liquid-level information is sent to a MySQL DataBase using the Wi-Fi module which is integrated in the chip and it provides the client the real-time remote access of the information with the web based application development. Moreover, the microcontroller and the sensor must be integrated in a custom-made case which must adapt to the existing setup environment.

It is expected that the system provides a useful and reliable solution that monitors, logs and alerts the managements services in case of low detergent liquid-level, avoiding waste and ensuring the quality of the industrial laundry service.

1.4 Document Structure

This document is organized in 6 chapters, where the present chapter presents the contextualization, proposal and objectives of the work.

The Chapter 2 presents a bibliographic review, which address fundamental contents necessary to understand the concepts and understanding of the work.

Chapter 3 provides an overview of ultrasonic sensors, demonstrating the method adopted for distance measurement, necessity of an embedded system and some basic characteristics about database and web development.

Chapter 4 starts with the presentation of the case study scenario, where the problem is explored and the solution adopted will be explained.

Chapter 5 presents the methodology used for testing and verifying the measurement system developed. Also, the influence of the temperature, battery performance and, overall considerations, regarding the solution adopted for the detergent supervision, are discussed. Moreover, the price list and the implementation of an IoT Ecosystem for Industrial Washing Machines are presented.

Finally, the last chapter outlines the main conclusions and points out the future work.

Chapter 2

Related Work

This chapter presents the State-of-Art, which is the bibliographic review necessary to understand the concepts of IoT and level measurement systems. Section 2.1 explores the definition, advances and challenges of the IoT. In the next section, it is presented the basic architecture regarding a typical IoT systems, their tasks and functions. Then, Section 2.3 highlight some studies about IoT regarding some concerns about it. In Section 2.4, it is presented the wide range of methods commonly used for level measurements. Section 2.5 present some important studies and researches regarding the advance of ultrasonic sensor usage as liquid level measurement devices.

2.1 Internet of Things

It is very natural to come across with the expression of IoT nowadays, but there is a certain of misunderstanding about its definition throughout the internet. In order to make it more clear, a well known definition of IoT is given by Institute of Electrical and Electronics Engineers (IEEE) as:

> "An IoT is a network that connects uniquely identifiable "Things" to the Internet. The "Things" have sensing/actuation and potential programmability capabilities. Through the exploitation of unique identification and sensing,

> information about the "Thing" can be collected and the state of the 'Thing' can be changed from anywhere, anytime, by anything." [9, p. 73-74]

This is an old term first used in 1999 by Kevin Ashton in a presentation made to Procter & Gamble (P&G). Differently from what it is today, it was first used with a restricted understanding to describe a system in which objects in the physical world could be connected to the internet by sensors without human intervention [10]. Many years have passed and the network of physical objects-devices has spread into a much larger scenario. The interrelation of heterogeneous computing objects provides the interoperability, which ensure the connectivity and ability to transfer data between several devices via internet [11].

The massive evolution of the IoT occurred mainly due to the improvement of some technologies, e.g., wireless network, wide adoption of Internet Protocol (IP), cloud computing alongside with cost reduction in storage systems, lowered cost of computing and communications devices [10]. The solutions used for IoT Systems create a complexity environment due the numerous use of several technologies which is rapidly changing [12]. Although considerable articles proposes standard solutions for IoT as approached by [13]–[17], there are still a lack of common standards which enhance questions about the connectivity, interoperability, IoT analytic, security and privacy, Return on Investment (RoI) and societal regarding the development of IoT systems [10], [17].

Beyond all the challenges of the IoT, there are a lot of domains which have a positive economic impact with the growing use of the technology, e.g., healthcare, manufacturing, electricity, smart city, security, etc [17]. Moreover, the large use of smart things and objects connected [18] will affect others industries as well and, as approached by [19], one of its impact it is in the industry of web development and the web technology market.

2.2 IoT Architecture

As the IoT systems are gaining popularity, it becomes important to understand the basic about their structure and which tasks and functions each of the layers are responsible.

Despite the fact there are some divergence in literature about the structure of the IoT, normally it is made-up by three layers namely as Perception, Network and Application layers [20].

The first layer called Perception, also known as "Sensors", is responsible for collecting the information from the environment using sensors. There are many different types of sensors that perform variety of tasks, e.g., level measurement, proximity, temperature , humidity, accelerometers, gyroscope, etc, which can be used in many useful applications [21]. Thereby, the gathered data by sensors are transmitted to the Network layer.

The Network layer consists of communication networks and communication protocols responsible for Routing and Transmitting the data to different IoT hubs and devices over the Internet. It uses different communications technologies such as Wi-Fi, Bluetooth, 3G network, Long-Term Evolution (LTE), etc. As approached by [20], it also takes place the Data aggregation, Data filtering and transmission.

The last one is the Application layer, which is subjected to provide the Data Integrity, Data confidentiality and Data authenticity, carrying out application specific functional ities. In some architecture it is divided in two parts: Firstly, the business layer which is responsible for application management and security and privacy issues; The second one, also known as application layer, being responsible for distinguishes among different applications [17].

2.3 Web Development applied to IoT

The advancements of IoT systems will have several impacts in the world of business [22]. The use of Transmission Internet Protocol (TCP) is on focus to have extensive deployment, allowing the IoT sensor nodes to send information directly to servers and users through Internet protocols [19].

The management of the data collected by the IoT device, as also approached in this work, uses the Web technologies in order to maintain the website functionality. The client-side/server-side and database technology connection is required as part of the hi erarchy for transferring data and enabling the communication with the user [23], [24]. A recent researched was proposed at the 12th International Conference Interdisciplinarity in Engineering in which Asynchronous JavaScript and XML (AJAX) technology is used in the context of IoT [22]. The work relies on the server-client paradigm, which the data collected by the IoT device is managed by the server-side, stored in the database and it responds to the client's continuous requests via AJAX. The adoption of AJAX as web-based application provides intuitive information and interaction, allowing the data to be stored and dynamic accessed by the client.

Another factor that is important is that the integration of Web development in IoT concentrates more on the system's scalability and security than conventional Web development [24]. In 2017, [18] presented an analytical perspective about the network scalability for addressing the IoT exponentially growing. The work intended to provide some new perspectives about the Internet Protocol version 6 (IPv6), considered to be one of the strongest candidate in terms of network protocol. The work exposed an extended scale of the address structure of the IPv6, in order of magnitude and large scale numbers, which made possible to assess its potential. It is demonstrated that the IPv6 addressing capacity is widely enough to meet all the present and future necessities of human-to-human and machine-to-machine at the scale of mankind.

A recent survey made by the Eclipse Foundation [25] revealed that 49% of the participants use Hypertext Markup Language (HTML) as a communication protocol, followed by 42% using Message Queuing Telemetry Transport (MQTT) and 26% using websockets. Also, the survey reported that 54.1% of the participants uses the TCP/IP as a connectivity protocols. These information are used to gain a better understanding of the requirements, priorities and perceptions that the IoT developers are having, demonstrating the path the IoT system is having through the web development industry.

2.4 Methods used in Level Measurement Systems

The level parameter is not a new term and it represents an important indicator for process control to know how much raw material there is in stock, how much material is in the manufacturing process and how much of final product is ready for the market [26]. Due to the purpose of the work, this chapter introduces a brief idea about the gamma of possibilities of determining the level of liquids in vessels and storage tanks.

In 2004, [27] exemplifies some methods to measure the level of liquids in vessels. Different methods can be used, e.g., floating position, Archimedes' principle, differential pressure, load cell, electrical conductivity level indicator, capacitive level indicator, ultrasonic and nuclear radiation. Although each method presented has its own principle and technique of operation, the advantages and disadvantages when applying for a specific function must be studied in order to have a better performance evaluation, as demonstrated by a research in which it was used water as the monitored material [28].

In 2016, [28] presented a review of techniques applicable for monitoring water level in a relative low range and proposes a method using capacitive-type sensor. The review address solutions using capacitive-type sensors such as cylindrical capacitive sensors or even different versions of capacitive-type sensors, although it shows low cost, easy installation and high linearity characteristics, it also has shown some concerns about the high level of humidity which can be created inside of the tank, compromising the electrodes that compose a capacitive sensor, when it is not made up of stainless steel type. Another type analysed by [28] is the optical sensing techniques, which may extend the applications to dangerous chemical liquids, but it shows high sensitivity to temperature variation. Others methods approached by the study are the microwave radars, used in both marine and non-marine environments, ultrasound sensor and a signal processing technique using Time-Domain Reflectometry (TDR). This type of method is widely used for liquid monitoring which requires electrodes immersed into the liquid.

The investigation of a novel capacitive-type water level measurement, as proposed by

[29], has shown operation characteristics and performance, through simulations and experimental tests, conducted in two water storage tanks, with a city-scale water distribution network. The comparison made with existing industrial water-level monitoring systems, demonstrate that the study comprises a competitive alternative for incorporation in water management systems.

A recent research has proposed a new water level sensor using a load cell and a enclosing floating pipe [30]. The idea is to perform a contact water-level-technique with an extend lifetime. In order to have a more precise sensing technique than the non-contact method, it was used an enclosing floating pipe responsible for making the link between the liquid and the load cell, which is the key sensing element. The result from the preliminary study of the indirect measurement has shown feasibility, however the solutions to solve the impacts of fluctuations caused by the water flows are still being analysed and studied.

Another study has addressed the level measurement techniques through the use of Radar Sensors in Industrial Process [31]. The study analysed some technological aspects of frequency-modulated continuous-wave (FMCW) concept of radar level meters and, over comparisons between the 24 GHz and 80 GHz frequency ranges, the 80 GHz level radars offer a better Signal-to-noise Ratio (SNR) over the 24 Ghz in general, which has shown better results only in special cases.

Therefore, there are a large gamma of possibilities for level measurement systems that can be used. Thereby, next section will approach techniques for level measurement using ultrasonic sensing methods.

2.5 Ultrasonic Sensing Methods for Level Measurement Systems

The ultrasonic sensor is a widely used technology in which its application have a large range of possibilities. The principle of work is similar to radar or sonar which evaluate attributes of a target by interpreting the echoes from radio or sound waves respectively.

This technology can be used in robotics barrier, object distance measurement, security systems, vehicle detection/avoidance, level detection, etc [32].

In 1994, [33] proposed a new technique with ultrasonic sensor used in solid level measurements, as the technology was already well established for liquid level measurements in the industrial process. Due to the variations in the shape of a solid surface, the idea of the project was to use a single emitter with multiple receiver in order to pick-up the distortions and directional returning waves, then the signals may be processed appropriately for improvements in reliability and accuracy. Through simulations techniques being used with all the relevant information modelled mathematically, the research verify that the result from the method can illustrate errors up to 60%, suggesting that further improvements still need to be made.

Already in 2004, researchers developed a Multi-layer Level Measurement for monitoring the propagation of ultrasonic waves in the oil, water and mixed oil-water liquids [34]. The idea of the project was based on that the amount of ultrasound waves received and the speed dependency of the liquid density. Through the vertical layout of the measurements of the signal response, the level detection of the two interface is made. Thus, extensive experiments was made in 5 consecutive steps, with the device developed, and some positive results were taken, showing a certain viability of the work.

A similar study, approached by [35], was presented in the next year, however, differently than the first one, the ultrasonic method now is responsible to measure the two-phase mixture level with the application to a nuclear reactor or steam generator during abnormal conditions as well as normal conditions. The development of the work demonstrated that, the method accurately measures the two-phase mixture using the correction formula, as approached by the study. Also, in order to reduce the loss of echo by the effects of attenuation, the waveguide developed effectively measures the level of the fluid more accurately than the conventional ultrasonic methods, at high temperature and high pressure environment.

In 2006, it was developed a method to measure the air conditioning compressor used in the passenger train car, in China, using the ultrasound method [36]. As approached by the study, most of the breakdown was caused because of the refrigerant oil in the container was reduced to a level under the definite line. Thereby, the transmitting and receiving circuit was designed and a software was developed, allowing the ultrasound signals to be analyzed at real time with the use of a computer. The study provided an effective method for the liquid measurement and, because of its modular structure as addressed at the work, the instrument can be easily transplanted to other relative fields, presenting a large potential for the integrated systems advancements.

Other advances were made by researchers in which they evaluated the level measurements from the ultrasonic sensors by means of the Wavelet Transform. The concept idea is based on the Time of Flight (ToF) technique, which is the time difference between the instant the ultrasonic signal is emitted to the instant when the ultrasonic signal is detected. Also, there is an uncertainty of the measurement originated by the attenuation, additive noise and multiplicative noise of the signal. As approached by the researchers, in order to calculate the levels with low uncertainty measurements, the Wavelet Transform is chosen because it decomposes the signals using filter banks, becoming possible to obtain a representation of the ultrasonic echoes with low noise level. Both of the studies demonstrated that the wavelet threshold technique is very reliable, being possible to estimate the distances with a good approximation to the theoretical values, even under severe noise conditions [37], [38].

In 2015, [39] proposed a new method for improvement the measuring accuracy of dynamic liquid level case. The study approached some new relevant findings in radar technology and proposed a distinctive liquid-level measurement that is based on the Multiple-input Multiple-output (MIMO) ultrasonic transducer array, thereby allowing it to achieve the reduction of system complexity and cost, and also making it possible to acquire rapid high precise samples of the level. The research development is composed of some relevant parts focused on the transducer array, signal transmitting and receiving channels, and signal processing unit. Moreover, [39] also proposed a simulation method of ultrasonic echo signal from liquid level based on the boundary-layer theory and the ultrasonic scattering theory. Thus, the method is verified by simulation and real system, the result indicates the method can present a higher accuracy in dynamically changed liquid-level case than the conventional approach. Furthermore, the study also indicates that the focus in beamforming is properly set in every scanning direction, keeping the noise of the echo signal effectively controlled.

In 2019, [40] proposed a characterization and optimization of the water level measurement in the marine environment context. The research was suggested in order to estimate the position of the water surface in order to determine the thickness and depth of the pollutant layer (hydrocarbons floating in the sea). The use of a low-cost SRF05 ultrasonic sensor is also provided by the research and the intention is to acquire a final device managed to have a sensibility of about 1 mm. The characterization was made in a close measurement range to its operating limit, with the envelope signal and Hilbert Transform methods being used in order to reduce the error of ToFs measurements. [40] suggests the use of another SRF05 sensor due to the systematic occurrence of jitter time anomaly (anomalies in the ToF values). Also, the use of another sensor will allow to extend the operative measurement interval while preserving high accuracy measures, enabling it to avoid the need of signal post-processing, in which it will result in a reliable and accurate real-time monitoring of the surface level of the material.

Chapter 3

Material and Methods

This chapter presents the technological tools used for the development of this work. Section 3.1 explores some concepts of ultrasonic sensors, specific characteristics of ultrasonic waves and the ToF method for distance measurement. Then, in the Section 3.2, the definition, and a brief overview, of what an Embedded System is will be provided. Section 3.3 explores the definition and operation of a database and some basic database system architectures. At last, Section 3.4 presents an overview of the operating mode of a web page and the programming languages which can be used for building it.

3.1 Ultrasonic Sensors

The ultrasonic sensors work on a principle by transmitting high frequency sound waves and evaluate attributes of a specific target by interpreting the echoes which is received back by the sensors [32].

3.1.1 Operation Principles

Ultrasonics is a specific branch of acoustics and it deals with vibratory waves, mechanical waves responsible for causing disturbance in a medium, transferring energy from one point to another. These vibratory waves can propagate in solids, liquids and gases with frequencies above within the hearing human range, that is, at frequencies above 16 kHz [41].

The lower limit of the ultrasonic range is in part arbitrary due the fact that the hearing range of a young person can sometimes extend to frequencies above 20 kHz [42]. Although the acoustic frequency scale covers the range from below 15 Hz to above of 1 THz (10^{12} Hz), in practice, most of the ultrasound transducers commercially used for the measurement of level in tanks and vessels work within a operation range between 25 kHz to 70 kHz [38].

The two most common technologies responsible for the ultrasonic sensor to send and receive the ultrasonic waves are those based on piezoelectric and magnetostrictive devices. Also known as electroacoustic transducer, it is the element that makes the electromechanical conversion through the piezoelectric effect, which is the ability of certain materials to induce an Electromotive Force (EMF) in response to applied mechanical stress. One important and unique characteristic of the piezoelectric effect is that it is reversible, i.e., the generation of electricity when stress is applied. Therefore, due to this unique characteristic of the element, many types of the ultrasonic transducers can function both as sender and receiver [42].

The design of a transmitter is often dependent upon the application, temperature, material, etc. Normally, the piezoelectric ceramic material is designed in different shapes and sizes and it has also the ability to operate at low voltages and at elevated temperature [43].

It is also important to emphasize that all forms of ultrasonic transducers have band-pass characteristics, which is responsible for limiting the frequency spectrum generated and received [42].

3.1.2 Characteristics of Ultrasonic Waves

In this sub-section, it is explained some basic characteristics about propagation of ultrasound waves.

Attenuation Characteristics

As the sound wave propagates in the medium, it gradually loses its energy proportionally with the distance through a process called attenuation. This effect is caused by reflection, refraction, scatter and absorption phenomena [41].

The reflection is responsible for the production of the required echoes, i.e., the pulse of the ultrasound waves is delivered to an object and, if the angle between the interface of the object and the transducer is greater than around 60 degrees, a proportion of the wave's energy is reflected to the transducer.

Already for the refraction, this one is responsible for causing a transmitted wave to be deflected from its original direction, usually it occurs when the transmitted waves pass from an interface to another which has different wave speed.

For the scatter, it describes the scattering of the wave in all directions and it takes place when a wave encounters a structure much smaller than its own wavelength.

Lastly, the absorption defines the energy of the sound wave which is converted into friction and is lost in the form of heat. This energy is absorbed by medium and it represents the majority part of the attenuation phenomenon [41].

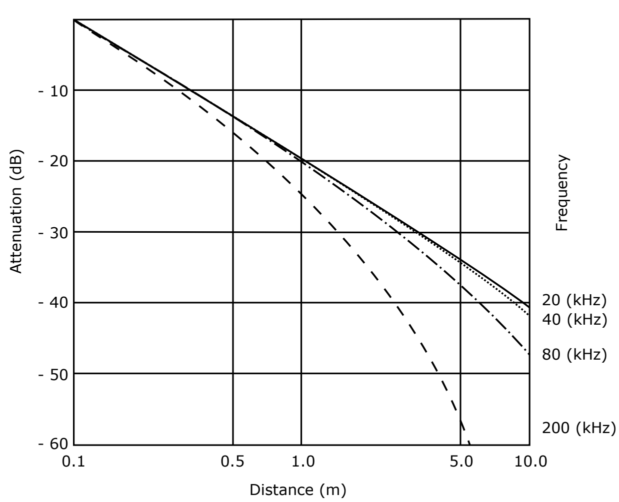


Figure 3.1: Attenuation characteristics of ultrassonic waves. Image from [43]

As shown in Fig. 3.1, it is represented the attenuation characteristics of the ultrasonic waves when propagated into the air with a temperature in 20°C. The attenuation is proportional to the distance, the higher the frequency of the ultrasonic wave, so the higher is the attenuation rate and shorter is the distance traveled by the wave [43].

Velocity of Sound

Hence ultrasound represents energy transmitted as stress waves, the velocity of the sound depends upon the type of wave, the elastic properties of the medium, the density of the medium, even in some cases, it depends of frequency and amplitude. Another important factor is that the rate of propagation is influenced by the mode of vibration, i.e., the direction of movement of the individual particles on the medium in comparison with the direction of the waves travel, which can be classified as longitudinal, transverse or surface waves type [42].

The following equations were taken from [42]. For all fluids (gases and liquids) and solids, the propagation speed of sound is derived from the equation of state, which is characterized by an equation of state as shown in the Equation 3.1

$$f(p, V, T) = 0 \tag{3.1}$$

where p is the pressure exerted by the system, V is the volume and T is the temperature on some suitable scale. From the Equation 3.1, it can be shown that

$$\left(\frac{\delta p}{\delta V}\right)_T \left(\frac{\delta V}{\delta T}\right)_p \left(\frac{\delta T}{\delta p}\right)_v = -1 \tag{3.2}$$

The propagation of ultrasonic energy in gases (or even in liquid) is considered an adiabatic process. This phenomenon occurs due the variations in pressure and corresponding volume changes are so rapid that the heat does not have time to flow from high-pressure regions to rarefaction regions. Therefore, no heat is lost in the process. The Equation 3.3 shows the equation of state for an ideal gas

$$pV = \frac{N}{N_0} RT \tag{3.3}$$

where the pressure p is measure in (Pa), the volume V in (m^3), N is the number of molecules in V, N_0 is the number of molecules in a gram-molecular weight of the gas, R is the universal constant of the gases ($Joule.mol^{-1}.Kelvin^{-1}$ or $N.m.mol^{-1}.Kelvin^{-1}$) and T is the absolute temperature in Kelvin (K). A interesting factor is that the ratio R/N_0 is called the Boltzmann's constant, which relate the average kinetic energy of a particle in a gas with the temperature of the gas, which is approximately 1.3807 x 10^{-21} ($J.K^{-1}$).

So, as shown in the Equation 3.4, the velocity of sound in a gas is given by the relation

$$c = \sqrt{\gamma \left(\frac{\delta p}{\delta \rho} \right)} \tag{3.4}$$

in which c is the velocity in meters per second (m/s), γ is the ratio between the molar thermal capacity at a constant pressure (C_p) and the molar thermal capacity at a constant volume (C_v) of a material and ρ is the density (kg/m^3).

Therefore, from the Equation 3.4, the equation for the velocity in an perfect gas is

$$c = \sqrt{\gamma \frac{RT}{M}} \tag{3.5}$$

where M is the molecular weight.

The Influence of the Angle

When the ultrasonic wave is about to reach an interface between two media with different acoustic properties, i.e., with different impedance, the energy of the incidence wave is partitioned between the reflected wave and the transmitted wave [42], as shown by the Equation 3.6.

$$\xi_T = \xi_I + \xi_R \tag{3.6}$$

where ξ_T, ξ_I and ξ_R are the potential functions for displacement of the transmitted, incident and the reflected wave, respectively [42].

Some materials, e.g., metal, wood, concrete, glass, paper, etc, reflect approximately

100% of the ultrasonic waves because of their acoustic properties, which have low absorption level of the energy provided by the incidence of ultrasonic waves. However, objects like cloth, cotton, wool, etc, absorb a large amount of the incidence ultrasonic wave energy and it may be often difficult to be detected by the receiver, mostly because of their acoustic characteristics [43].

Furthermore, the energy of the wave is also partitioned upon how the wave approaches the interface. The angle of the reflection and refraction is defined by the Snell's law and it is a little bit more complicated than the optical analogue of a light beam incident on the surface, principally due the acoustic impedance from the various medium and different wave types, as demonstrated in the Fig. 3.2.

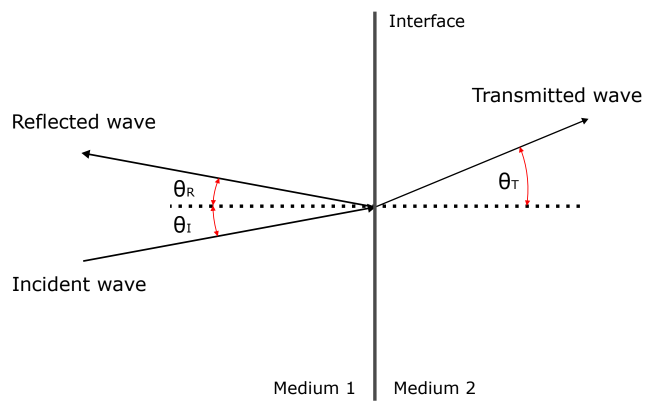


Figure 3.2: Development of Snell's law. Adapted from [42]

In addition, a practical problem that may appear due the incident angle of the ultrasonic wave is when the sensor is not directed perpendicular to the object of measurement, if the angle of incidence is too large, the receiver transducer may not receive the reflected ultrasonic wave, leading to an incorrect measurement [44], as demonstrated by the Fig. 3.3.

This error may occur for liquid level measurement systems which makes use of ultrasonic sensors as well. As approached by [39], when the surface of the liquid to be measured changes dynamically, it may lead the sensor to acquire incorrect measurements. Therefore, the ultrasonic sensor must be positioned correctly and the data acquisition method must be specifically directed to its application, otherwise the sensor may acquire

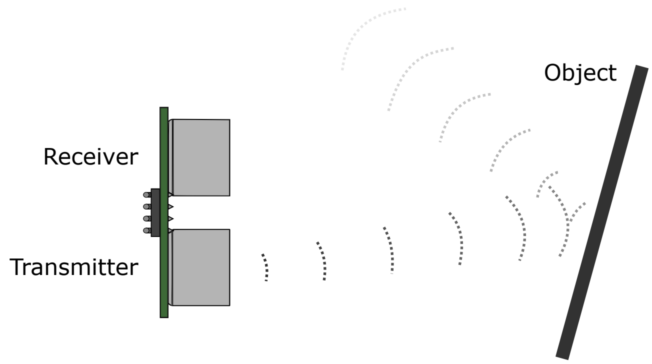


Figure 3.3: The incorrect measurement of the ultrasonic wave. Adapted from [44]

false measurements for the system. [42].

Another factor that can interfere in the readings of the ultrasonic sensor is the shape of the beam (see Fig. 3.4), which is characteristic of the sensor used. The radiation is determined by the dimensions of the ultrasonic radiation surface and the frequency, or it can be manipulated by using a horn outside of the ultrasonic sensor. If the objective of the ultrasonic sensor is to detect a specific object within the sensors field, the use of a more acute radiation from the ultrasonic sensor is preferred [43].

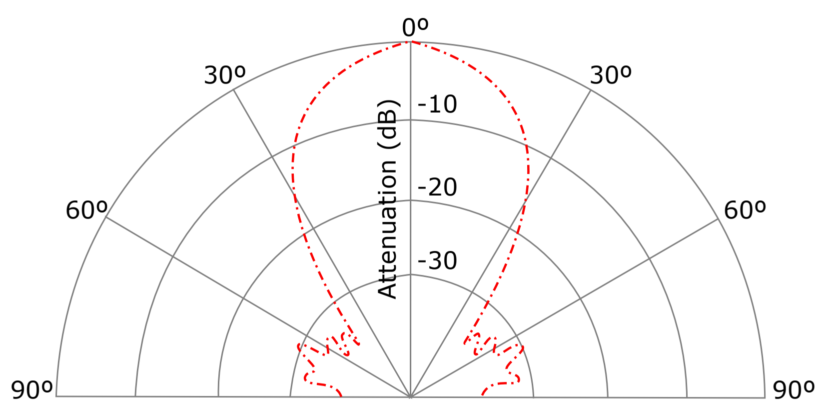


Figure 3.4: Beam width of ultrasonic wave radiation. Adapted from [43].

3.1.3 Time of Flight Measurement

A common method for distance measurement using ultrasonic transducers is called ToF technique and it is based on the time propagation of the ultrasound wave, in which a pulse of the ultrasound wave is emitted and delivered to an object. As approached in Sub Section 3.1.2, because of the reflection phenomenon, a proportion of the wave's energy is reflected back to the receiver [38] and the time is counted from the instant the ultrasonic wave is emitted until the instant when it is delivered back to the receiver. Then, as approached by [45] it is possible to define the distance D by the following Equation 3.7

$$D = k.t_f.c_{air} \tag{3.7}$$

where t_f is the ToF of the ultrasonic pulse given in s, k is a constant which normally is 0.5, but it also can depend over the sensor geometry and c_{air} is the velocity of sound in air given in (m/s).

As the ToF is counted by the ultrasonic sensor in microseconds μs, in order to have a distance measurement unit being measured in centimeters cm, it is necessary to divide the Equation 3.7 for 10^4. Therefore, the Equation 3.7 is transformed conveniently in

$$D = \frac{1}{2} \frac{t_f \ c_{air}}{10^4} \tag{3.8}$$

in which the distance D being measured in cm.

As the velocity of sound is characterized by an equation of state, demonstrated by the Equation 3.1, so the function it is dependent of the environment variables, which for air (mixture of different gases) is affected by the temperature T and the air humidity h as shown by the following Equation 3.9

$$c_{air} = f(T, h) \tag{3.9}$$

As approached by [45], the humidity effects on the velocity of the sound is only about 0.15% at a temperature of 20 °C . Therefore, the humidity does not have a large impact over the result, so it can be disregarded. So, from the Equation 3.5, using the values of R = 8.314 J.mol^{-1}.K^{-1} (gas constant), γ = 1.4 (adiabatic constant for air) and M = 28.95 gm/mol (0.02895 kg/mol) for the dry air, the speed of sound equation can be defined as a function of temperature as follows

$$c_{air} = \sqrt{1.4 \frac{8.314}{0.02895}} \sqrt{T} \tag{3.10}$$

Then, the equation of the velocity becomes

$$c_{air} = 20.05 \sqrt{T} \; m/s \tag{3.11}$$

with the temperature T given in Kelvin.

As studied by [44], another consideration which must be taken an account is the propagation path of the signal. Due to the geometric of the sensor, as shown in the Fig. 3.5, the distance from the sensor to the object of measurement is equal to find the distance of the height of an isosceles triangle.

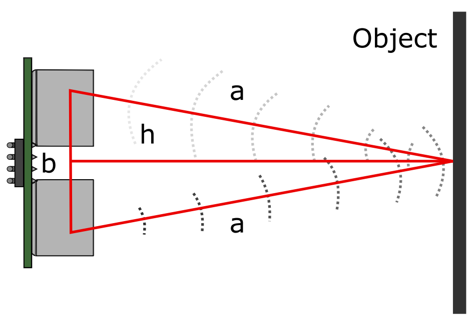


Figure 3.5: Geometric representation of the signal propagation path. Adapted from [44].

It is possible to find the distance using the Pythogorean Theorem in which the height h of the isosceles triangle is given by 3.12

$$h = \sqrt{a^2 - \left(\frac{b}{2}\right)^2} \tag{3.12}$$

where h is the distance from the sensor to the object of measurement, a is the distance the sound wave travels from the transmitter to the object or the reflection wave (the distance from the object to the receiver) and b is the distance from the transmitter to the receiver (base).

For the US-015 sensor, the distance of the base is equivalent to 23 mm, therefore, replacing b from the Equation 3.12 to 2.3 cm, the equation of distance becomes

$$h = \sqrt{a^2 - 1.32} \tag{3.13}$$

The correction equation is going to have a significant influence over the distance measured from the object for small distances. As an example, from the datasheet of the sensor US-015 [32], the minimum and maximum value of the range assured by the manufacturer is 2 cm and 400 cm. Therefore, using the minimum and maximum values for h (the real distance from the object of measurement), the distance measured by the sensor without the correction is

$$a = \sqrt{2^2 + 1.32} = 2.3065\ cm, \quad h = 2\ cm \tag{3.14}$$

$$a = \sqrt{400^2 + 1.32} = 400.0016\ cm, \quad h = 400\ cm \tag{3.15}$$

Based on the calculations, the relative error when measuring the object in a real distance of 2 cm is 15.32 %, and for 400 cm, it is 0.0004 %.

Thus, replacing the velocity of the sound found from the Equation 3.11 into the Equation 3.8 and using the value of $k = 1/2$, the distance D becomes

$$D = \frac{1}{2}\ \frac{t_f\ 20.05\sqrt{T}}{10^4} = 10.05\ 10^{-4} t_f \sqrt{T} \tag{3.16}$$

This new equation represents the distance measured by the sensor in function of time and temperature. As the Equation 3.16 does not have the correction factor applied yet, it is necessary to replace it result into the Equation 3.13. Thereby, the real distance from the object of measurement becomes

$$Distance = \sqrt{(10.05\ 10^{-4} t_f \sqrt{T})^2 - 1.32} \tag{3.17}$$

Developing this equation and transforming the temperature which is being measured in K to °C, the Equation 3.17 becomes

$$Distance = \sqrt{1010.025\ 10^{-9}\ t_f^2\ (T + 273.15) - 1.32} \tag{3.18}$$

in which the *Distance* is measured in cm, t_f in μs and the temperature T in °C.

3.1.4 Modes of Operation

The ultrasonic sensors, as addressed in Section 2.5, can be used in many different types of applications, as much for level measurement systems as for robotics, counting instruments, parking meters, automatic doors, back sonar of automobiles, intruder alarm systems, densitometers, flowmeters, etc. Based on that, in order to keep the sensor as accurate as possible, different modes of operation can be used for each purpose [43]. There are three operation modes used in ultrasonic sensors and they can be classified as: reflection mode, direct measurement mode and, pulsed versus continuous measurement mode [46].

In reflection mode, the transmitter emits a short burst of sound that bounces off a target and returns to the receiver after a time interval, enabling the distance to be calculated as demonstrated in Section 3.1.3. For the direct measurement mode, the transmitter and the receiver works in two separate units that moves relative to each other, allowing some characteristics to be retrieved from the ultrasound wave according to each application. The pulsed measurement mode is dependent to the signal return delay time, which can increase the confusion in taking readings when trying to take successive measurements in a short period of time, thereby, the use of continuous measurement mode can be applied in this case scenario. In this mode, a constant wave of ultrasound is emitted and the received ultrasound wave can be analysed by its attenuation in frequency, increasing the sensor sensitivity [46]. The Table 3.1 refers to examples of these applications and the operating principle of the ultrasonic sensor.

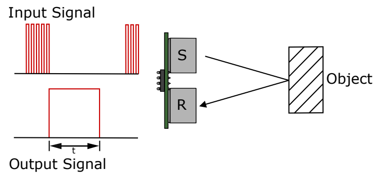
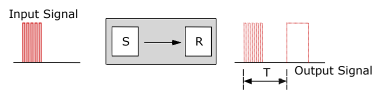
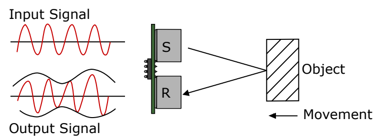
Function Method	Performance Principle	Applications
Pulsed measurement mode		Automatic doors Back sonar of automobiles Level gauges
Direct measurement mode		Densitometers Flowmeters
Continuous wave mode		Intruder alarm systems

Table 3.1: Application examples using ultrasonic sensors. Adapted from [43].

3.2 Embedded System

Exploring the definition and overview of what an embedded system is, as approached by [47], it is a combination of hardware and, software parts, as well as other components responsible for running specific tasks. The large amount of applications that make use of embedded systems are intended to work alongside with the physical world, sensing various analog or digital signals while controlling, manipulating, or even responding to others. In order to deal with all the information provided by the signals from the outside and send the data back, the Central Processing Unit (CPU) coordinates the activities of the system, performing communication, computation and data manipulation.

Commonly, an embedded system consist of a microcontroller programmed to do a specific job. Differently than the microprocessor, as defined by [48], the microcontroller corresponds to a microprocessor and its typical peripherals, however, now they are all integrated into a single unit. The rich collection of peripherals Input/Output (I/O) into a single integrated circuit, e,g., timers, analog-to-digital converters, digital-to-analog converters, digital I/O, serial or parallel communications channels, etc, it shows the great importance for embedded applications in which low cost is a significant matter [47].

In this work, the microcontroller is responsible for receiving the readings from the ultrasonic sensor, manipulating and controlling the information in an orderly manner and send the information to a database (Section 3.3). The Figure 3.6 demonstrated a simple model of the data process and the microcontroller role.

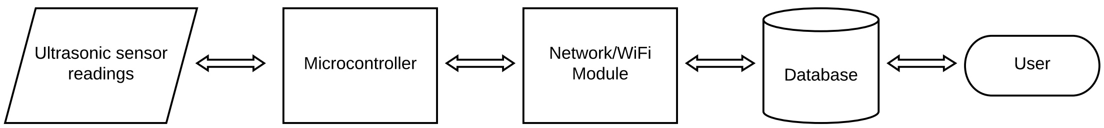


Figure 3.6: Simple model of the data process.

In order to store data in a database, the microcontroller makes use of a network module capable to transfer data to a server. So, it is the communication model that makes it possible to interact with other systems [49]. For that, the ESP32 represents a series of low-cost microcontroller with an integrated network module which is widely used for IoT projects and it is used as a microcontroller for the development of this work.

3.3 Database Systems

Database systems play a critical role in almost all areas where computers are being used [50]. Understanding how someone or some computer program interact with the database are important in order to see how the data can be stored and accessed. There are the traditional database applications whereby the information to be stored and accessed may be either textual and numerical and, there are the noSQL systems (also referred as big data storage systems) by which is mostly used to manage data for social media applications.

As defined by [50], a database is a collection of related data that can be recorded and have implicit meaning. Therefore, the database needs to have some source from which the data is derived in which represents some aspect from the real world. The database can be of any size and complexity and can be managed by Database Management System (DBMS), which is a *general-purpose software system* that is designed to define, manipulate, retrieve and manage data, sharing databases among users and applications. Besides the stored information, defining a database involves specifying data types, structures and constraints of the data to be stored in database, commonly know as database-catalog or meta-data. The manipulation of database comprise of functions such as querying the database to retrieve a specific data, update the database and generate reports from the data. Also, the database is shared among users and applications. The Figure 3.7 illustrates a simple database system environment, in which the database and the DBMS software build the database system.

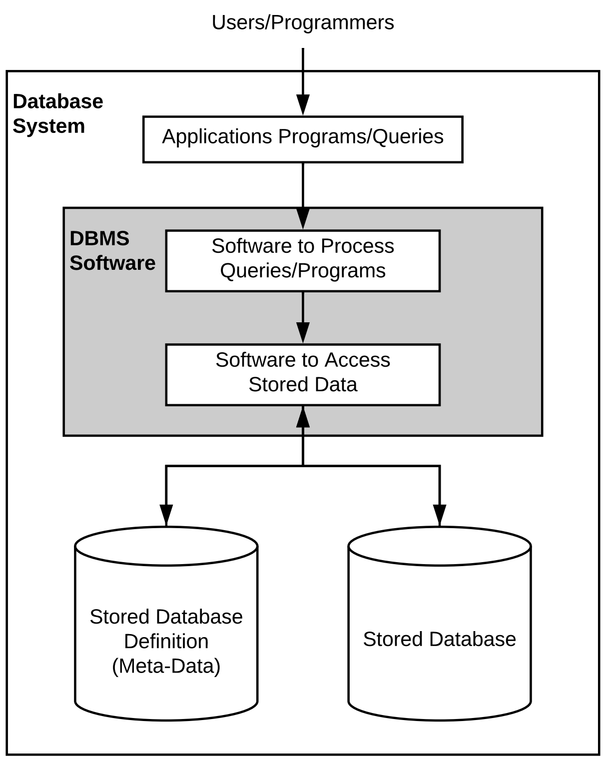


Figure 3.7: Simple database architecture. Image from [50].

In a complexity database, typically it can have many types of users which may require different perspectives of the database and must allow multiple users to access the database at the same time. Furthermore, the database needs to have the responsible for design, use and administer a database and the ones whose are responsible for the development and operation of the DBMS *software and system.* Although they are instrumental in making the database available, these workers do not use the contents of the database for their own purpose.

3.3.1 Database System Architecture

The architecture of the DBMS packages are based on the client-server system, by which it may be either centralized or distributed across thousands of computers that manage the data stores. In a basic client-server architecture, the client module is designed to run on a user workstation, Personal Computer (PC) or even on mobile devices through application programs and user interfaces (mostly as Graphical User Interface (GUI)) for (PC)s. On the other side, the server module is responsible for the data storage, access, search and other functions.

The DBMS needs an interface with communications software, whose function is to enable the clients to connect via wireless network, Local Area Network (LAN)s and others types of computers networks to have the access to the database remotely. The Figure 3.8 shows the client/server architecture at logic level, the client in this framework is viewed as an user machine with user interface capabilities and local processing, so when the client requires a database access, it connects to a server that provides the request, instead of processing it locally. Already for the server side, it is considered the system which contains both the hardware and software, and is responsible for affording services to the client machines such as printing, archiving or accessing the database.

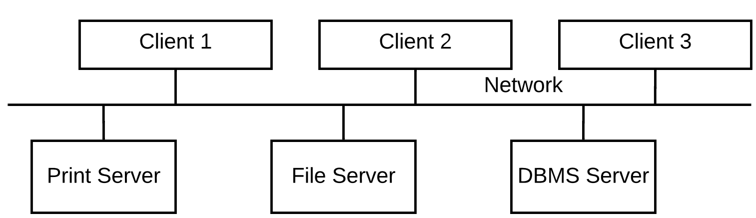


Figure 3.8: Logical two-tier client/server architecture. Adapted from [50].

Basically, for the two-tier architecture, when the DBMS is required by the the client side, the program establishes a connection to the DBMS (server side), and they can communicate with each other through Application Programming Interface (API) provided by Open Database Connectivity (ODBC). In order for this connection to work, both client and server side needs to have the necessary software installed. Adding a intermediate layer between the client and the database server, the system becomes three-tier architecture (see Figure 3.9). The middle term represented by *Tier 1* is called application server or Web server and it is now responsible for running application programs and procedures or constraints, which may improve the security by verifying the client's credentials before doing a request to database server. Furthermore, the middle layer may work as a Web server, retrieving query results from the database server and formats them into dynamic Web pages, viewed by the client side through Web browser.

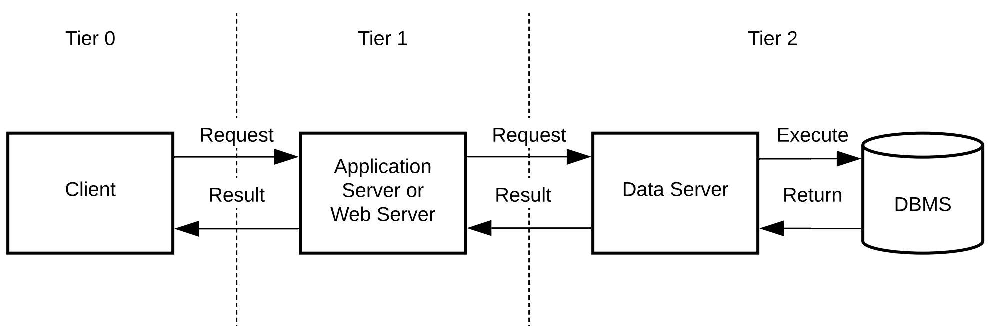


Figure 3.9: Logical three-tier client/server architecture. Adapted from [50].

When using a Relational Database Management System (RDBMS), which is a type of DBMS, the set of data is stored in table and represents a collection of related data organized in row, column and cells. The interaction with this type of database can be done by typing directly Structured Query Language (SQL) commands into a monitor for execution by the database system. However, mostly of databases interactions are executed through application programs, commonly known as database applications, and they are normally developed in a general-purpose programming language such as Java, C/C++/C#, or even in some other programming languages. Recently, some script languages, e.g, Hypertext

Preprocessor (PHP), JavaScript and Python, have become widely used for programming of database access within Web applications. In this work, all APIs were written in PHP and it will be approached in the Section 4.5.

3.3.2 Sequence of Interaction in Database Programming

In order to have an understanding about the sequence of interaction in database programming, a common sequence is adopted and it can be divided in three steps.

First, when the client requires an access to a particular database, the application program or Web server is the one responsible for enabling this interaction between them. Regularly, the client request is specify by the Internet address Uniform Resource Locator (URL) of the machine where the database server is located and uses a HyperText Transfer Protocol (HTTP) with specific know HTTP methods, to indicate the desired action to be performed, e.g., GET, POST, HEAD, DELETE, etc. After the request is done, the program must first *establish* or *open* a connection to the database server and provide a login account name and password to have the access to the database server (see Figure 3.10).

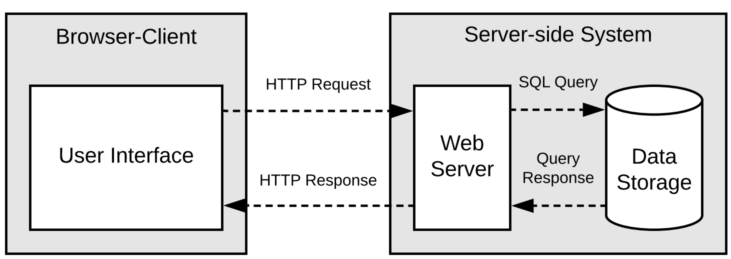


Figure 3.10: Basic diagram of HTTP request/response. Adapted from [50].

As soon the connection is *established*, the program can interact with the database server by submitting queries, updates and other database commands. As a result, the server returns a HTTP response to the client in which it may contains information about the request as desired.

Lastly, when the program execute all the necessary functions and no longer needs access to a database server, it must *terminate* or *close* the connection to the database.

3.4 Web Development

This section provides an overview of the languages used for the development of a basic Web site, either for client-side and server-side model, commonly know as front end and back end, respectively. These terms are used to refer the difference between the presentation layer viewed by the client and the data access layer. The concepts of developing a Web page involve simple static pages of plain text to complex based-web applications with dynamic content, therefore, different languages approaches can be taken according to the model that best suits the application.

3.4.1 Server-side Programming using PHP

The PHP is a language that runs directly on the server and it is used as a pipeline that collects client user input through forms, formulate database queries and submits them to the database, creating dynamic HTML Web pages. Although there are other server-side languages such as Java Servlets, Java Server Pages (JSP) and JavaScript, which use a type of JavaScript called Node.js for server-side work, all the APIs were written in PHP and this overview is only going to cover the PHP script language.

The method of PHP to connect with any RDBMS, as introduced by [51], it is based on following the steps as approached in the Section 3.3.2. These steps can be done by using some PHP functions such as *mysql_connect()* and *mysql_close()*, which allows the application program to interact with the database server.

Once the connection is established, it is possible to retrieve and manipulate data from MySQL database. For retrieving data, it can be used *SELECT* statements with *mysql_query()* and, the returned result identifier is passed into result memory, which can be stored in a variable normally called *$result*. Already for the manipulation of user records, it is used functions to insert, update and delete records in tables using *INSERT*, *UPDATE* and *DELETE* statements, respectively. These basic functionalities are suitable for enabling the data from the ultrasonic sensor to be stored and manipulated in a MySQL database.

3.4.2 Client-side Programming Language

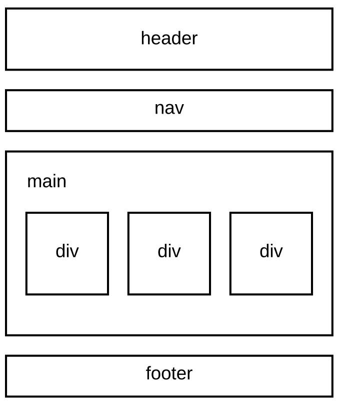
As studied by [52], the HTML is one of the language used to create web pages and it basically consist of sets of directions that tell the browser software how to display and manage a web document. The commonly know name for these directions are called tags and it performs functions such as displaying graphics, formatting text and referencing hyperlinks.

These markup symbols and codes can identify structural elements such as paragraphs, headings and lists such a way that, when the browser interprets the markup code, it will render the page, independently of what type of computer the web page was created. Therefore, any browser running on any operating system will be capable of displaying the web page.

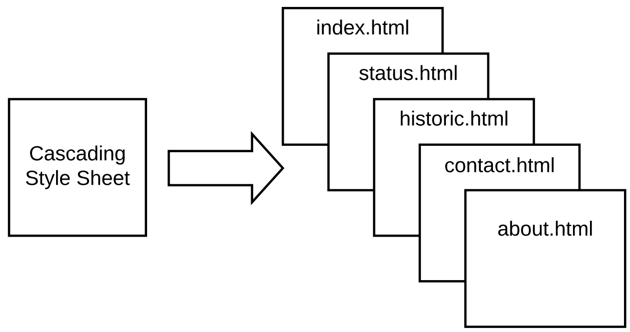
Essentially, there are two sections on a web page and they are separated in head and body. The head section contains information about the title of the web page, the meta tags which describe the documents and references to script and style of the web page. Already for the body section, it includes elements that display directly in the browser window (browser viewpoint). These elements are represented and manipulated by the Document Object Model (DOM), which is the fundamental API that treats the HTML document as a tree structure, wherein each node represents tags and elements of the document.

The HTML is composed by structural elements as show in Figure 3.11(a). These elements have been used for many years as they configure structural areas or divisions on a web page. While the HTML is responsible for the website structure, the Cascading Style Sheets (CSS) is responsible to deal with the text, color and page layout. It provides functionalities by providing typographic styles and space instructions to printed media.

As can be noticed in Figure 3.11(b), the typographic and page layout may be better controlled, also, the style is separate from the web page structure, allowing the configuration to be stored, all of these features make the document smaller and the site maintenance easier.



(a) Structural elements of a web page.



(b) The power of a single CSS file.

Figure 3.11: HTML and CSS structure. Adapted from[52].

Albeit the HTML/CSS can work very well together, in order to add interactivity into web page then just simple static pages of plain text, it is necessary embedding the JavaScript in HTML, as approached by [53]. The use of JavaScript in Web Documents can define the *behavior* of document elements by invoking an appropriate *event handler* function to respond to each event accordingly, whereby the properties of these event handler have names that begins with the word "on", e.g., *onload, onclick*. The combination of scriptable content, presentation and behavior is called Dynamic Hypertext Markup Language (DHTML).

The best know of the features brought by DHTML is the XMLHttpRequest object, which enables networking through scripted HTTP requests [53]. This is a part of the Web 2.0 movement, which makes the transition of the Web from isolated static websites to a platform, with interfaces that can obtain new information from the server without a page load. This is called AJAX and it is a web development technique that pushes more of the processing on the client by using JavaScript and Extensible Markup Language (XML) and sometimes, behind-the-scene, asynchronous requests to the server to refresh a portion of the browser display, instead of loading the entire web page [52].

Another important point, when an API is requested, by an AJAX method, to push elements data from the server, the server's response takes the form of JavaScript Object Notation (JSON) string, which is a lightweight data-interchange format used for data exchange between the server and the client. Therefore, in order to retrieve the useful information received back from the web server, the JSON string is parsed using JSON.parse() method, which is responsible for parsing the JSON string and constructing the JavaScript value or object described by the string. However, as the JSON.parse() method is a JavaScript's standard built-in JSON object method, it means that it may not be supported by some browsers (in case of the old ones). A solution for that is to use jQuery, which is a JavaScript library that is written on top of JavaScript, i.e., it makes use of JSON.parse() method internally. This library is browser independent, so if the JSON.parse() is not available, the jQuery can be responsible for parsing the JSON string.

Chapter 4

The System Development

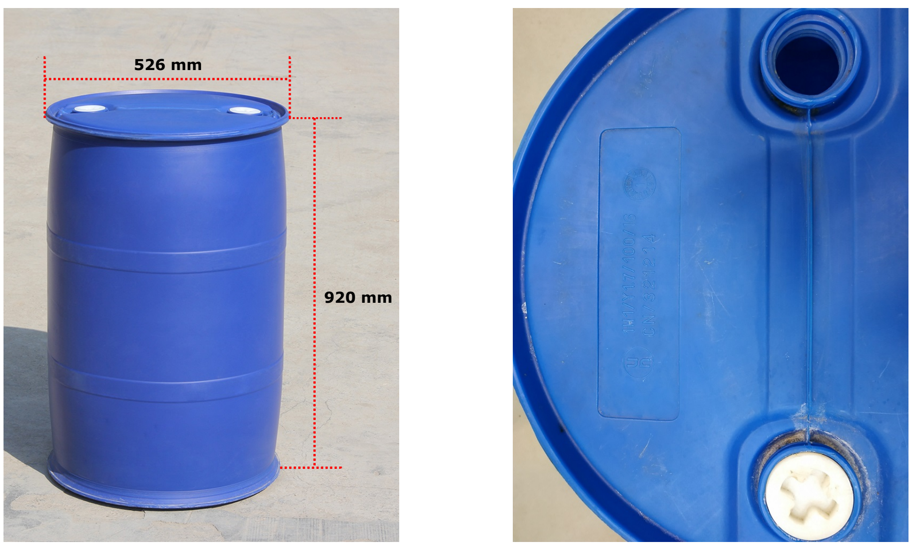
This chapter discusses the approach steps for the work development. Starting with the Section 4.1, it is studied the Case Study Scenario, where the solution adopted for the problem is presented. Then, in Section 4.2, the electronic architecture overview of the system will be provided, following with the solution devised for the device case implemented using 3D printer technology. Section 4.4 explores the software architecture design for retrieving and managing the ultrasonic measurements. Lastly, Section 4.5 demonstrates the database structure, the APIs diagram and an overview of the website's structure and features.

4.1 Case Study Scenario

In the facilities of the SCMB there are a set of barrels with 200 liters of volume which are used to store the laundry products (liquids) for the garment cleaning. The plastic drum barrels are made of High-density Polyethylene Resin (HDPE) material, which is a strong plastic used to carry and store detergents. The format and dimensions of the barrel can be seen in Figure 4.1.

Although the reservoirs from the SCMB may look similar, some of them are made from different manufactures, which may demonstrate slight differences in diameter and height when compared with each other. Thereby, the dimensions of the reservoir does not need to be specific, as it can be changed later, through the microcontroller programming, according to each specific reservoir. The only important thing is that the height must be within the range of the ultrasonic sensor adopted.

From the top view of the barrel, as represented by the Figure 4.1(b), there are two openings which give access to the content of the reservoir. As all washing machines get the product from the reservoirs through a set of peristaltic pumps, the suction tubes pass through one of these opening, which ends up making one of the openings impossible to use. Therefore, the other opening can be used to place the ultrasonic sensor, a non-invasive method, in order to perform the measurements.



(a) Dimensions of the plastic barrel. (b) Top view of the barrel.

Figure 4.1: Plastic drum barrel with 200 liters made of HDPE material.

In order to take advantage of this situation, the most efficient solution found was printing a 3D device to be threaded in one of these openings. The main purpose of this device is to place the sensor, in a position, that ensures it can send and receive the ultrasonic waves without interference. From the Figure 4.2, L represents the height of the liquid surface and H the height of the barrel or, to be more precise, the height of the ultrasonic sensor relatively of the reservoir.

Using Equation 3.18, the distance from the liquid surface and the sensor can be found

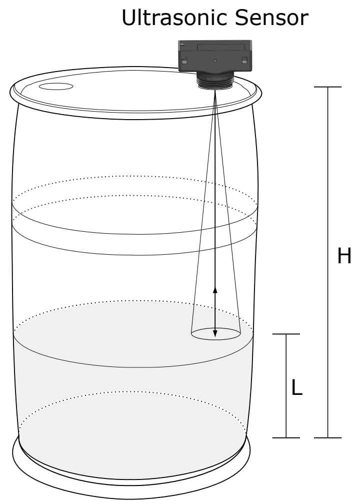


Figure 4.2: Position of the ultrasonic sensor in the plastic barrel.

though the ToF technique. Thereby, it is possible to estimate the volume of the liquid in the reservoir by considering it as a cylinder. The total volume is given by the following Equation 4.1.

$$V_{Total} = \pi \frac{d^2 H}{4000} \tag{4.1}$$

where the V_{Total} is measured in liters. The diameter d and height H comes from the dimensions of the barrel, as can be seen in Figure 4.1(a). In this case, the diameter is 52.6 cm and the height 92.0 cm.

The volume of the liquid may be estimated by, subtracting the volume relatively to the distance measured by the sensor from the total volume of the cylindrical barrel. Thus, the volume of the liquid is given by Equation 4.2.

$$V_{Liquid} = V_{Total} - \left(\pi \frac{d^2 distance}{4000}\right) \tag{4.2}$$

in which the *distance* is measured in cm.

The reservoir capacity is given by

$$Capacity = \left(\frac{V_{Liquid}}{V_{Total}}\right) 100 \tag{4.3}$$

with the capacity represented in percentage (%).

Therefore, the estimated parameters, such as the distance, volume and capacity can be used to monitor, log and alert the managements in case of low detergent liquid-level.

4.2 Hardware Architecture

The electronic architecture overview of the system is based on three modules responsible for keeping the system operating. As shown in Figure 4.3, the modules are divided in: ultrasonic sensor, microcontroller and power supply. The interaction with the database is not demonstrated in this diagram, as it will be approached, with a deeper discussion, in the Section 4.5.

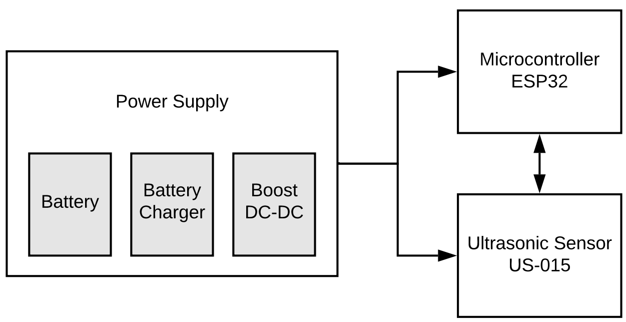


Figure 4.3: Basic electronic architecture overview.

The power supply unit consists on a battery, battery charger module and a Direct Current (DC)-(DC) boost converter, responsible for stepping up the voltage.

Microcontroller ESP32

Starting with the microcontroller module, the ESP32 Development Board version 1 (see Figure 4.2) was selected. Although an Arduino module or, even a Raspberry Pi could be used, the ESP32 was considered due to its size, price and its Wi-Fi onboard feature. The ESP32 is a System-on-Chip (SoC) created by Espressif Systems with integrated Wi-Fi and Bluetooth (BLE) [49].

Figure 4.4: ESP32 Development Kit V1 Board. Image from [54]

The ESP32 has a dual core processors and a large numbers of peripherals, e.g., Digital to Analog Converter, Ultra Low Power (ULP) Co-processor, Pulse Width Modulation (PWM), etc. The Wi-Fi and Bluetooth (BLE) operate at 2.4 GHz frequency and it has 34 General Purpose Input/Output Interface (GPIO) pins which can be assigned various functions by programming the appropriate registers [54].

As the ESP32 has a operating voltage which varies from 2.3 V to 3.6 V, the recommended voltage when using a single-power supply is 3.3 V, with an current output of 500 mA or more [54]. When the power supply V_{in} receives a DC voltage of 5 V, it will automatically turn on the red Light-Emitting Diode (LED) D1 and, through the low dropout positive voltage regulator named NCP1117, it will provide to ESP32 an output of 3.3 V [55].

Moreover, there is the Micro Universal Serial Bus (USB) which can be used as a power supply and as a USB to Universal Acrychronous Receiver/Transmitter (UART) communication converter integrated. Besides that, the ESP32 development board includes an antenna and antenna matching circuit [54].

Owning so many functionalities and having the Wi-Fi module integrated, the ESP32 is all-rounded chip for the development of IoT projects. The development environment setting for ESP32 is provided by Espressif through the Software Development Kit (SDK), which is a bundle of utilities and device-level API that enable computer programs to directly communicate with each other, interacting and sharing data [52]. There are several development platforms [56], e.g., Arduino Integrated Development Environment (IDE), PlatformIO, Make, ESP-IDF (Espressif IoT Development Framework). As demonstrated by [49], the ESP32 boards support Arduino development, one of the biggest community for open source hardware and it is chosen to be used for the work development, with the programs of the ESP32 DevKit V1 being written in C language.

Ultrasonic Sensor US-015

The US-015 High Accuracy Ultrasonic Sensor, produced by Synacorp Technologies was selected as the ultrasonic sensor module for this work (see Figure 4.5).

Figure 4.5: US-015 High Accuracy Ultrasonic Sensor.

The sensor can provide non-contact measurements in a range between 2 cm to 4 m with an operating temperature from 0°C up to 70°C. The power supply voltage is DC 5 V with working current of 2.2 mA, and it has support to GPIO communication mode [32]. As presented in Figure 3.4 (Section 3.1.2), an important feature is to have a short detection angle in order to avoid interference from the barrel walls and, the US-015 sensor provides a relative short detection angle within less than 15°. The pin assignments from the US-015 can be seen at the Table 4.1.

When the ESP32 sends a pulse to the US-015 "Trigger Input Pin" with duration of 30 μs, the transmitter generates a series of sound waves, the Echo Pin is set to "1" and the time is started to count. After the reflection from the object and the returning to the receiver, the Receiver Output Pin is set to "0". The result is a pulse duration which is equal to the time propagation of the ultrasound wave (see Figure 4.6), allowing the

	Pin Symbol	Pin Function Description
1	Vcc	5 V Power Supply
2	Trig	Trigger Input Pin
3	Echo	Receiver Output Pin
4	GND	Power Ground

Table 4.1: Pin assignments of US-015.

distance to be measured.

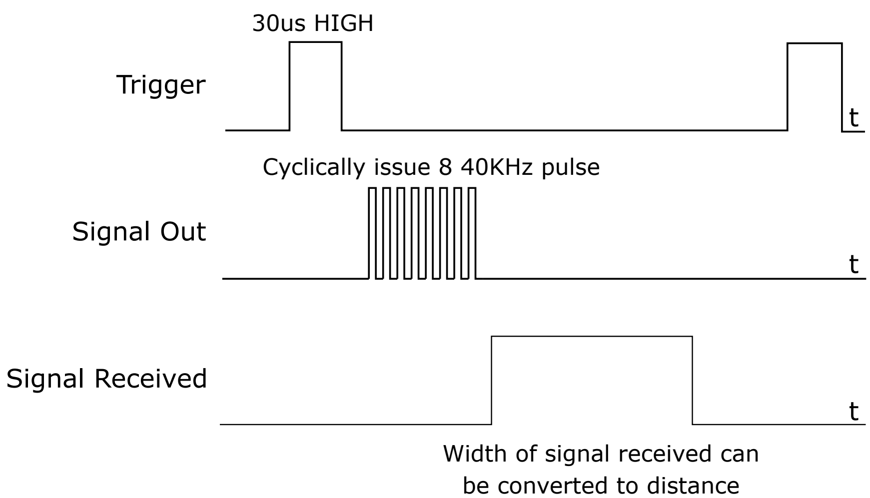


Figure 4.6: Ultrasonic timing diagram. Adapted from [44].

Power Supply Module

The power supply module is composed by the battery, the battery charger and the DC-DC boost converter. The battery used for this work is the LIR18650 model, with a nominal energy capacity of 2600 mAh, produced by EEMB. Figure 4.7 shows the cylindrical lithium-ion rechargeable cell. As described by [57], the working voltage during the whole discharge process is 3.7 V with an internal impedance of $\leq 70m\Omega$.

The Table 4.2 exemplify some basic electrical characteristics of the battery cell when charging and discharging in an ambient temperature of 25 ± 5^{o}C and relative humidity of 65 ± 20 %.

Since a lithium-ion battery cell is used, a Battery Management System (BMS) needs

Figure 4.7: Lithium-ion battery model LIR18650 with 2600mAh.

Standard Charge	Constant Current and Constant Voltage (CC/CV) Current = 520 mA Final charge voltage = 4.2 V Final charge current = 52 mA
Standard Discharge	Constant Current (CV) Current = 520 mA Cut-off voltage = 3.0 V

Table 4.2: Basic electrical characteristics of LIR18650 when charging and discharging. Taken from [57].

to be taken in order to enhance safety characteristics [58]. There are several cautions and warnings appointed by the manufacturer in order to provide necessary protection required by lithium batteries [57]. The BMS used is the 03962A module (see Figure 4.8), it is made for charging lithium batteries using constant current and constant voltage (CC/CV), moreover, the module provides necessary protection for the batteries, e.g., overdischarge/overcharge protection, overcurrent and short-circuit protection, soft start protection to limit inrush current and trickle charge for battery reconditioning.

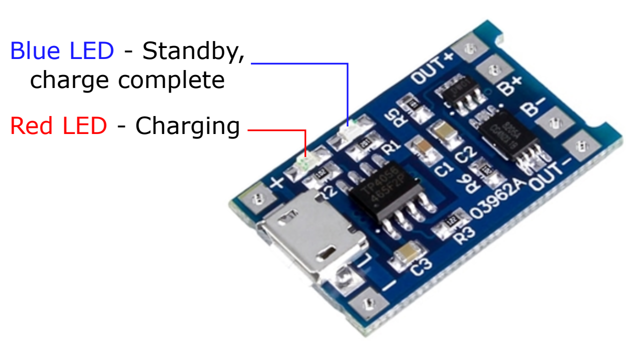


Figure 4.8: TP4056 - 03962A lithium battery charger and protection module.

The battery can be powered, for charging, from the micro USB cable or from the + and - input with DC 5 V. Also, the power source needs to be able to provide at least 1 A for correctly charging the connected battery.

The integrated circuit responsible for the constant-current/constant-voltage linear charger is the TP4056 integrated circuit and it includes several features such as current monitor, under voltage lockout, automatic recharge and two status pin, to indicate charge termination and presence of an input voltage [59]. The DW01A and the FS8205A work together in order to protect the battery from damage or degrading the lifetime due to overcharge, overdischarge, and/or overcurrent [60], [61].

With the charger module being set, as the nominal voltage during the whole discharge process is 3.7 V and, the final charge voltage is 4.2 V, the battery does not have enough voltage to supply the ESP32 development board and neither the US-015 ultrasonic sensor, while in discharging process, as they both requires a DC voltage of 5 V. Because of that, the power supply module requires a DC-DC boost converter, connected to its output, in order to give a properly power supply for the ESP32 and the US-015. Moreover, the step up converter has a voltage indication, that means the LED will be turned on with a load presence and, when the input voltage is lower than 2.7 V, the LED indicator will be turned off.

4.2.1 Electronic Circuit Diagram

Once presented the necessary electronic components for the hardware architecture development, it is time to show how these components are going to be connected. The Figure 4.9 illustrates the electronic circuit diagram developed.

As the ESP32 is going to receive a signal from the Echo Pin that may be "1" or "0", as described in Figure 4.6, they do not need an analogic-to-digital converter. Therefore, the ultrasonic sensor pins can be directly connected to any GPIO of the ESP32 development board. Thereby, the trigger pin of the ultrasonic sensor is connected to the GPIO D15 of the ESP32 board and, the echo pin is connected to the GPIO D4. Also, the DC-DC boost

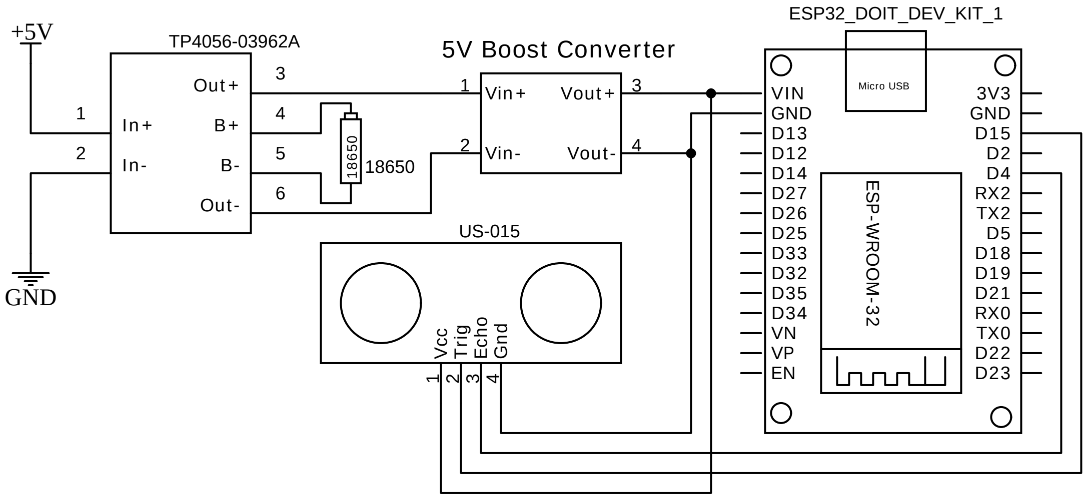


Figure 4.9: Electronic circuit schematic of the project.

converter is power supplying to both ESP32 board and the US-015 ultrasonic sensor.

4.3 Enclosure Design

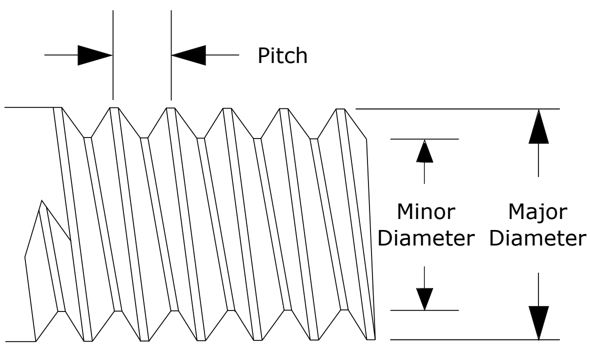
As demonstrated in Figure 4.2, the solution adopted is to create a custom-made hardware enclosure that allows the measurements to be taken from a top position of the barrel. Therefore, the enclosure must be able to thread, into one of the openings, and it must allow that all the electronic components can be fitted in a well organized and structured manner, allowing the wiring connections to be made as clean as possible. The enclosure was first drawn by using the software SolidWorks version 2017/2018.

Starting with the screw thread, the measurements used for the software design were taken from the bung cap, as shown in Figure 4.10. As it was difficult to find the exactly measures, due the lack of information about the maker of the plastic drum barrels and bung caps, it was necessary to perform the measurements manually using a digital caliper.

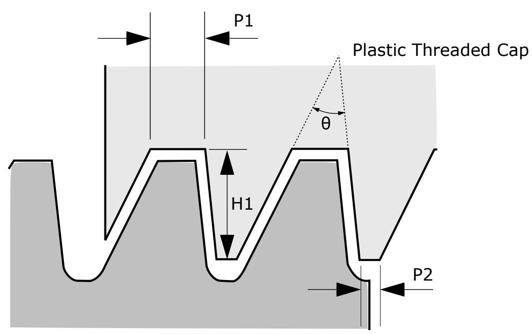
It is important to have some basic considerations when designing a screw thread. First, as demonstrated in Figure 4.11(a), the pitch is given by the distance between the crests, the major diameter is the diameter of the imaginary co-axial cylinder that touches the crests and, for the minor diameter is the imaginary cylinder that touches the grooves.

Figure 4.10: Plastic drum screw cap.

Also, the length of the screw is important in order to know how many revolutions the screw thread will have.



(a) Screw thread measurements overview.



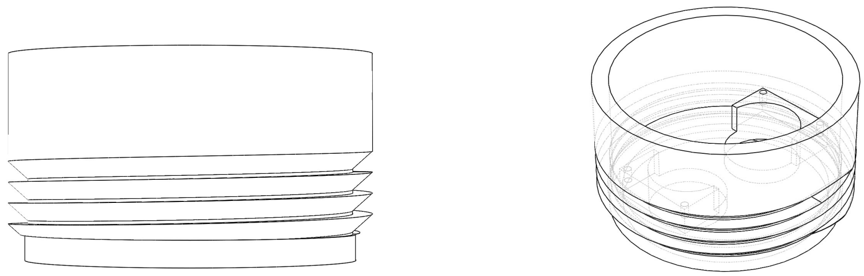
(b) Basic profile of the buttress screw threads.

Figure 4.11: Basic plastic screw threads considerations.

Already for the Figure 4.11(b), it is showing a basic profile of a screw thread. The measures P1 and P2, the height H1 and the angle θ of the screw thread are important measurements in order to have a good fit between the parts.

Ensuring these considerations, a design of screw cap can be made. As shown in Figure 4.12, it is demonstrating the front and isometric view of the buttress screw thread.

As can be noticed from Figure 4.12(b), inside of the screw there must be two openings allowing the ultrasonic sensor to fit, allowing the ultrasonic sensor to take readings from the liquid surface. Then, using the Fusion3 F400 3D printer, the screw thread designed



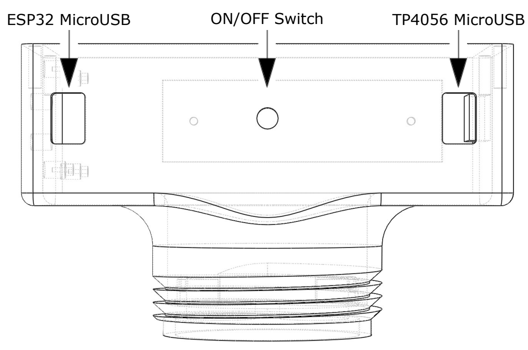
(a) Front view. (b) Isometric view.

Figure 4.12: Overview of the buttress screw thread design.

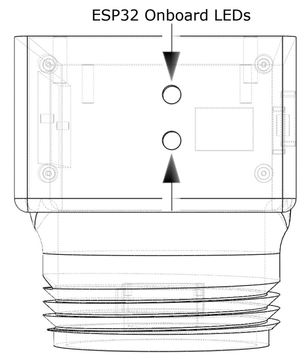
is printed and the 3D model is proceeded to be tested on the plastic drum barrel (see Figure 4.13).

Figure 4.13: Printed 3D screw thread being tested.

Thus, the electronic components is drawn in solid model and is used in order to have a better understanding about the dimensions and design of the whole device model. In Figure 4.14, it is shown a preview model of the whole device. From the front view in Figure 4.14(a), there are two access openings, one for the micro USB module charger and one for the ESP32. In the middle, it will be placed a switch button for turning the device ON and OFF. The openings from the side view, in Figure 4.14(b), are for the ESP32 onboard LEDs, responsible for alerting if the device is powered up and for the alert system, warning in case the liquid's surface is under a predetermined value.



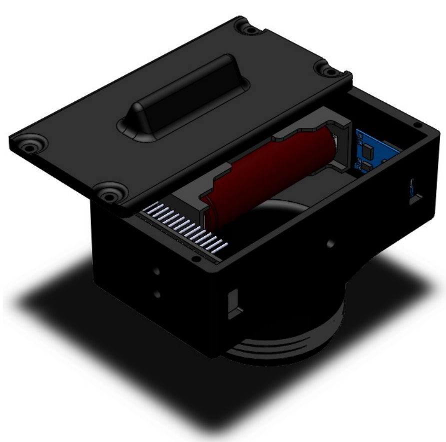
(a) Front view.



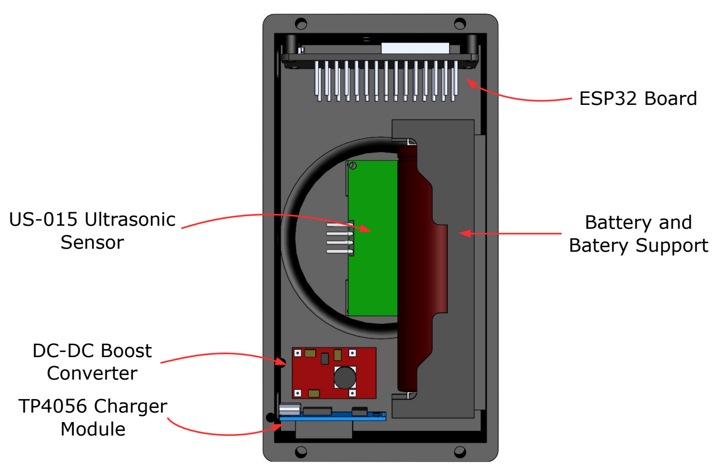
(b) Side view.

Figure 4.14: Preview of the 3D device model.

Therefore, the final version of the device is demonstrated in Figure 4.15. As can be viewed, the device has a cover which is secured by 4 screws located at the corners. Already for the Figure 4.15(b), it is shown the position of the electronic components inside of the model.



(a) Isometric view of the device.



(b) Position of the electronic components in the device.

Figure 4.15: Final device model.

Now that the device model is defined, it is time for the printing process. The printer uses the Simplify3D software control, which is responsible for translating the 3D models into instructions that the printer can understand. There are a wide range of information on their website in order to have better printing results. Mainly, regarding the support structures. The printed model can be seen in Figure 4.16, in which PLA (short term for Polylactic Acid) filament was used as the material for the printed model.

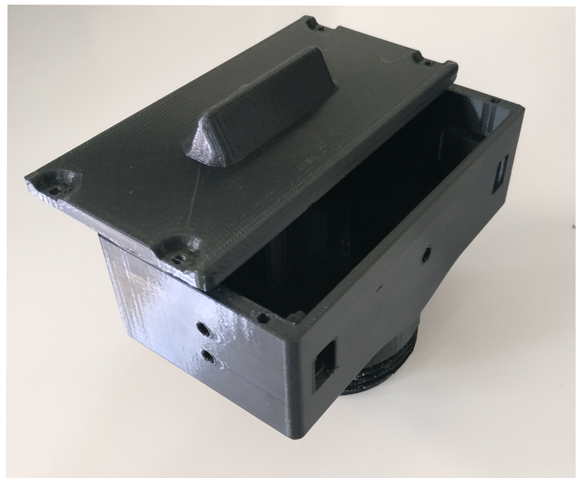


Figure 4.16: 3D printed model.

After all the printing process, it is time to install the electronic components inside the printed device. Following the electronic circuit schematic, as illustrated in Figure 4.9, the implementation resulted is shown in Figure 4.17.

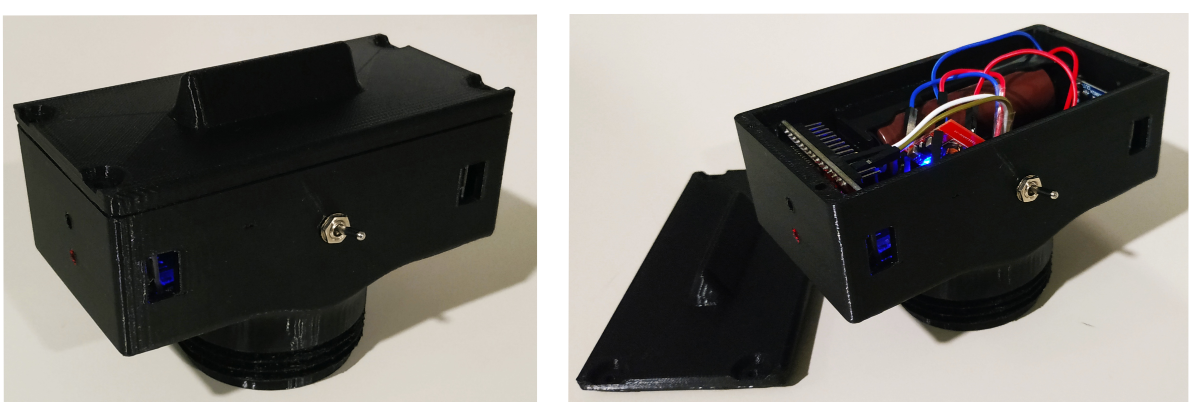


Figure 4.17: Final version of the 3D printed device.

4.4 Setting up the ESP32

In this section, it is demonstrated the software development responsible to retrieve and manage the ultrasonic measurements. The development environment used to program the ESP32 Board is the Arduino IDE, the installation of the board in the software can be done by following the steps provided by [49] or directly in [56]. After it is established the programming tool, it is time to define the characteristics adopted for the system and the flowchart overview of how the embedded software works.

4.4.1 Software Design

Starting with the Wi-Fi configuration, it refers to the information related to the name of the Wi-Fi network (SSID), the password and the IP host address, responsible for allowing the connection between the client and the server, where the data will be stored.

Analyzing the barrel characteristics, it is adopted the diameter, height and volume. As there is no mathematical model that describes exactly the geometry of the barrel, it is used the Equation 4.1 for the volume calculation.

The alert system is responsible for emitting a light warning, by turning on an ESP32 onboard LED, in which it will inform the managements when the barrel capacity is less then a predetermined value. The LED will maintain its state until the capacity of the sensor is above the predetermined value.

Another feature is the check system, which is responsible for saving the old value of the distance measured, in the internal memory of the ESP32, in order to compare with the new value, before the information is sent to the database. This prevention system is important for level measurement systems, specially when the liquid level to be measured does not change quickly between two consecutive measurements. Thereby, it avoids possible nonsense values to be send to the database, by comparing them before the data to be sent.

For the environment temperature, as all reservoirs are located at centralized in a room inside the facilities of the SCMB and, each plastic barrel has only two openings, as shown in Figure 4.1(b), due the material of the plastic barrel and the location where they are placed, it is assumed that the average temperature is closely to constant.

Furthermore, the system has a variable which allows to define a number of samples. This variable is responsible for the US-015 ultrasonic sensor to take successively measurements, in a short period of time, with the objective to decrease the errors from the readings.

Measurement System Flowchart

The flowchart of the sensor readings are shown in Figure 4.18. It is basically responsible for retrieving, avoiding and treating the ultrasonic sensor readings, calculating and returning the distance, volume and capacity of the barrel's liquid.

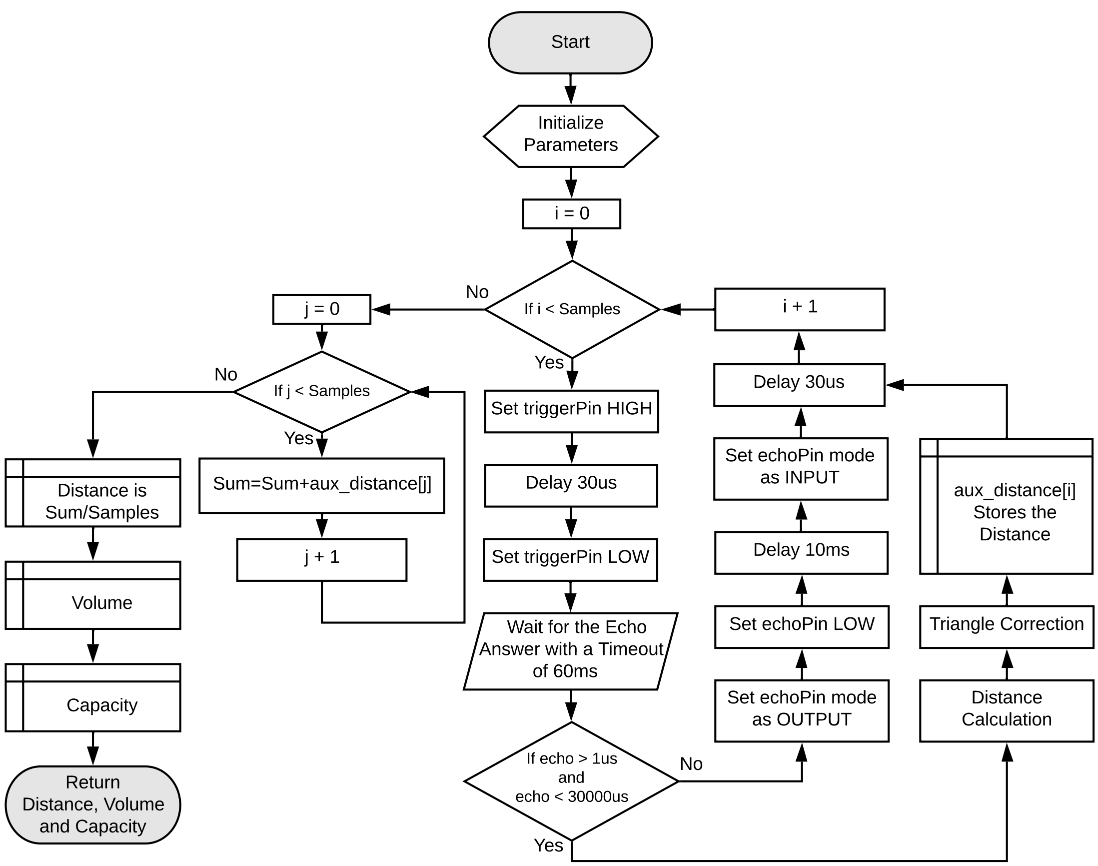


Figure 4.18: Flowchart of the ultrasonic sensor readings.

This function makes the ESP32 to send a pulse to the trigger pin of the US-015 with a period of 30 μs, than it will wait for the echo answer with a timeout of 60 ms. At this point, the time is being counted.

If the echo exists, the system will make another process to check if the returned time value is appropriate or not. In case the time is appropriate, the system will make the distance calculation, using the Equation 3.8, and the result will be stored in a auxiliary vector. However, if the time value is not appropriate, the ESP32 will send a low pulse to the echo pin of the US-015 in order to reset the readings received from the echo pin, preventing the system to make new readings with the same errors, due to interference factors.

The system will make repetitively measurements until the number of samples is reached. After this point, all the measurements stored in the auxiliary vector will be added and the distance mean will be calculated. Thus, the volume and capacity is calculated with the Equations 4.2 and 4.3, respectively, and the parameters are returned from the function.

System Flowchart

Upon the completion of the software design, Figure 4.19 demonstrates the flowchart of the code written and programmed into the microcontroller, it also can be found by checking in [62]. It begins with the initialization of the parameters presented in the previous section and the libraries necessary for the development of the program.

The libraries used are the <Wi-FiClient.h> and the <WebServer.h>, they enable the ESP32 Board to connect with a Wi-Fi network and sending information through HTTP request method. Following, the system defines the pin mode and, makes reads from the ultrasonic sensor module, as shown in Figure 4.18. Thus, the distance returned is stored in an auxiliary vector for further comparisons. Lastly, the microcontroller connects to a local Wi-Fi network.

Already inside of the infinite loop, the system will update the distance value stored at the auxiliary vector by making new readings from the sensor, then, it makes an absolute difference between the old and new values. The system will make 5 comparisons if the

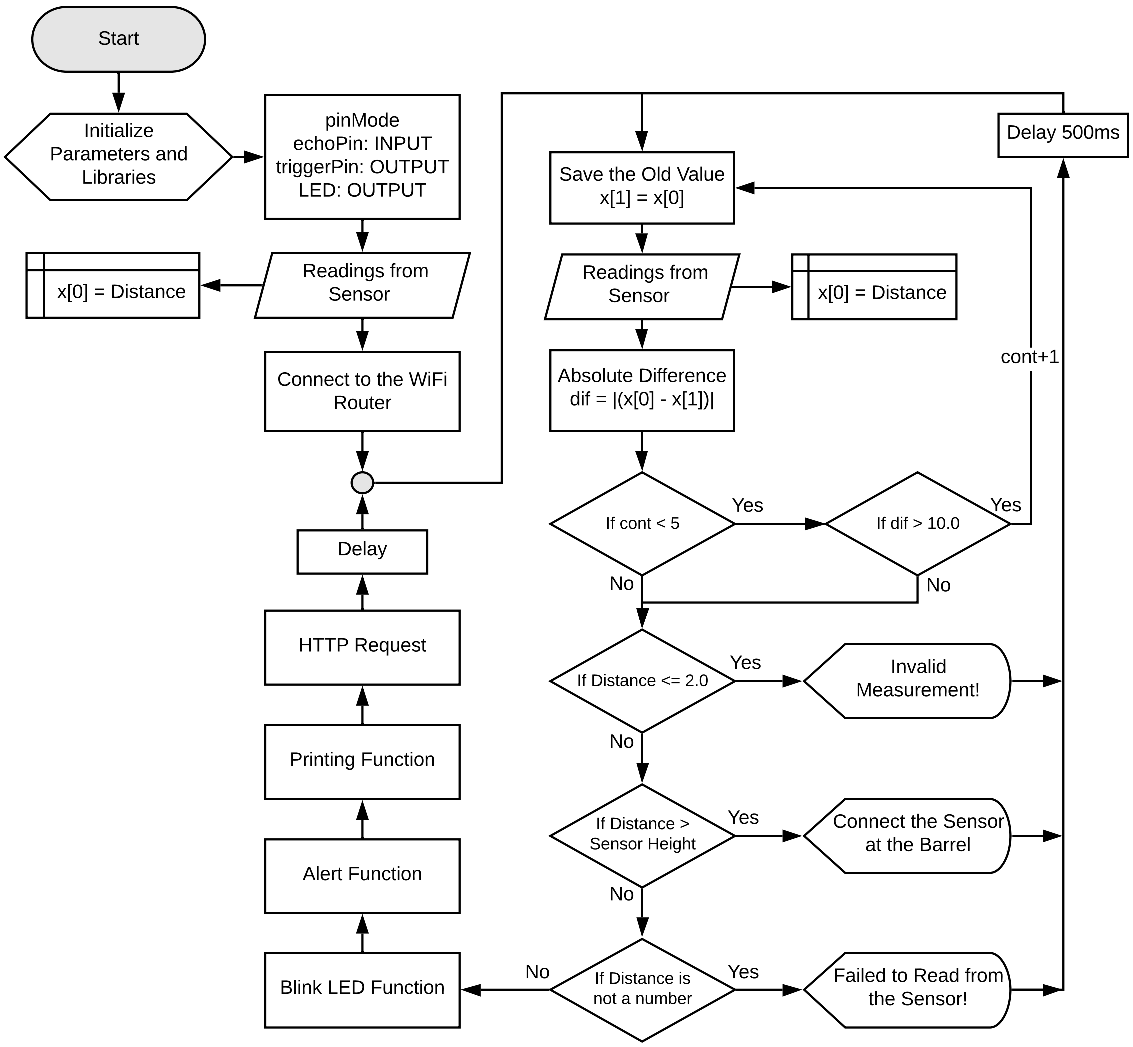


Figure 4.19: The system flowchart.

distance difference is greater than 10.00 cm. In case after this 5 comparisons, the system continues providing this big difference, the system will decide that this value is true and it will continue with the program flow. Otherwise, the value will be discarded and the system will be forced to do other readings, from the sensor module, in order to check if the value measured is correct.

After these strict comparisons, the system will make some basic checkup and it will print, through the serial monitor, specific alerts in case of nonsense values. Then, the system will rerun the program until a reasonable distance measurement is taken.

Starting the checkup process with the US-015 ultrasonic sensor, as it is capable of doing measurements in a range of 2 cm to 4 m, the system will print *Invalid measurement!* when the distance is shorter then 2.0 cm and, for the maximum operating range of the sensor, it will be limited to the barrel's height. Thereby, in case the distance measured is greater, the sensor will print a message *Connect the Sensor at the Barrel!*, as it is impossible for the system to detect a higher measurement than it is. Lastly, it is verified if the distance is a number or not, in case this function is true, it will be printed *Failed to Read From the Sensor!*.

At this point, the distance measured is valid and the values of the distance, volume and capacity is ready to be sent for the database. It will blink a LED, alerting that the system took the measurements, and it is about to send the data to the database. Finally, the Alert Function will turn on the ESP32 onboard LED, in case the capacity parameter is under a predetermined value, and the values will be printed in the serial monitor.

Following, the client makes a request by using the GET method, which is one of the HTTP methods used to indicate that a desired action is to be performed. The action is to communicate with an API responsible for inserting the data in a RDBMS. The distance, volume and capacity information are passing in the form of an entity embedded in the URL where the database server is located.

Lastly, the ESP32 board will go into a sleep state and it will remain for a while until further measurements are required. The delay time can be set according to the application necessities.

4.5 Database Development

Upon to complete the review of the whole system development, this last section approach the structure of the database, APIs and web pages developed [62]. As they are hosted on server, it was chosen *000webhost* services, which is a free web hosting fully-functioning with PHP and MySQL features. The disk space available is up to 1 GB with 10 GB of bandwidth, which is more than enough for development and testing the laundry integrated system.

The Figure 3.7 illustrates the server architecture overview. As can be seen, the APIs communicate either with the database and the Web pages, allowing the users to access the database content, dynamically and interactively, through the HTML Web pages.

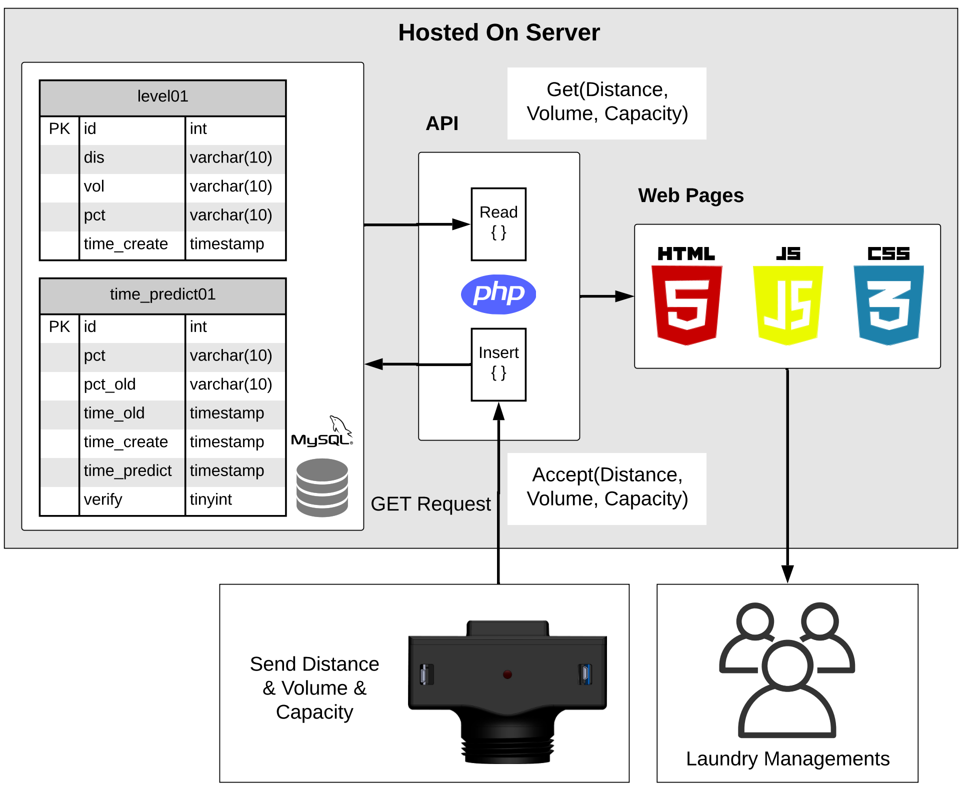


Figure 4.20: Web database architecture overview.

Although the Figure 3.7 is showing only two APIs, one for inserting data in the tables and another for making readings, in practice, the structure is a little bit more complex. In order to understand how the database structure works, it is necessary to make an overview about the website flowchart and the APIs diagram.

4.5.1 Website Structure Overview

The laundry managements can access the database content by navigating through the *Início, Status, Histórico, Projeções, Contacto* and *Sobre*, as illustrated in Figure 4.21. The useful information, for each Web page, is provided by the PHP APIs when requested.

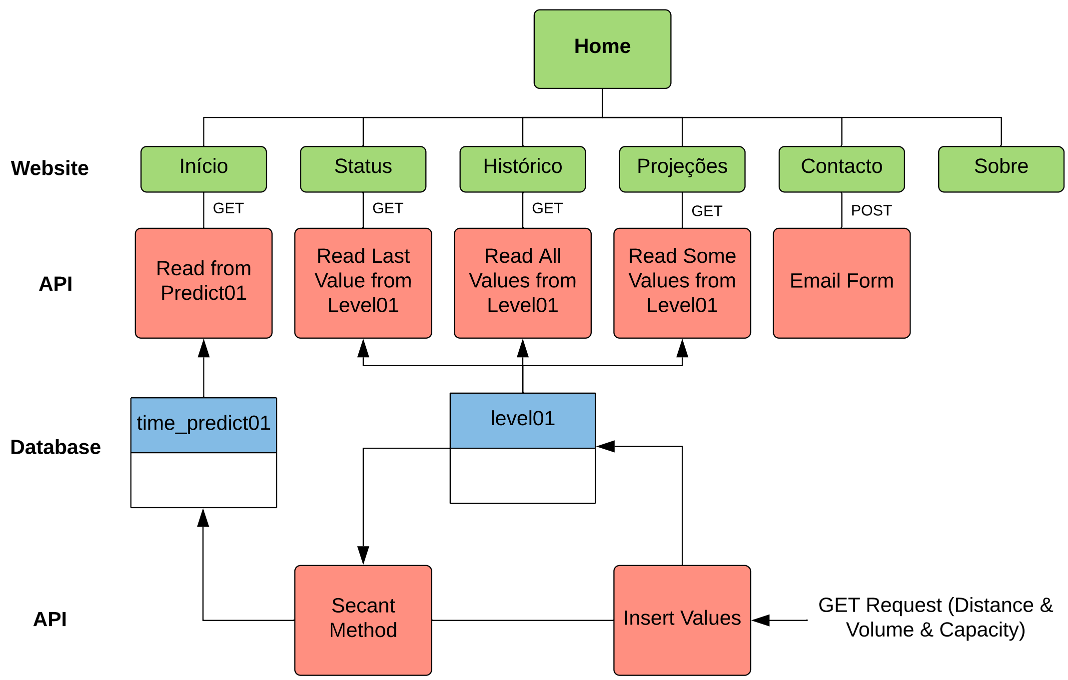


Figure 4.21: Website structure diagram.

The communications are done by using HTTP protocols, mostly through the GET and POST methods. It allows a large number of clients to access the platform simultaneously and, moreover, as the HTTP supports the content negotiation, the client and servers can negotiate the desired format for a given resource, permitting the server to provide the same URL in different formats, like JSON, as approached by the Section 3.4.2. These features increase the efficiency, flexibility and integration of the system.

The JavaScript is embedded inside of the *main* element of the web document, where it will be located some features about the website 4.5.2. As the information is being dynamically updated, the consumer may have access of the last level measurement through the DHTML document, by which provides a lot of benefits, as preview talked in Section 3.4.2.

4.5.2 Web Application Features

In this Subsection, it is explored some features about the Web application relative to the data acquired from the measurements. It is important to highlight that, all the graphs were developed using Google Chart API, which is a powerful free service that creates graphical charts from user-supplied data.

Início

In *Início* (Start), the client might check the actual capacity of the reservoir and the status in case the system is unloading or loaded/loading. If the system is unloading, it will calculate the time remaining for the reservoir to drain out and, it will automatically show the date and time the reservoir will be totally empty. On the other side, if the system is already loaded or loading, it will only shows the actual capacity, as there is no date to estimate of when the reservoir will be empty (see Figure 4.22).

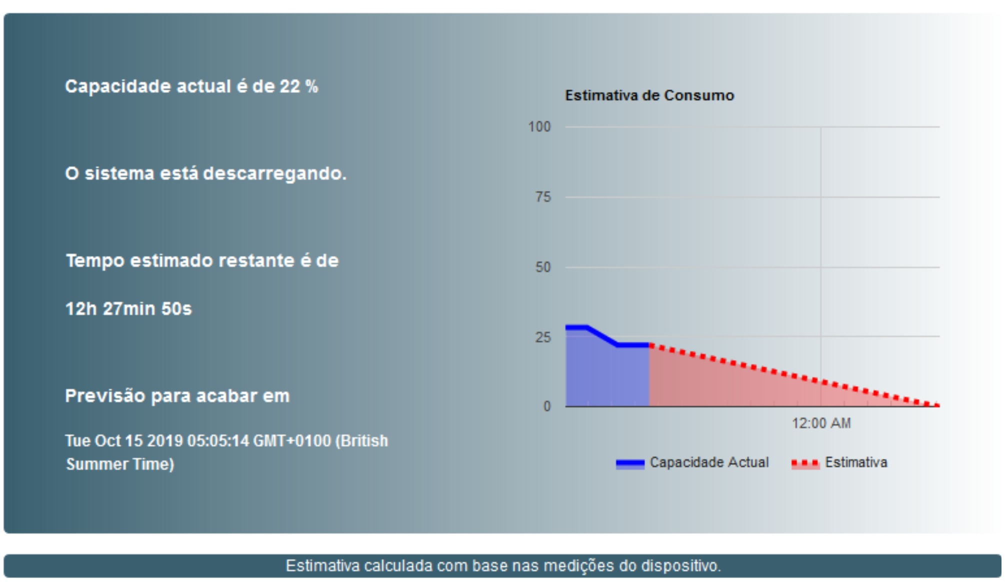


Figure 4.22: Informative web page about the estimate graph of when the reservoir will be empty.

This calculus is possible by using a numerical solution for root-finding called secant method. As approached by [63], the method uses two points in neighborhood of the solution to determine a new estimate value. As this method uses two points to find a solution, it is possible to develop it, by using a PHP API, where a new estimate of the solution x_{i+1} is determined from the previous two solutions x_i and x_{i-1}.

$$x_{i+1} = x_i - \frac{f(x_i)(x_{i-1} - x_i)}{f(x_{i-1} - f(x_i))} \tag{4.4}$$

The algorithm from the Equation 4.4 were applied in the API called Secant Method, as seen in Figure 4.21. It is responsible for reading the new information from the level01 table, process the data and stores the estimate date and time values in time_predict01 table. Thus, the information is requested through AJAX technique.

Status

In *Status* page, as shown in Figure 4.23, the customer has the access to the last measurement values. It is a simple interface responsible for dynamically displaying the distance, volume, capacity and date and time values. The PHP API liable to provide the information for this Web page, only read the last value of the level01 table. Thereby, the server's response becomes much more responsive due the short length's size of the JSON string.

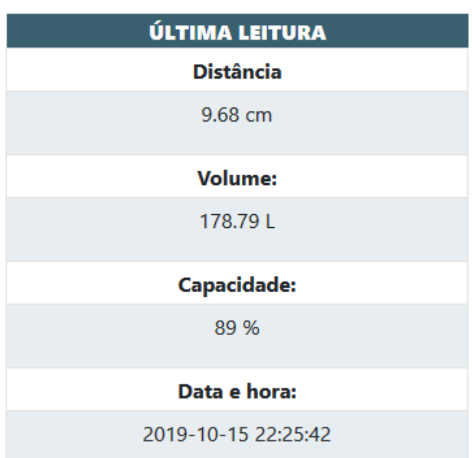
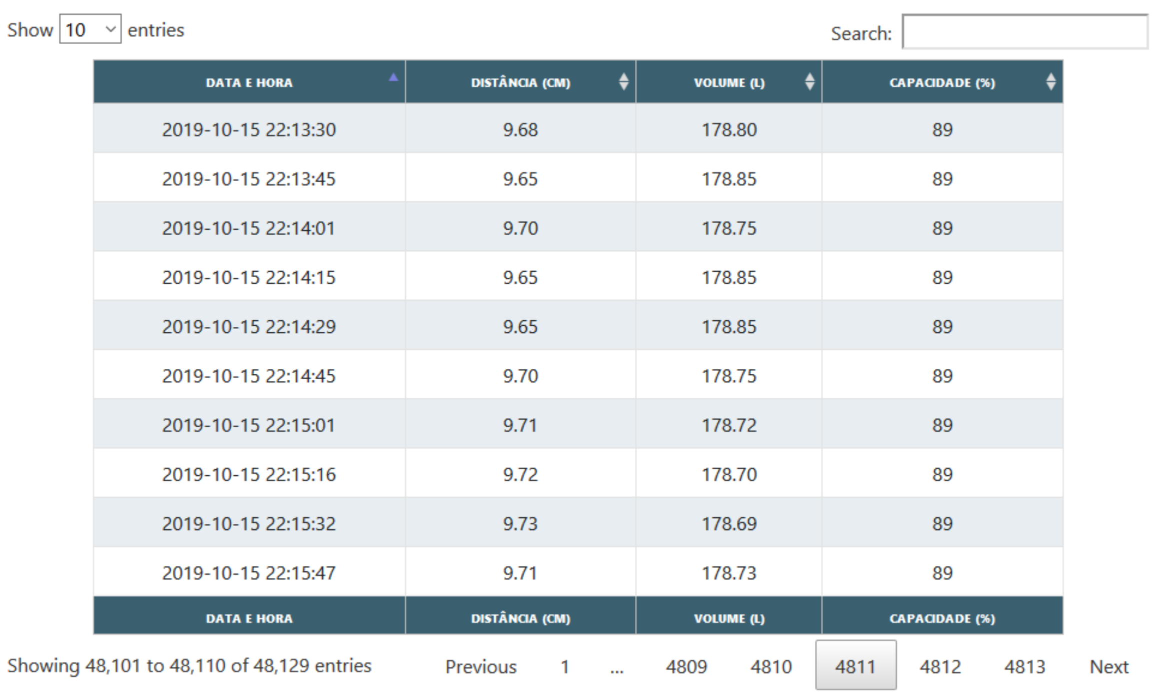


Figure 4.23: Status layout.

Histórico

Already for the *Histórico* (Historical), it was used the Bootstrap framework, which is an free and open source toolkit directed at responsive, mobile front-end web development that allows the client to navigate through the whole database content, permitting the user to sort and search all the information from the database however they want.

Although this feature brings a lot of functionalities for the Web document, the API responsible for that, needs to read all the information from the database at once, which makes the JSON string, from the server's response, to be excessively large when the table has a large number of rows. Therefore, it can not be dynamically updated. The resulting interface can be seen in Figure 4.24.


Show 10 entries

Search:

DATA E HORA	DISTÂNCIA (CM)	VOLUME (L)	CAPACIDADE (%)
2019-10-15 22:13:30	9.68	178.80	89
2019-10-15 22:13:45	9.65	178.85	89
2019-10-15 22:14:01	9.70	178.75	89
2019-10-15 22:14:15	9.65	178.85	89
2019-10-15 22:14:29	9.65	178.85	89
2019-10-15 22:14:45	9.70	178.75	89
2019-10-15 22:15:01	9.71	178.72	89
2019-10-15 22:15:16	9.72	178.70	89
2019-10-15 22:15:32	9.73	178.69	89
2019-10-15 22:15:47	9.71	178.73	89
DATA E HORA	DISTÂNCIA (CM)	VOLUME (L)	CAPACIDADE (%)

Showing 48,101 to 48,110 of 48,129 entries

Previous 1 ... 4809 4810 4811 4812 4813 Next

Figure 4.24: Historical table layout design and functionalities.

Projeções

Taking a close look at *Projeções* (Projections) page, it is responsible for showing the client a graph overview about the consumption of the reservoir's content. The Google Chart API will read the last measurements from the device, this value can be configured by changing how much information the customer prefers, through the PHP API named *Read Some Values from Level01*, shown in Figure 4.21. Although this value might be configured, it is not recommended to use a higher number as set in default, which is pre-configured for showing the last 500 measurements, due to the fact the Web page is being continuously updated via AJAX, and it may overload the browser's cache memory, making it necessary to restart the browser in the course of time (see Figure 4.25).

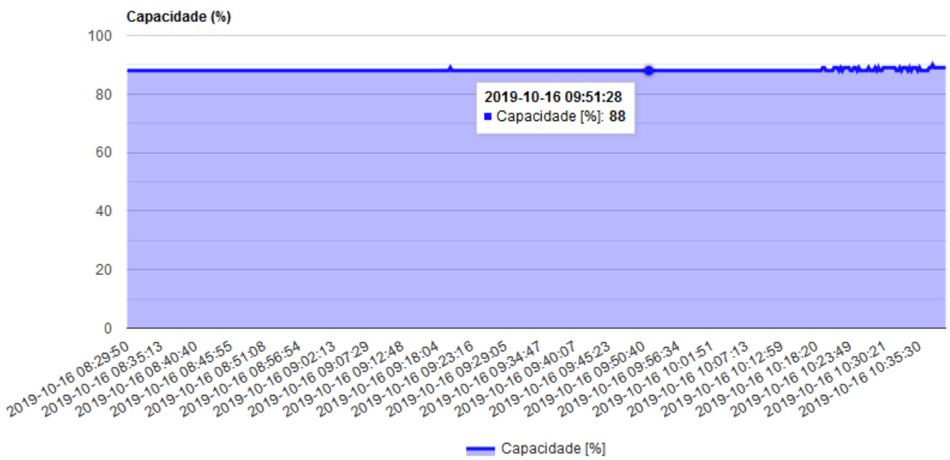


Figure 4.25: Graph design overview.

Contacto

The last feature from the website is the *Contacto* or Contact form, this feature allows the consumer to get in touch with the technicians, by sending to an pre-configured email address the description of the problem. It is a basic contact form that uses the POST method to request the API to send an email using a local *sendmail program*, through the PHP function *mail()*.

This feature is an integral part of any project or business, which allows a responsiveness and well-planned communication between the client and the system's responsible. The contact form layout can be seen in Figure 4.26.

Figure 4.26: Contact form layout design.

Sobre

Lastly, in *Sobre* (About) page, it is presented just a static HTML text that provides, for the client, some basic information about the project.

Website Address

The website developed can be found by accessing the following URL: `https://scmb-esp32.000webhostapp.com/application/index.php`.

It is important to point out that, due to the web technologies used here, the website content may not appear correctly for everyone, as it will depends about the hardware characteristics that is being used by the user. The bronser version where the website was developed is based on *Firefox version 69.0.3 (64-bit)*.

Chapter 5

Results and Discussions

This chapter presents the overall system behavior. Starting with the Section 5.1, it is presented the methodology used to characterize the measurement system. Section 5.2 aims to verify the reliability of the system, performing statistical analysis in order to provide the system's accuracy. Section 5.3 analyzes the temperature influence on the measurements, with focus on the capacity level measured from the device. Following, Section 5.4 provides an overview of the battery performance. In Section 5.5, some basic considerations are made about the solution adopted for the detergent supervision. At last, it is provided the price list of the electronic components used and an overview of the implementation of an IoT Ecosystem for Industrial Washing Machines.

5.1 Experimental Testing Methodology

There were performed some tests on the the reservoirs from the SCMB and the system integrated worked well. Although some difficulties were presented, principally due the format of the thread pitch, the 3D device model was able to fit in the openings of the plastic drum barrels, and the measurements could be taken from the detergent surface level.

In order to characterize the developed measurement system, as demonstrated in Figure 4.18, some experimental tests were performed with the objective of verifying the system's accuracy. For this purpose, the device was submitted to take 50 measurements from an object surface, as can been in Figure 5.1, and four tests were performed with eight different distances, within a range of 5 cm to 400 cm. For each test, it was varied the filter size, which is responsible for the ultrasonic sensor to take successively measurements, in a short period of time, and to return the mean of these values.

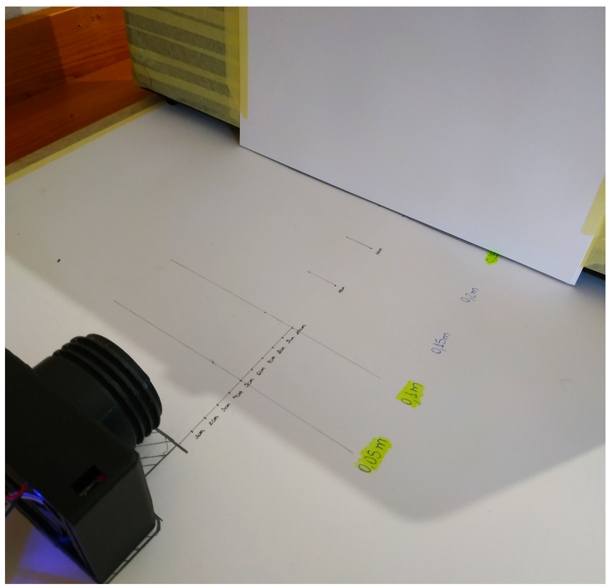


Figure 5.1: Elaborate scenario for the test measurement systems.

Table 5.1 shows the distances and values for each test realized. It is important to point out that these tests were performed in an controlled environment where the temperature was a known factor.

Tests	**Distances (cm)**	**Filter Size**
A	5/10/25/50/100/200/300/400	1
B	5/10/25/50/100/200/300/400	5
C	5/10/25/50/100/200/300/400	20
D	5/10/25/50/100/200/300/400	50

Table 5.1: Summary of the experimental tests with different distances being measured.

5.1.1 Analysis of the Experimental Results

The tests performed will be presented in this subsection. Due to the large quantity of information, only some of them will be provided, however, sufficient for the analysis of the results. The rest of the tests can be found in Appendix B.1.

In Figure 5.2, it is presented the measurement results with the object placed in a distance of 50 cm from the sensor. The first thing that can be noticed is the high value of the average systematic error presented. Although it is an inherent characteristic from any measurement process, its high value is mostly influenced due to the offset adopted for the system, in which it is considered the zero point as the beginning of the device thread, and not from the ultrasonic sensor itself.

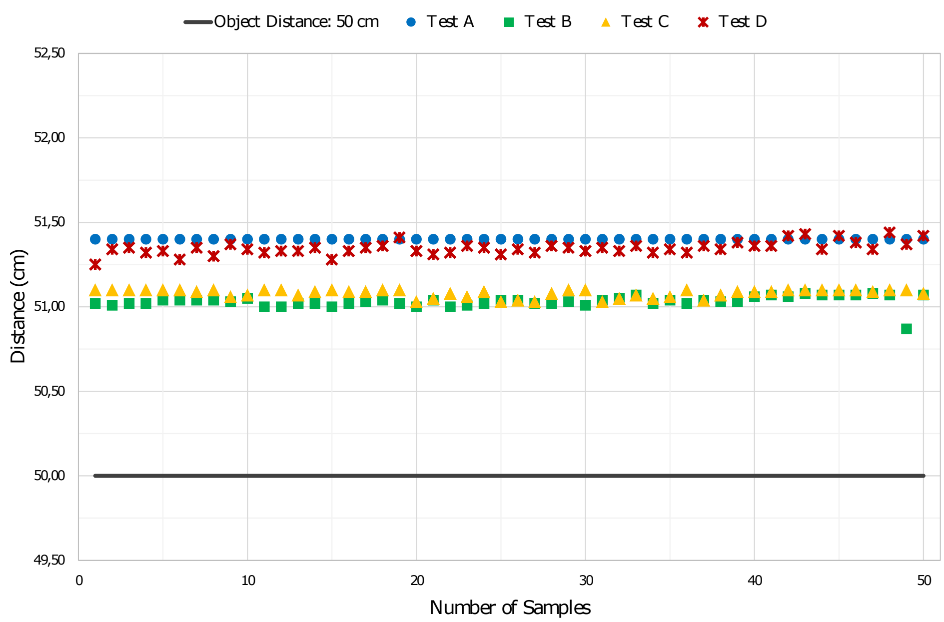


Figure 5.2: Analysis #1 with the object placed 50 cm from the sensor.

Another important factor is the standard deviation, in which it could be noticed that, even for distances shorter than 100 cm, all tests provided low rates of the variation, indicating that the values tend to be close to the mean of the set.

Already for greater distances, the tests provided better results for the tests C and D, as the values from the tests A and B are spread out over the range, which proves that, successively measurements taken from the ultrasonic sensors decrease with higher

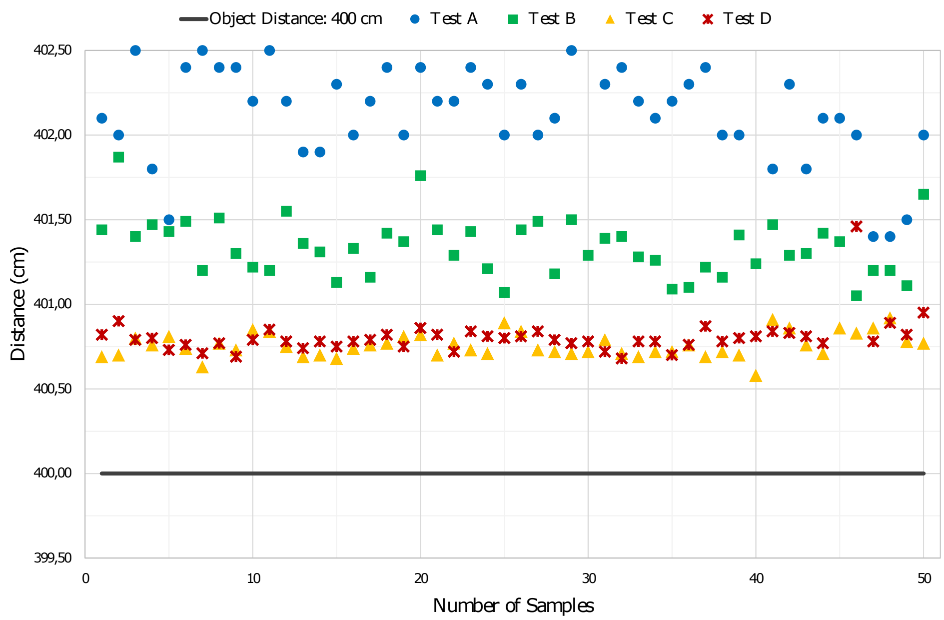


Figure 5.3: Analysis #1 with the object placed 400 cm from the sensor.

numbers of collected samples. Figure 5.3 shows the test results, with the object placed in a distance of 400 cm. It can be noticed that, for the tests A and B, the values of each sample are scattered along the graph, differently than the results from the test C and D.

The Figure 5.4 presents the systematic error from all tests performed. It can be noticed that test A has demonstrated highest values, in which decrease successively until test D.

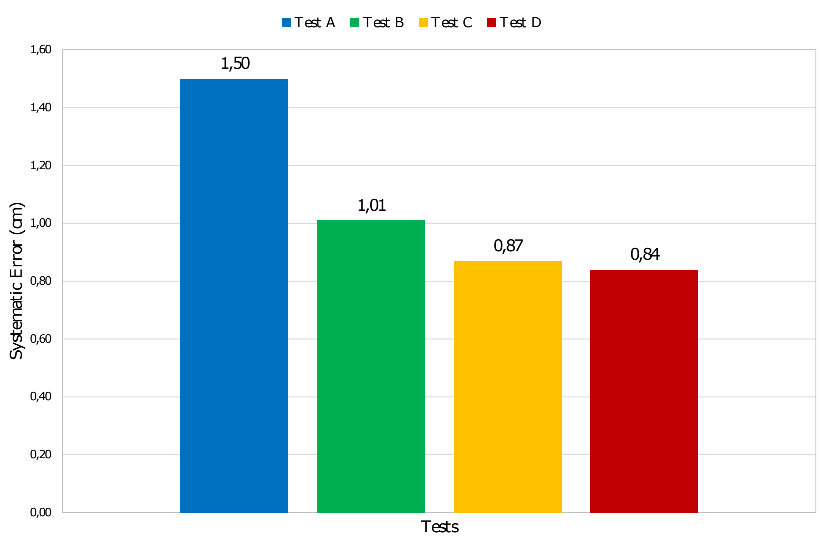


Figure 5.4: Average systematic error presented from all the experimental results (see Appendix B.1).

Therefore, from the analysis, the test C and D has demonstrated promising results, principally for the test D, in which it has shown the lowest systematic error and standard deviation. However, everything comes with a cost and, in this case, the cost is the time that the ultrasonic sensor takes the readings. If the liquid's level surface changes while the sensor is reading, it may directly influence on the results of the measures.

Using a digital oscilloscope, it was possible to evaluate this time value. For the test A, the time is 50 ms for each reading. Already for test B, it is around 250 ms. The test C, the value of the readings is 1.1 s and, for test D, the time is around 2.6 s. Therefore, using higher values of samples, as the ones used for the test D, may have a direct impact on the readings. As the detergent's liquid level does not change quickly, it would be affordable for this application to use the values approached by test D. However, if the readings are showing variations, it would be interesting to reduce the number of samples, in order to make the readings from the ultrasonic sensor faster.

After this set of tests, the best number of samples to be used as default, in terms of systematic error and standard deviation, is the one that is used on test D. Even for distances up to 400 cm, the system has demonstrated some good results, evidencing that the device may be used for reservoirs with higher heights.

5.2 System's Reliability

This section will approach the reliability of the system, e.i., if the system is able to take the measurements, for a long period of time, without detecting fail readings. For this purpose, the device was submitted to take 1000 measures, within a range of distances from 10 cm to 90 cm. Higher values will not be considered, due to fact that the reservoirs from the SCMB have height of 92 cm. Thus, it is performed some statistical analysis, in order to provide the system's accuracy.

In order to simplify the analysis process, it is chosen only three cases wherein the the object is placed 10 cm, 50 cm and 90 cm from the sensor, represented by Figures 5.5, 5.6 and 5.7, respectively. The rest of the results can be found in Appendix B.2.

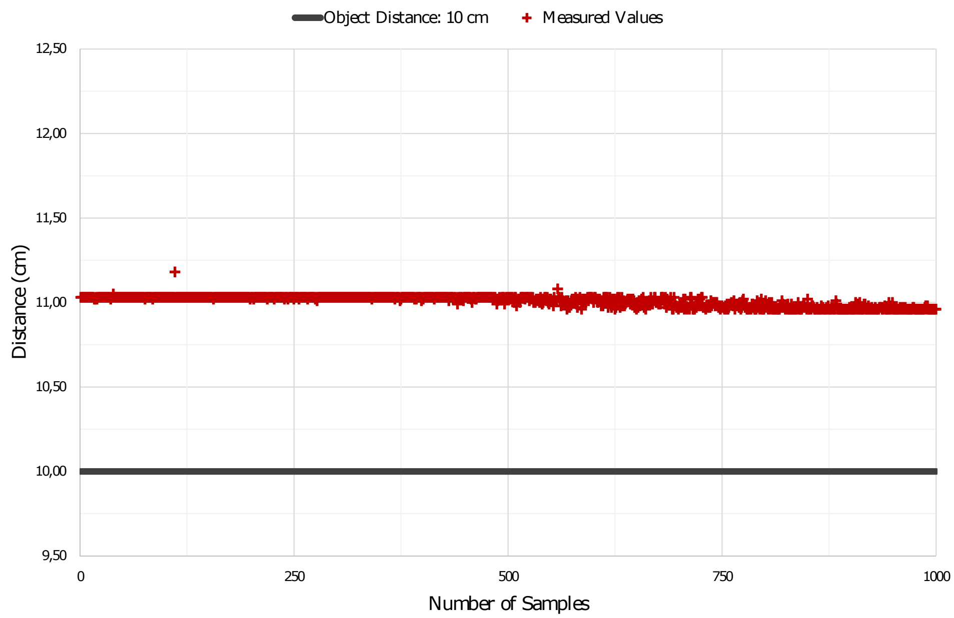


Figure 5.5: Analysis #2 with the object placed 10 cm from the sensor.

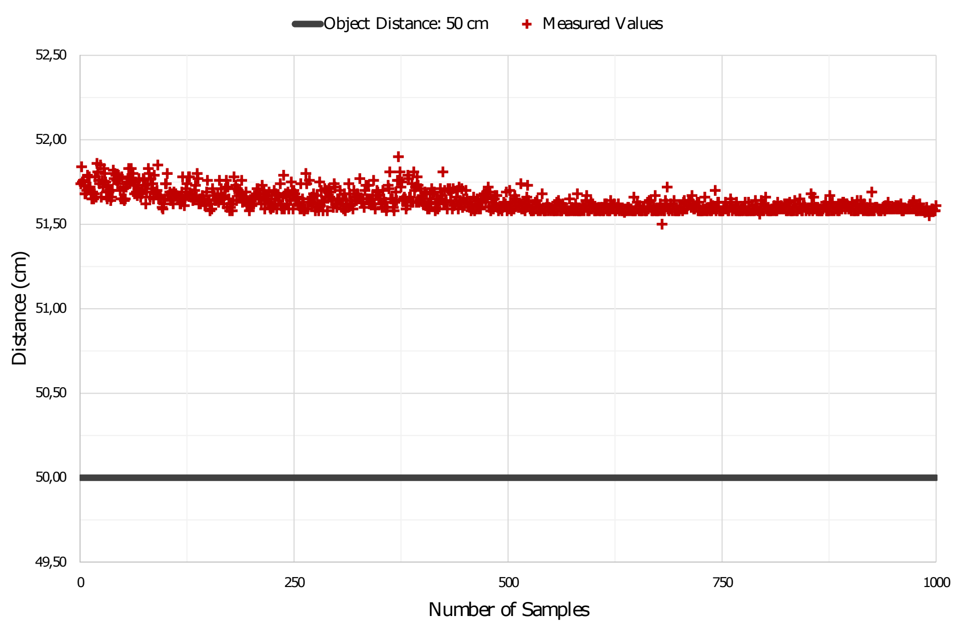


Figure 5.6: Analysis #2 with the object placed 50 cm from the sensor.

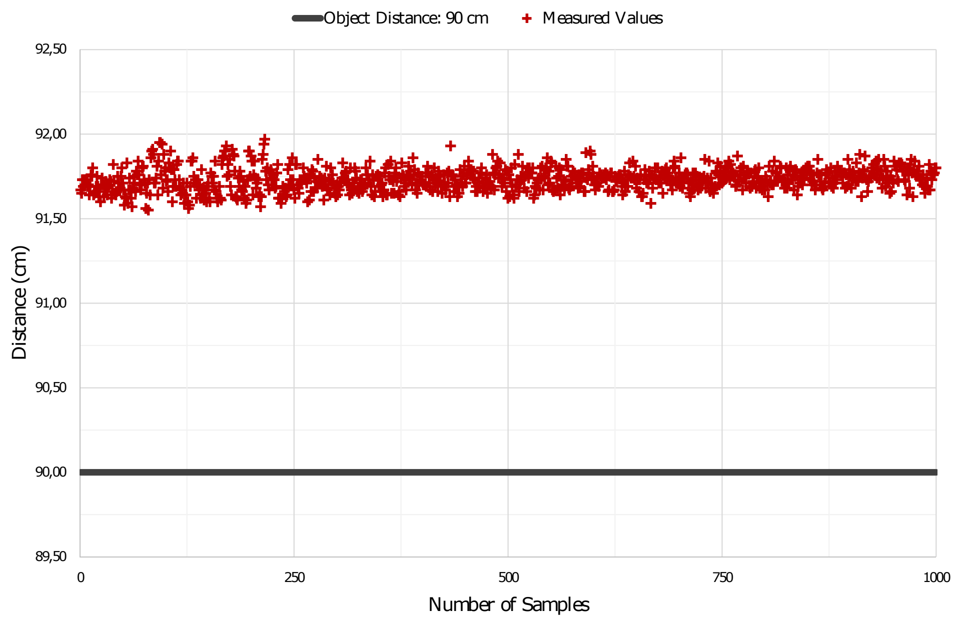


Figure 5.7: Analysis #2 with the object placed 90 cm from the sensor.

The Table 5.2 presents the object distance, the mean values of the samples $\bar{x}$, the standard deviation σ_s, the systematic error S_E and the relative error ε of the 1000 samples taken.

Distance (cm)	$\bar{x}$ (cm)	σ_s (cm)	S_E (cm)	ε (%)
90	91.73	0.07	1.73	1.92
50	51.63	0.06	1.63	3.27
10	11.01	0.03	1.01	10.08

Table 5.2: Summary of the result values presented from the 1000 samples collected.

As can be noticed, for longer distances, the samples has demonstrated higher values of standard deviation σ_s, principally when comparing with shorter distances. This is a expected result, due to the fact the ultrasonic waves are travelling for longer distances. Taking a close look at the relative error ε, shorter distances have presented higher values, which is an expected result, as the variations for small distances will have a significant impact, on the relative error, than for longer distances.

In order to make a better assessment of the measurements, it will be selected 15 random values from the 1000 samples collected, and the system measurement will be evaluated with a confidence interval of 95%. As approached by [64], measurement results can be evaluated through the Equation 5.1,

$$MR = \bar{x} - S_E \ \pm \ \frac{Re}{\sqrt{n}} \tag{5.1}$$

where n is the number of samples and Re is the repeatability of a measurement instrument, defined by the Equation 5.2,

$$Re = \pm \ t \ _x \ \sigma_s \tag{5.2}$$

in which t is the Student t-distribution.

Therefore, for a n = 15 samples, considering one degree of freedom (n - 1) = 14 and 95% of probability, from the table of t-distribution [64], it is found that t = 2.14. Thereby, it is possible to find the repeatability of the system and define the measurement system results. Its results is demonstrated in Table 5.3.

Distance (cm)	$\bar{s}$ **(cm)**	σ_x **(cm)**	S_E **(cm)**	Re **(cm)**	**MR (cm)**
90	91.71	0.06	1.71	0.1	90.00 ± 0.03
50	51.65	0.07	1.65	0.1	50.00 ± 0.03
10	11.02	0.02	1.02	0.04	10.00 ± 0.01

Table 5.3: Measurement system result using a confidence interval of 95 % and a t-distribution of t = 2.14 [64].

From the analysis, it can be noticed that, for the distances 90 and 50 cm, there are 95% of probability that the resultant values from the measurements would be within the range of ± 0.03 cm. Already for the distance of 10 cm, the range is shorter, presented a range of values within ± 0.01 cm. These values represent very positive results, indicating that the accuracy of the measurement system, from the developed device, is in agreement for the detergent supervision application.

5.3 Analysis of the Temperature Influence

As it is more interesting, for the client, to know about the capacity and volume of the reservoir than the distance measured from the sensor, in this section, it will be approached the influence of the temperature on the reservoir capacity measured by the sensor, once it is not being used a temperature sensor. Also, it is important to highlight that reservoirs are kept in a close environment, so the temperature variation presented here are only for comparison effects.

Using the *MATLAB* software, it was possible to evaluate the capacity variation as a function of the temperature. As can be seen in Figure 5.8, it is analyzed three tests with the capacity of the reservoir being at 5%, which is considered one of the cases where the temperature will have significant influence on the capacity measured. Thereby, for the test A, the temperature set in the ESP32 Module is 15ºC, for test B, 20ºC and for test C, 25ºC. Thus, the temperature is varied in a range of 5ºC to 35ºC.

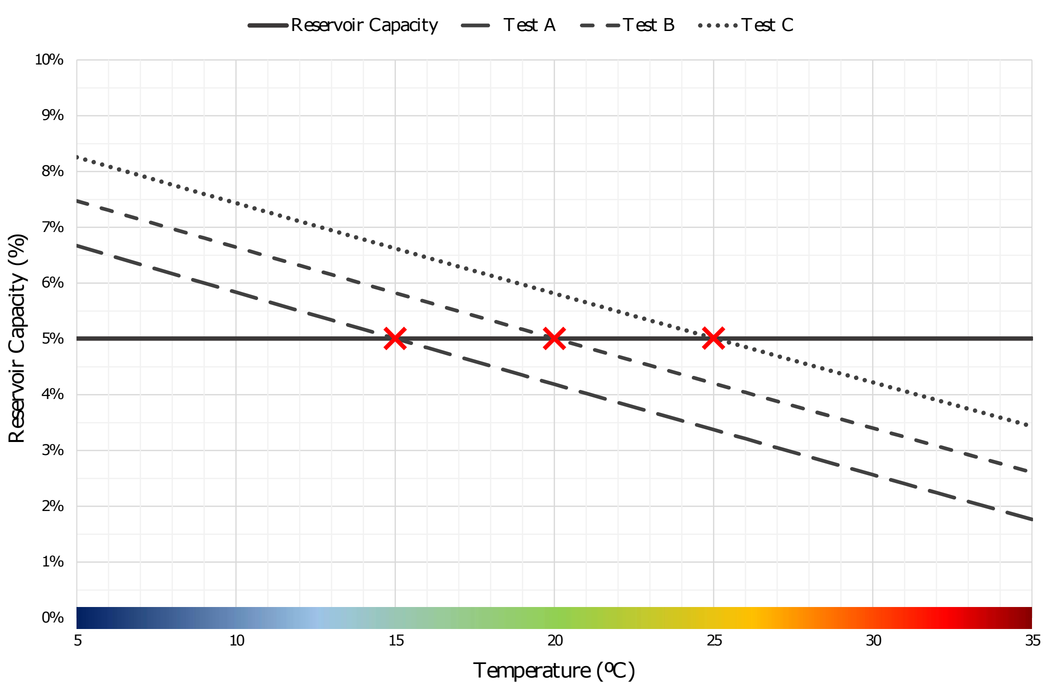


Figure 5.8: Reservoir Capacity: 5 %; Test A: 15ºC; Test B: 20ºC; Test C: 25ºC.

From the analysis, the best case happens when the environment temperature is the same as the one programmed at the ESP32 Module, where the device detects the exact level measurement of the reservoir. In mostly normal conditions, the variation on the capacity would be around ± 1%. However, when extrapolating the variation of the temperature for 35ºC, the system would detect an maximum error slightly above 3%.

In Appendix B.3, it can be found others cases where it was analyzed the capacity variation with the reservoir being at 50% and 95%. The results of the variation presented was around 1%, for the reservoir capacity being at 50%, and practically null for the reservoir that is almost full.

Therefore, the temperature sensor is not so important in this kind of application, as it will have a minimum impact on the capacity measurements. Although, in applications where the variation of 1 %, in the reservoir's capacity, is important, it would be interesting to evaluate the use of a temperature sensor.

5.4 Battery Performance

In order to have an assessment of the battery performance, first, it is important to point out that, the time for the system to update the *status* of the detergent level on the database, may differ according to the stringency criteria that the application requires.

The time value that the sensor will take the readings, is best estimate by implementing the system on the reservoirs at the SCMB, and evaluate the time that would provide the best conditions, both for the battery usage and, for the readings.

Therefore, it is more interesting to talk about how many measurements (readings) the system is able to make. After some practical tests, it was possible to evaluate that, the system can make readings and update the information on the database around 9300 times. If the stringency criteria of the information to be updated is high, it would be interesting to use another battery connected, in parallel, in order to make the working time of the device longer or, it is possible to use it plugged directly with a 5 V charger, with a maximum current output of 1 A.

5.5 Overall Considerations

In this section, it will be presented some basic considerations about the solution adopted for the detergent supervision.

First, as any IoT application, the device must be 100 % of the time connected with a network, otherwise, the system will no longer be able to take the readings and update the information on the database. In case the internet access is not available, some adjusts can be made, with the objective of making the ESP32 Module to save the values from the readings on its internal memory and, when the internet access becomes available again, the system would update the information all at once. Although it would be an interesting solution, for the time period that the system is offline, it would not be considered a real-time monitoring solution.

The Web platform developed in this work does not make use of any API protection. This means that the APIs may be target of security threats and, additional vulnerabilities, due to the none use of authentication and lack of encryption. Therefore, the use of Simple Object Access Protocol (SOAP) or Representational State Transfer (REST) would be interesting in order to deal with transactional massaging security considerations, principally using an authentication and authorization architecture.

Another point to be considered is regard to the environment where the device will be placed. In the laundries facilities of the SCMB, it is used five types of products to clear the clothes, e.g., liquid detergent, chlorinated and oxygenated blancher, neutral detergent and softener. Therefore, the device must be evaluated in order to check if the environment is being aggressive for the equipment and, if the measurements is going to be affected in the course of time.

5.6 System Cost and Architecture Proposal

This section will provide an overview of the price of the components used for the work development. The values of the plastic usage (PLA) for the printing process and the wiring connections will not be considered. Moreover, the services provided from the *000webhost*, for the database storage, is free, although with a limit of disk usage up to 1 GB.

From the Table 5.4, it can be noticed that the developed integrated system provides a low-cost solution IoT for industrial washing machines, with prices varying around 8 to 9 €. Due to the number of functionalities and the reliability performed from the tests analysis, it makes the product a very interesting solution for the measurement level.

Items	**Quantity**	**Price (€)**
ESP32 Development Kit v1	1	3.54
US-015 Ultrasonic Sensor	1	0.52
DC-DC Boost Converter 3 V to 5 V	1	0.61
03962A Li-Ion Battery Charger	1	0.16
LIR18650 2600 mAh	1	3.50
Battery Case Holder	1	0.52
Total	-	**8.85**

Table 5.4: Price table of the electronic components used. *Prices based on Aliexpress and eBay (October, 2019).*

The advantages of having a low-cost device is the scalability, as its application can be transferred for others reservoirs, making the production more flexible. Also, it will improve the efficiency of the productive process, as it can be add actuators that can pump the liquid from spare reservoirs when a low level of capacity is detected. This IoT Ecosystem is illustrated in Figure 5.9, where all the reservoirs are connected with the device developed, and all the information may be accessed through different platforms.

Figure 5.9: IoT Ecosystem for Industrial Washing Machines.

Chapter 6

Conclusions and Future Work

The concepts of the Industry 4.0 comprises the idea of making the production more flexible, by using cutting edge technologies in order to maintain the competitive business environment. In the field of laundry industry, the necessity to ensure an effective logistics is essential to keep the quality and productivity of the service. In this context, the present work developed an solution based on IoT to be applied in industrial washing machines. The developed integrated system demonstrated to be capable of monitoring and recording the detergent liquid level in a web database, allowing the laundries management to access the measurement results through a web platform.

To implement the system in the reservoirs, the printed device model evidenced to be efficient, as it provides a good positioning, for the ultrasonic sensor, to take the readings from the detergent liquid surface. Furthermore, it performs a very simply and compact solution, as it allows the measurements to be collected without being necessary to make modifications on the reservoir's structure, making it an attractive differential for the adopted solution. The analysis results from the measurements indicated that the use of low-cost ultrasonic sensor is very appropriate for this application, as the failed readings could be treaties, with the use of an embedded system, providing very good accuracy of the measurements. Also, the developed device proved promising to be used for reservoirs with heights up to 400 cm. For the web database connection, the use of PHP APIs demonstrated to be efficient, being able to read large amounts of data from the database without compromising the user experience, however, security threats may be a problem due to the none use of authentication and lack of encryption. Finally, the use of AJAX technique provides a wealth combination with the IoT solution adopted, enabling the Web document to be dynamically displayed through the DHTML web pages.

In general, there are several ways to perform level measurements and it represents an important indicator for process control. The use of direct methods may be simpler than the indirect ones, however, it may not be suitable for automated control. The non-contact level measurement using ultrasonic sensor, embedded alongside with a microcontroller, demonstrated to be affordable as a part of IoT solution for industrial washing machines. Besides the detergent liquid level, the solution developed here may be applied for others liquids, since it does not have dynamic changes.

For the future works, it is expected the system to be implemented, in the laundry facilities of the SCMB, with the objective to be tested others parameters, especially regarding the durability of the developed device, i.e., to check if the environment is damaging, in the course of time, the electronic components and/or the PLA material. Moreover, another important criterion is the implementation of API protection, such as REST and SOAP, which must be developed for the work advancement.

Bibliography

[1] M. Brettel, N. Friederichsen, M. Keller, and M. Rosenberg, "How virtualization, decentralization and network building change the manufacturing landscape: An industry 4.0 perspective", *International Journal of Mechanical, Industrial and Aerospace Sciences*, vol. 7, no. 1, Nov. 2014. DOI: 10.5281/zenodo.1336426. [Online]. Available: http://doi.org/10.5281/zenodo.1336426.

[2] J. Lee, H.-A. Kao, and S. Yang, "Service innovation and smart analytics for industry 4.0 and big data environment", *Procedia CIRP*, vol. 16, pp. 3–8, 2014. [Online]. Available: https://doi.org/10.1016/j.procir.2014.02.001.

[3] F. Almada-Lobo, "The industry 4.0 revolution and the future of manufacturing execution systems (mes)", *Journal of Innovation Management*, vol. 3, pp. 16–21, Jan. 2016. DOI: 10.24840/2183-0606_003.004_0003.

[4] TechAmerica Foundation's Federal Big Data Commission, "Demystifying big data: A practical guide to transforming the business of government", 2012.

[5] A. Lazzari, J. Pou, C. Dubois, and L. Leblond, "Smart metrology: The importance of metrology of decisions in the big data era", *IEEE Instrumentation Measurement Magazine*, vol. 20, no. 6, pp. 22–29, Dec. 2017, ISSN: 1094-6969. DOI: 10.1109/MIM.2017.8121947.

[6] A. E. Branch, "Global supply chain management and international logistics", 2008.

[7] Hsuen-Feng Chang, Chia-Pao Chang, Wen-Tsann Lin, and You Goung Li, "A study of application of assessment modes in development of smart automatic production

systems in industry 4.0", in *2016 International Conference on Fuzzy Theory and Its Applications (iFuzzy)*, Nov. 2016, pp. 1–8. DOI: 10.1109/iFUZZY.2016.8004967.

[8] D. Cemernek, H. Gursch, and R. Kern, "Big data as a promoter of industry 4.0: Lessons of the semiconductor industry", in *2017 IEEE 15th International Conference on Industrial Informatics (INDIN)*, Jul. 2017, pp. 239–244. DOI: 10.1109/INDIN.2017.8104778.

[9] R. Minerva, A. Biru, and D. Rotondi, "Towards a definition of the internet of things (iot)", 2015.

[10] J. Sen, S. Lee, Y. Choe, M. Lee, M. Domb, A. Pal, H. K. Rath, S. Shailendra, A. Bhattacharyya, A. Mihovska, M. Sarkar, H. Lee, M. Kim, and A. Averian, *Internet of things: Technology, applications and standardization*. Aug. 2018, ISBN: 978-1-78923-549-4. DOI: 10.5772/intechopen.70907.

[11] K. A. Eldrandaly, M. Abdel-Basset, and L. A. Shawky, "Internet of spatial things: A new reference model with insight analysis", *IEEE Access*, vol. 7, pp. 19 653–19 669, 2019, ISSN: 2169-3536. DOI: 10.1109/ACCESS.2019.2897012.

[12] J. H. Nord, A. Koohang, and J. Paliszkiewicz, "The internet of things: Review and theoretical framework", *Expert Systems with Applications*, vol. 133, pp. 97–108, 2019, ISSN: 0957-4174. DOI: https://doi.org/10.1016/j.eswa.2019.05.014. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0957417419303331.

[13] S. Narang, T. Nalwa, T. Choudhury, and N. Kashyap, "An efficient method for security measurement in internet of things", in *2018 International Conference on Communication, Computing and Internet of Things (IC3IoT)*, Feb. 2018, pp. 319–323. DOI: 10.1109/IC3IoT.2018.8668159.

[14] O. Mavropoulos, H. Mouratidis, A. Fish, and E. Panaousis, "Apparatus: A framework for security analysis in internet of things systems", *Ad Hoc Networks*, vol. 92, p. 101 743, 2019, Special Issue on Security of IoT-enabled Infrastructures in Smart

Cities, ISSN: 1570-8705. DOI: https://doi.org/10.1016/j.adhoc.2018.08.013. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1570870518305936.

[15] M. Asif-Ur-Rahman, F. Afsana, M. Mahmud, M. S. Kaiser, M. R. Ahmed, O. Kaiwartya, and A. James-Taylor, "Toward a heterogeneous mist, fog, and cloud-based framework for the internet of healthcare things", *IEEE Internet of Things Journal*, vol. 6, no. 3, pp. 4049–4062, Jun. 2019, ISSN: 2327-4662. DOI: 10.1109/JIOT.2018.2876088.

[16] C. Dong, G. He, X. Liu, Y. Yang, and W. Guo, "A multi-layer hardware trojan protection framework for iot chips", *IEEE Access*, vol. 7, pp. 23 628–23 639, 2019, ISSN: 2169-3536. DOI: 10.1109/ACCESS.2019.2896479.

[17] A. Tewari and B. Gupta, "Security, privacy and trust of different layers in internet-of-things (iots) framework", *Future Generation Computer Systems*, 2018, ISSN: 0167-739X. DOI: https://doi.org/10.1016/j.future.2018.04.027. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0167739X17321003.

[18] S. Ziegler, "Considerations on ipv6 scalability for the internet of things — towards an intergalactic internet", in *2017 Global Internet of Things Summit (GIoTS)*, Jun. 2017, pp. 1–4. DOI: 10.1109/GIOTS.2017.8016238.

[19] J. K. Hart and K. Martinez, "Toward an environmental internet of things", *Earth and Space Science*, vol. 2, no. 5, pp. 194–200, 2015. DOI: 10.1002/2014EA000044. eprint: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1002/2014EA000044. [Online]. Available: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1002/2014EA000044.

[20] S. N. Swamy, D. Jadhav, and N. Kulkarni, "Security threats in the application layer in iot applications", in *2017 International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC)*, Feb. 2017, pp. 477–480. DOI: 10.1109/I-SMAC.2017.8058395.

[21] M. AlOtaibi, L. A. Tawalbeh, and Y. Jararweh, "Integrated sensors system based on iot and mobile cloud computing", in *2016 IEEE/ACS 13th International Conference of Computer Systems and Applications (AICCSA)*, Nov. 2016, pp. 1–5. DOI: 10.1109/AICCSA.2016.7945812.

[22] T. Turc, "Ajax technology for internet of things", *Procedia Manufacturing*, vol. 32, pp. 613–618, 2019, 12th International Conference Interdisciplinarity in Engineering, INTER-ENG 2018, 4–5 October 2018, Tirgu Mures, Romania, ISSN: 2351-9789. DOI: https://doi.org/10.1016/j.promfg.2019.02.260. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S2351978919302951.

[23] *Web development*, techopedia.com, 2019.

[24] R. S. Aggarwal, ""is iot affecting the future of web development? let's see how"", Jul. 2019.

[25] *"iot developer survey 2019"*, Apr. 2019. [Online]. Available: iot.eclipse.org.

[26] D. O. J. deSá, *Instrumentation fundamentals for process control*. Jul. 2001.

[27] W. Bolton, *Instrumentation and control systems*. Jun. 2004.

[28] K. Loizou and E. ibits a much lower manufacturing cost., "Water level sensing: State of the art review and performance evaluation of a low-cost measurement system", *Measurement*, vol. 89, pp. 204–214, 2016, ISSN: 0263-2241. DOI: https://doi.org/10.1016/j.measurement.2016.04.019. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0263224116300768.

[29] K. Loizou, E. Koutroulis, D. Zalikas, and G. Liontas, "A low-cost capacitive sensor for water level monitoring in large-scale storage tanks", in *2015 IEEE International Conference on Industrial Technology (ICIT)*, Mar. 2015, pp. 1416–1421. DOI: 10.1109/ICIT.2015.7125295.

[30] S. Wang, C. Chen, C. Wu, and C. Huang, "A continuous water-level sensor based on load cell and floating pipe", in *2018 IEEE International Conference on Applied System Invention (ICASI)*, Apr. 2018, pp. 151–154. DOI: 10.1109/ICASI.2018.8394554.

[31] M. Vogt, "Radar sensors (24 and 80 ghz range) for level measurement in industrial processes", in *2018 IEEE MTT-S International Conference on Microwaves for Intelligent Mobility (ICMIM)*, Apr. 2018, pp. 1–4. DOI: 10.1109/ICMIM.2018.8443505.

[32] Synacorp. Datasheet, *US-015 High Accuracy Ultrasonic Sensor*, US-015 Datasheet.

[33] F. Longbottom and H. Eren, "Ultrasonic multiple-sensor solid level measurements", in *Conference Proceedings. 10th Anniversary. IMTC/94. Advanced Technologies in I M. 1994 IEEE Instrumentation and Measurement Technolgy Conference (Cat. No.94CH3424-9)*, May 1994, 749–752 vol.2. DOI: 10.1109/IMTC.1994.351992.

[34] M. Meribout, M. Habli, A. Al-Naamany, and K. Al-Busaidi, "A new ultrasonic-based device for accurate measurement of oil, emulsion, and water levels in oil tanks", in *Proceedings of the 21st IEEE Instrumentation and Measurement Technology Conference (IEEE Cat. No.04CH37510)*, vol. 3, May 2004, 1942–1947 Vol.3. DOI: 10.1109/IMTC.2004.1351467.

[35] D. W. Lee, H. C. No, and C.-H. Song, "Measurement of two-phase mixture level using an ultrasonic method", *Experimental Thermal and Fluid Science*, vol. 29, no. 5, pp. 609–614, 2005, ISSN: 0894-1777. DOI: https://doi.org/10.1016/j.expthermflusci.2004.07.003. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0894177704001001.

[36] Lei Chen, Xinmin Dong, Jie Han, and Ping Ye, "Development of a ultrasonic instrument for the sealed container's liquid level measurement", in *2006 6th World Congress on Intelligent Control and Automation*, vol. 1, Jun. 2006, pp. 4972–4976. DOI: 10.1109/WCICA.2006.1713333.

[37] N. S. C. Ingaroca, J. M. M. Villanueva, S. Y. C. Catunda, J. L. G. Santiago, and C. E. T. Vargas, "Multilayer measuring system and uncertainty analysis using ultrasonic sensors with wavelet transform", in *2011 IEEE International Instrumentation and Measurement Technology Conference*, May 2011, pp. 1–6. DOI: 10.1109/IMTC.2011.5944308.

[38] K. N. D. Grassi, R. C. S. Freire, and J. M. M. Villanueva, "Evaluation of wavelet analysis performance in multiphase level measurement using ultrasonic sensors", in *2014 IEEE International Instrumentation and Measurement Technology Conference (I2MTC) Proceedings*, May 2014, pp. 756–760. DOI: 10.1109/I2MTC.2014.6860844.

[39] P. Li, Y. Cai, X. Shen, S. Nabuzaale, J. Yin, and J. Li, "An accurate detection for dynamic liquid level based on mimo ultrasonic transducer array", *IEEE Transactions on Instrumentation and Measurement*, vol. 64, no. 3, pp. 582–595, Mar. 2015. DOI: 10.1109/TIM.2014.2357586.

[40] A. Rocchi, E. Santecchia, F. Ciciulla, P. Mengucci, and G. Barucca, "Characterization and optimization of level measurement by an ultrasonic sensor system", *IEEE Sensors Journal*, vol. 19, no. 8, pp. 3077–3084, Apr. 2019. DOI: 10.1109/JSEN.2018.2890568.

[41] A. E. Powles, D. J. Martin, I. T. Wells, and C. R. Goodwin, "Physics of ultrasound", *Anaesthesia and Intensive Care Medicine*, vol. 19, no. 4, pp. 202–205, 2018, ISSN: 1472-0299. DOI: https://doi.org/10.1016/j.mpaic.2018.01.005. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1472029918300171.

[42] D. Ensminger and L. J. Bond, *Ultrasonics: Fundamentals, technologies, and applications*, 3rd ed., C. Press, Ed. Sep. 2011.

[43] Murata. Catalog, *Ultrasonic Sensor, S15E-5*, Application Manual, Oct. 2008.

[44] V. Zhmud, N. Kondratiev, K. Kuznetsov, V. Trubin, and L. Dimitrov, “Application of ultrasonic sensor for measuring distances in robotics”, *Journal of Physics: Conference Series*, vol. 1015, p. 032 189, May 2018. DOI: 10.1088/1742-6596/1015/3/032189.

[45] A. Carullo and M. Parvis, “An ultrasonic sensor for distance measurement in automotive applications”, *Sensors Journal, IEEE*, vol. 1, pp. 143–147, Sep. 2001. DOI: 10.1109/JSEN.2001.936931.

[46] S. K. Chaulya, *Sensing and monitoring technologies for mines and hazardous areas : Monitoring and prediciton technologies*. Amsterdam, Netherlands: Elsevier, 2016, ISBN: 9780128031957.

[47] J. Peckol, *Embedded systems : A contemporary design tool*. Hoboken, NJ: John Wiley, 2008, ISBN: 978-0-471-72180-2.

[48] D. Nisolosi, *Microcontrolador 8051 : Detalhado*. São Paulo: Editora Érica, 2009, ISBN: 85-7194-721-X.

[49] A. Kurniawan, *Internet of things projects with esp32: Build exiting and powerful iot projects using the all-new expresif esp32*, 1st ed., ser. 1290319. Packt Publishing, 2019, ISBN: 978-1-78995-687-0. [Online]. Available: http://gen.lib.rus.ec/book/index.php?md5=7F42216D1545D2EA2B5C48C01639D2CE.

[50] S. B. N. Ramez Elmasri, *Fundamentals of database systems*, 7th ed. Pearson, 2015, ISBN: 978-0133970777. [Online]. Available: http://gen.lib.rus.ec/book/index.php?md5=8E085025CA9A5D0C89FE0B8B364D8DF0.

[51] D. Squier, D. Mercer, A. Kent, S. Nowicki, C. Morgan, and W. Choi, *Beginning php5*, ser. Programmer to Programmer. Wrox, 2004, ISBN: 0764557831. [Online]. Available: http://gen.lib.rus.ec/book/index.php?md5=7EC202B49DD2338B37FF0F9BCBD911E1.

[52] T. Felke-Morris, *Web development and design foundations with html5*, 9th, ser. Web development and Design Foundations with HTML5. Pearson, 2019, ISBN:

0134801148. [Online]. Available: http://gen.lib.rus.ec/book/index.php?md5=ABBE6BB1F72365359788F83A643876E7.

[53] D. Flanagan, *Javascript: The definitive guide, 6th edition*, 6th. O'Reilly Media, 2011, ISBN: 0596805527. [Online]. Available: http://gen.lib.rus.ec/book/index.php?md5=FCF2EA6931E32073C1AE85EBBEA0B483.

[54] Espressif Systems. Datasheet, *ESP32 Series, Version 3.1*.

[55] ON. Datasheet, *1.0A Low-Dropout Positive Fixed and Adjustable Voltage Regulators, Rev. 29*, NCP1117 Datasheet, Jul. 2018.

[56] Espressif Systems. GitHub, *Arduino core for the esp32*. [Online]. Available: https://github.com/espressif/arduino-esp32.

[57] EEMB. Datasheet, *Lithium-ion Battery DATA SHEET*, Battery Model : LIR18650 2600mAh, Nov. 2010.

[58] M. K. G. (eds.), *Lithium-ion battery materials and engineering: Current topics and problems from the manufacturing perspective*, 1st ed., ser. Green Energy and Technology. Springer-Verlag London, 2014, ISBN: 978-1-4471-6547-7. [Online]. Available: http://gen.lib.rus.ec/book/index.php?md5=6686A1D3E7D3FEF06081351CDBED32E6.

[59] NanJing Top Power. Datasheet, *1A Standalone Linear Li-Ion Battery Charger*, TP4056 Datasheet.

[60] Fortune. Datasheet, *One Cell Lithium-ion/Polymer Battery Protection IC, Rev. 1.7*, DW01A DataSheet, May 2014.

[61] ——, *Dual N-Channel Enhancement Mode Power MOSFET, Rev. 1.2*, FS8205A DataSheet, Aug. 2009.

[62] G. G. Coelho, *Developed Codes for an IoT solution for detergent supervision in industrial washing machines*, version v1.0.0, Oct. 2019. DOI: 10.5281/zenodo.3516423. [Online]. Available: https://doi.org/10.5281/zenodo.3516423.

[63] V. S. Amos Gilat, *Numerical methods for engineers and scientists - an introduction with applications using matlab*, 3rd. Wiley, 2013, ISBN: 9781118554937. [Online]. Available: http://gen.lib.rus.ec/book/index.php?md5=C7CB214EB62807E955167BF60309F95B.

[64] J. N. (Auth.), *Metrologia e controle dimensional. conceitos, normas e aplicação.* 2012, ISBN: 978-85-352-5579-9. [Online]. Available: http://gen.lib.rus.ec/book/index.php?md5=4555FE2055CDC8AA79BFF9C98A54ABBA.

Appendix A

Publications

Paper Submitted and Awaiting for Evaluation

Coelho, G. G., Coelho, J. P., & Moretti, E. H. (2019). Development of an IoT Solution for Detergent Supervision in Industrial Washing Machines. *Carpathian Journal of Electronic and Computer Engineering, 12*(2).

Appendix B

Analysis of the System Measurement

In this appendix, it is demonstrated the results of the several tests performed during the experimental analysis, with the objective to have a better evaluation of the measurement system developed for the detergent supervision.

According to Table 5.1, the tests from Section B.1 desire to verify the behavior of the measurement system when trying different numbers of readings from the ultrasonic sensor.

Already, for the Section B.2, it is presented the experimental results of the measurements in order to verify the system's reliability. The range of values approached in this test are varied between 10 cm to 90 cm, in which represents the values of interest for the measurement system to operate.

Finally, the Section B.3 illustrates the result of the analysis of the temperature influence on the capacity level measured from the device.

B.1 Experimental Results

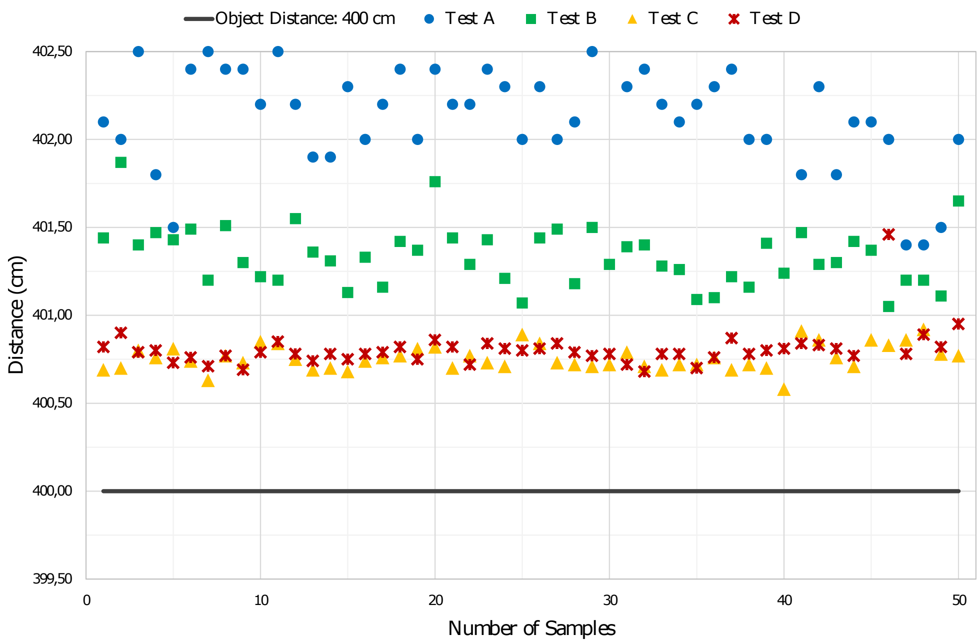


Figure B.1: Analysis #1; Object Distance: 400 cm.

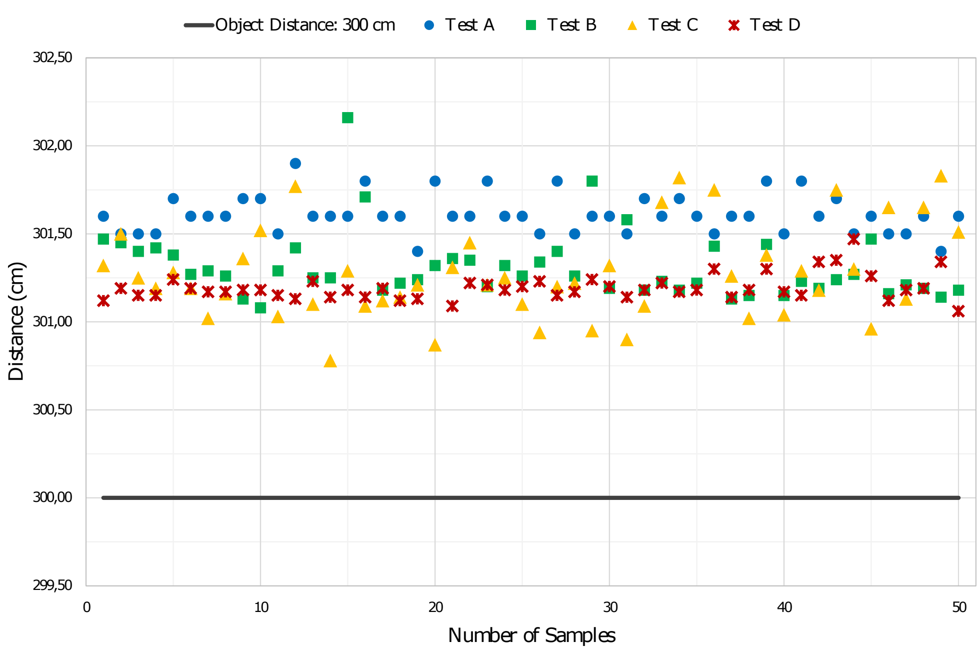


Figure B.2: Analysis #1; Object Distance: 300 cm.

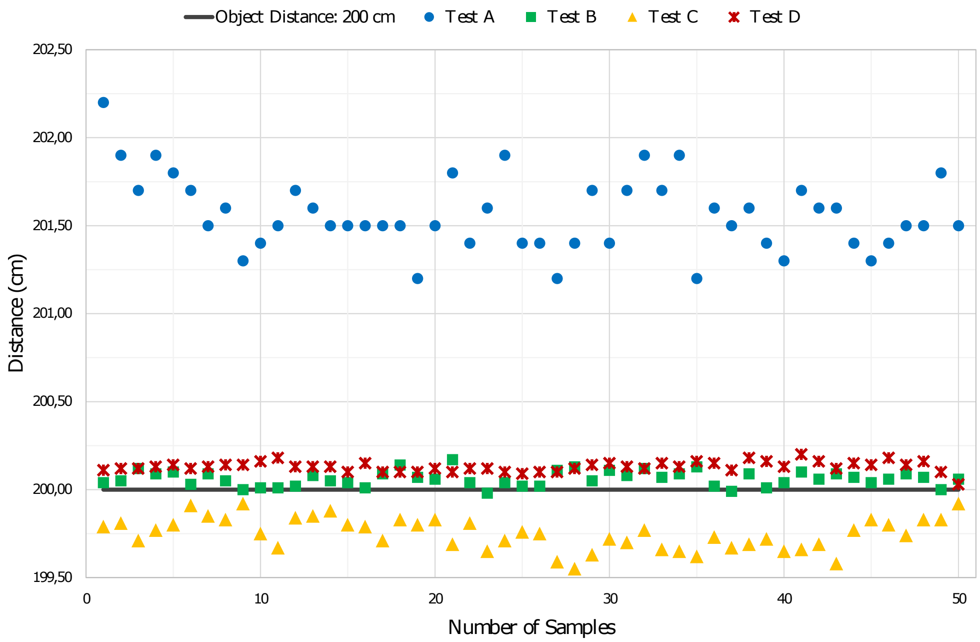


Figure B.3: Analysis #1; Object Distance: 200 cm.

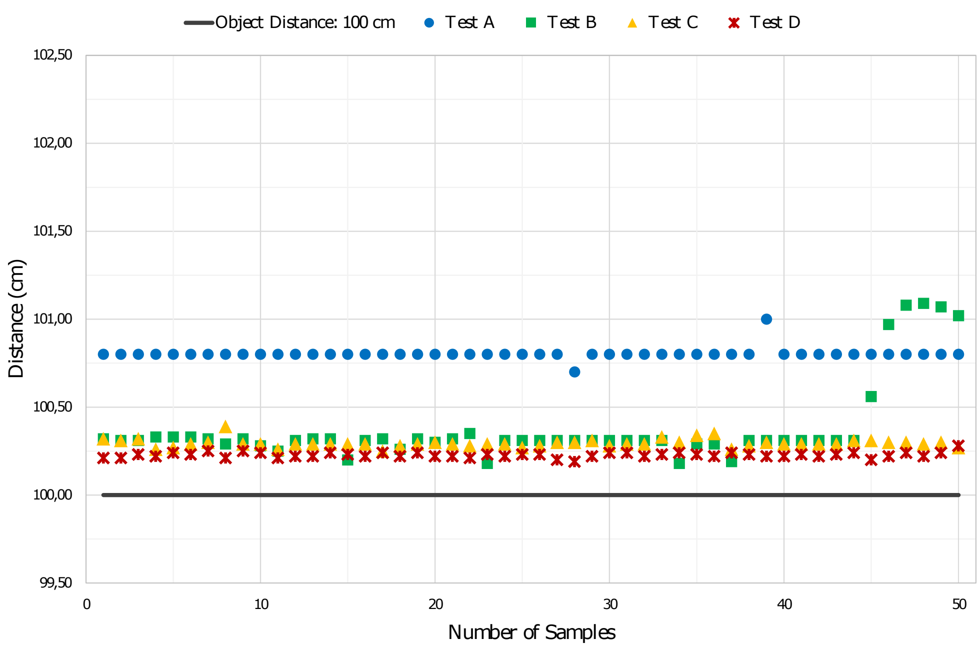


Figure B.4: Analysis #1; Object Distance: 100 cm.

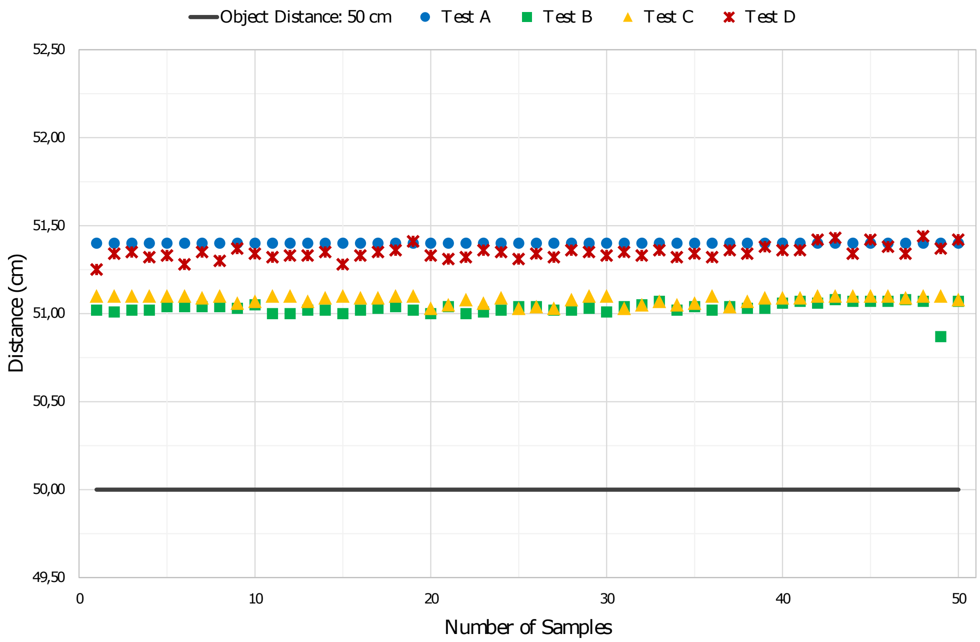


Figure B.5: Analysis #1; Object Distance: 50 cm.

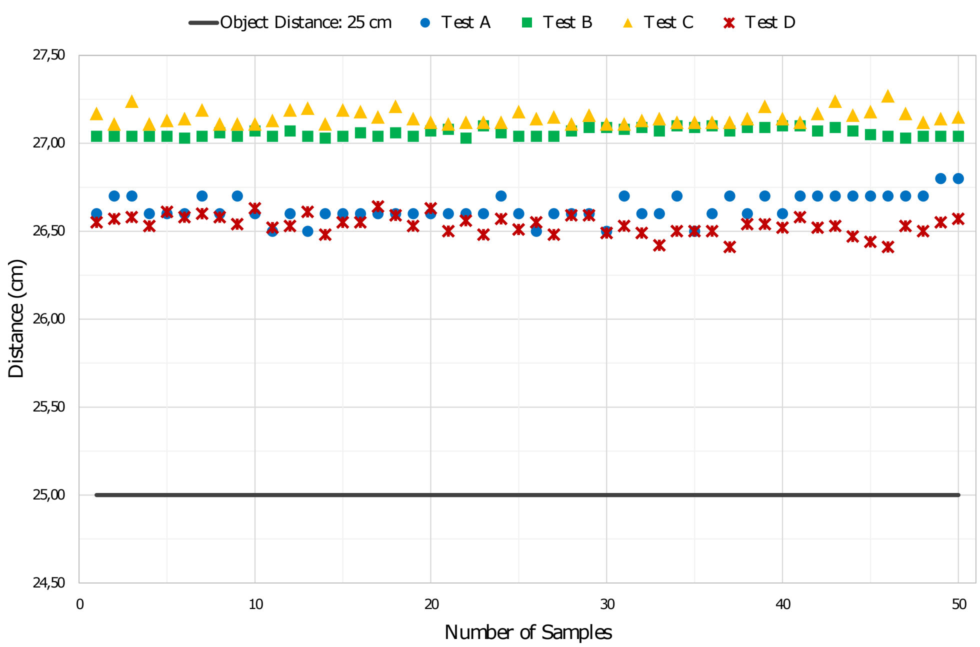


Figure B.6: Analysis #1; Object Distance: 25 cm.

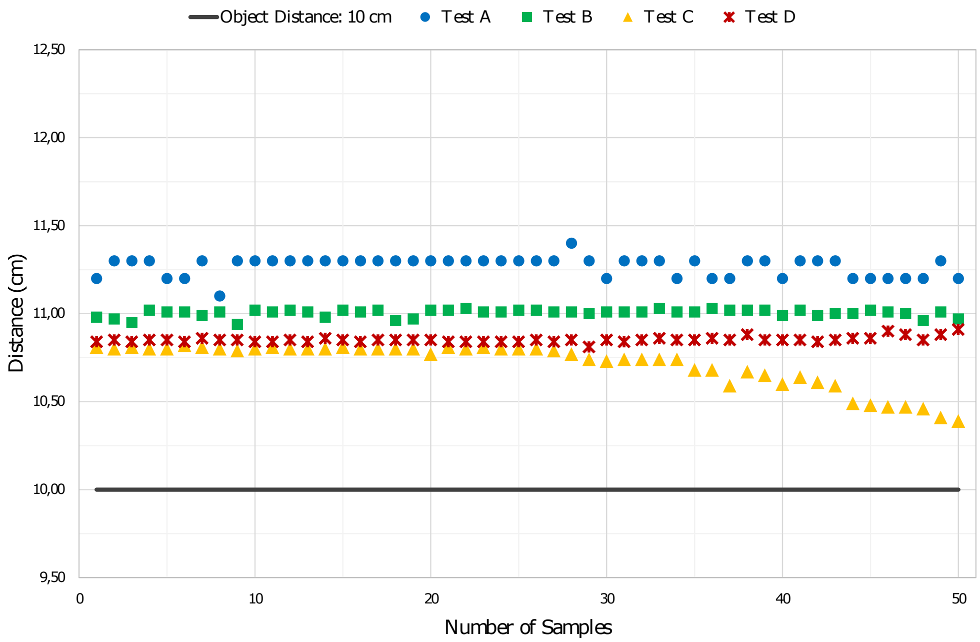


Figure B.7: Analysis #1; Object Distance: 10 cm.

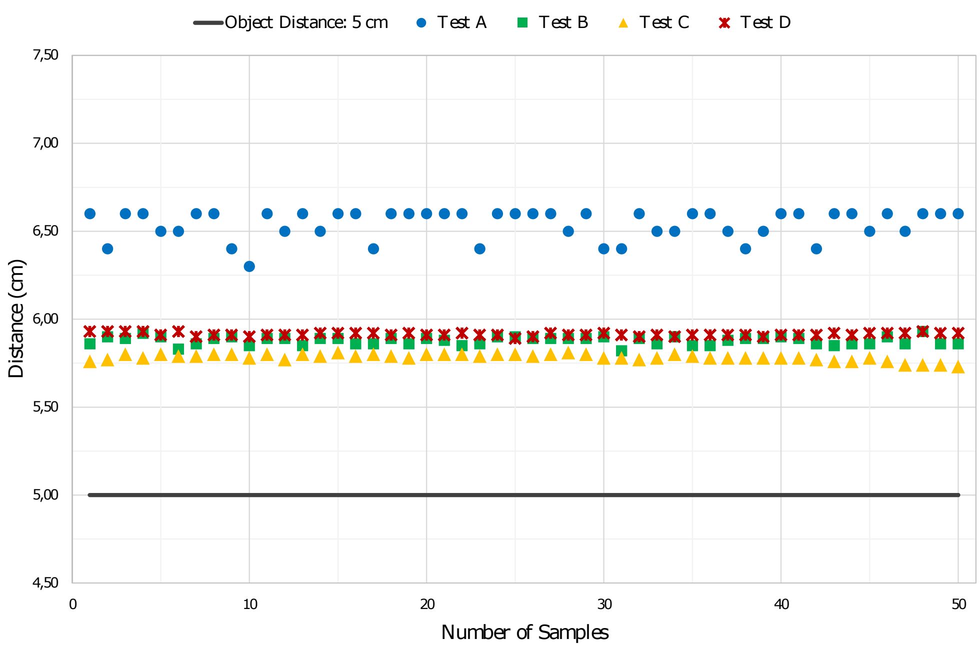


Figure B.8: Analysis #1; Object Distance: 5 cm.

B.2 System's Reliability

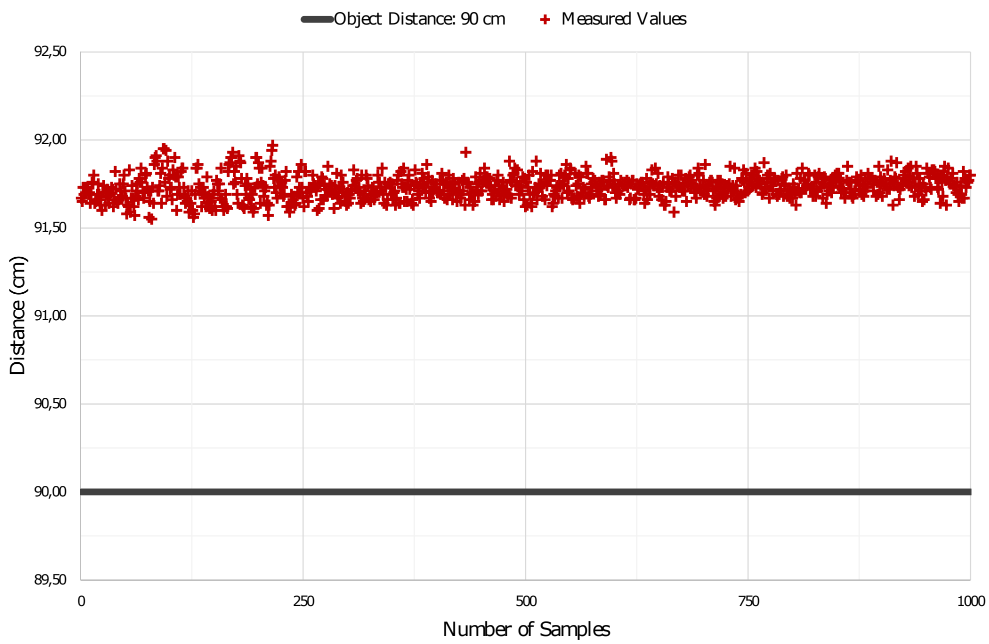


Figure B.9: Analysis #2; Object Distance: 90 cm.

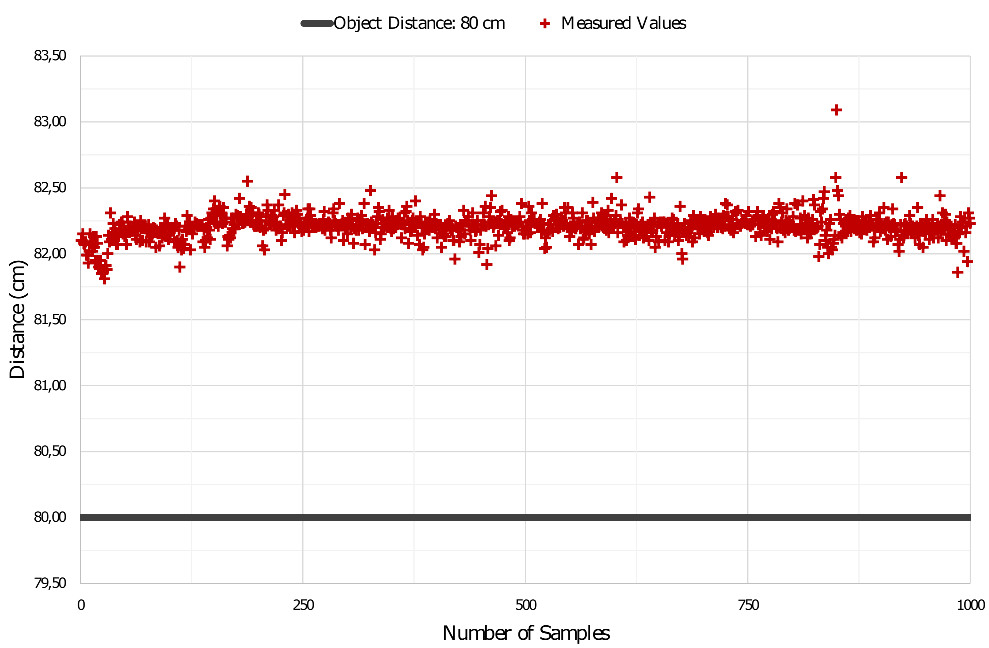


Figure B.10: Analysis #2; Object Distance: 80 cm.

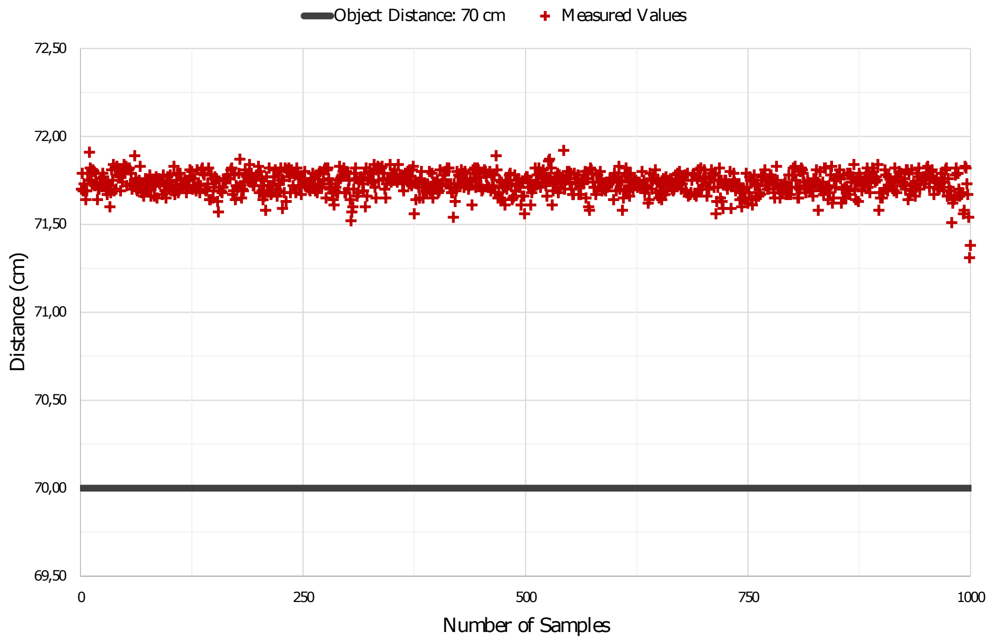


Figure B.11: Analysis #2; Object Distance: 70 cm.

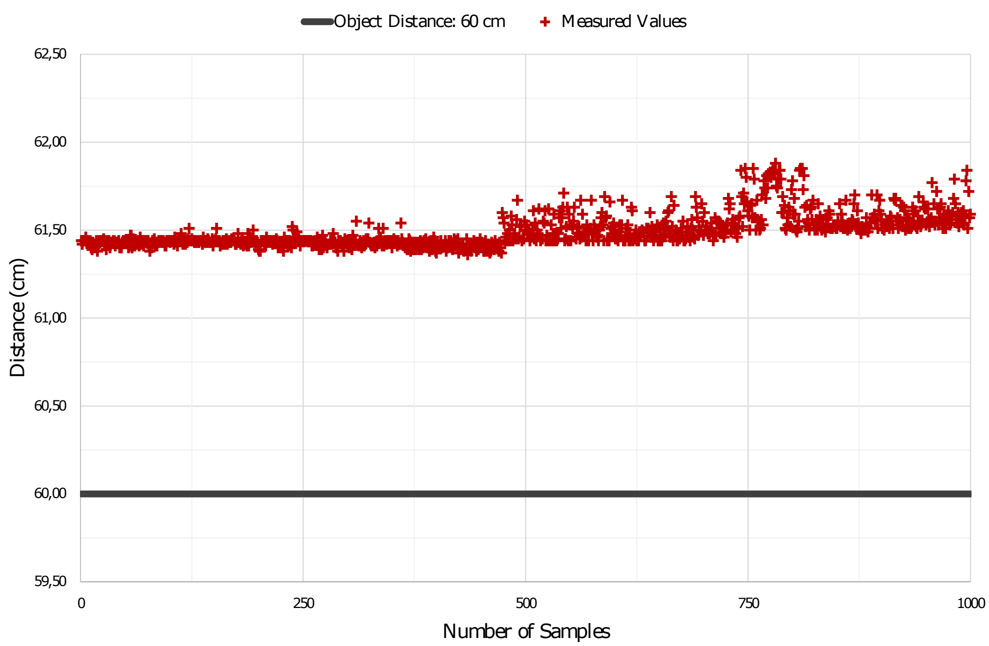


Figure B.12: Analysis #2; Object Distance: 60 cm.

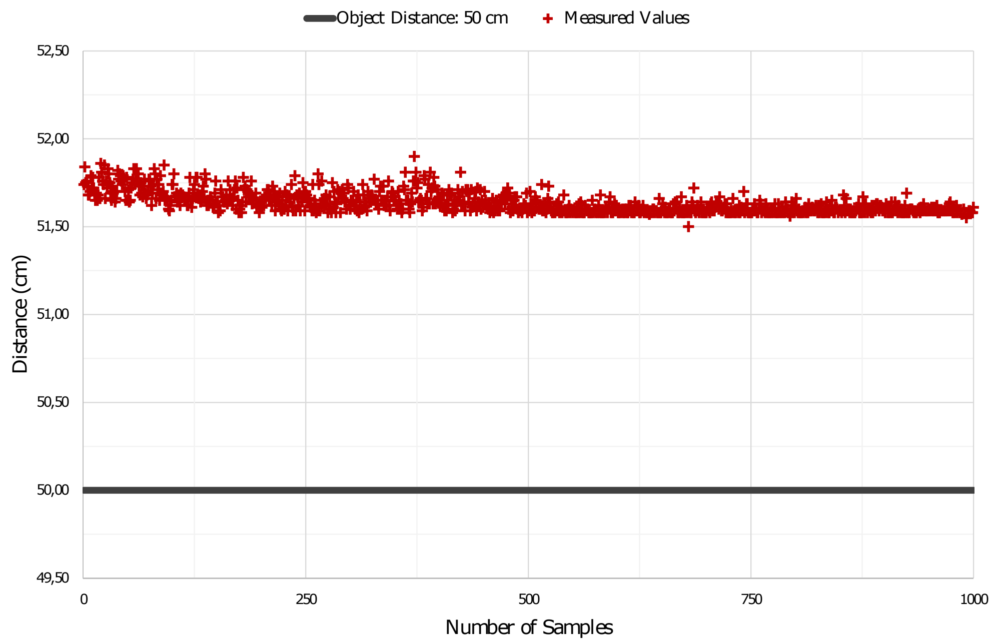


Figure B.13: Analysis #2; Object Distance: 50 cm.

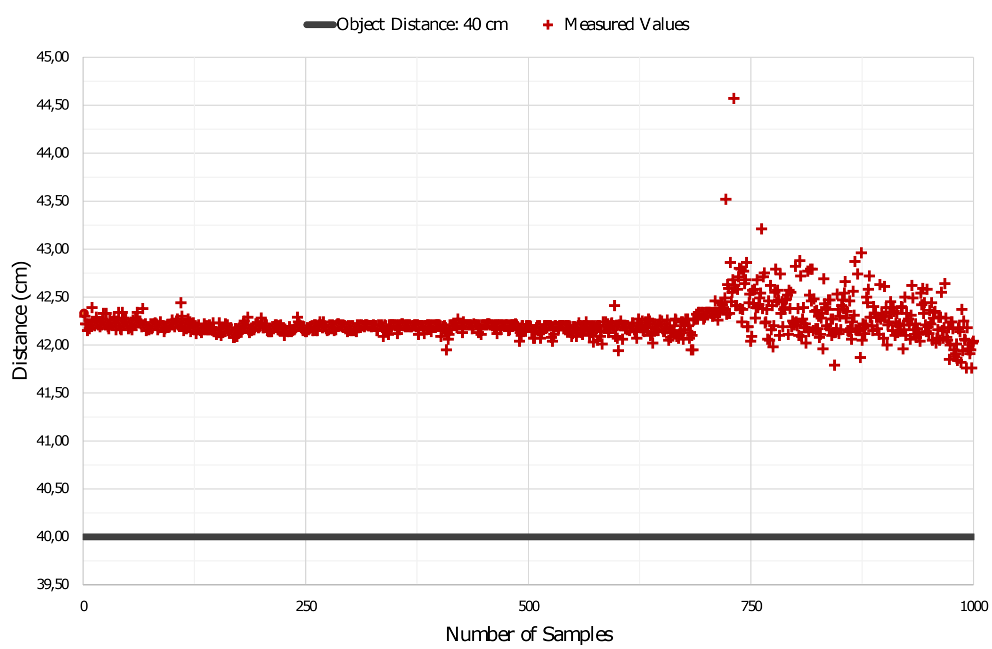


Figure B.14: Analysis #2; Object Distance: 40 cm.

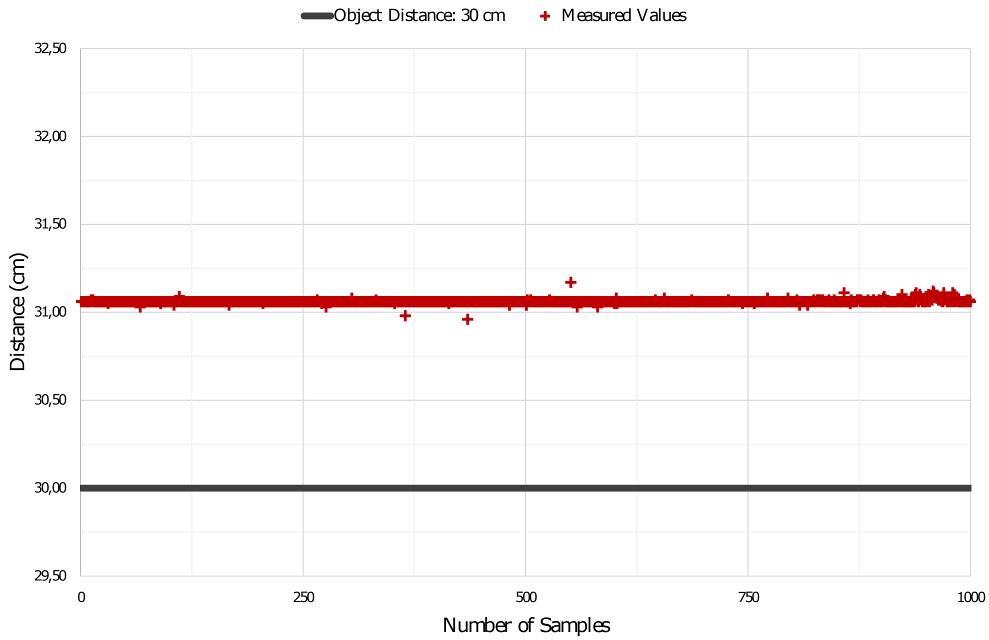


Figure B.15: Analysis #2; Object Distance: 30 cm.

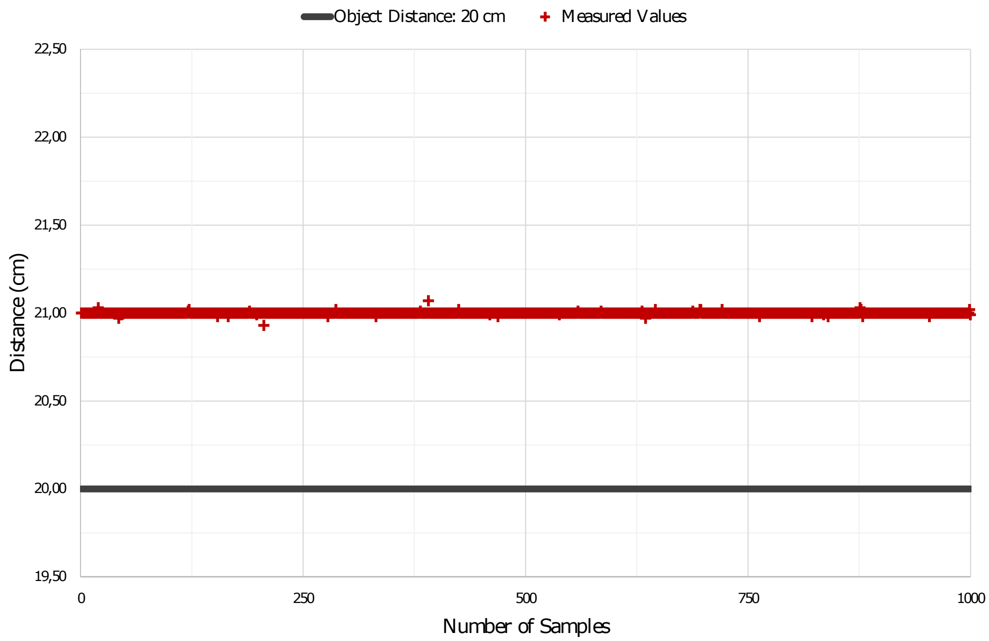


Figure B.16: Analysis #2; Object Distance: 20 cm.

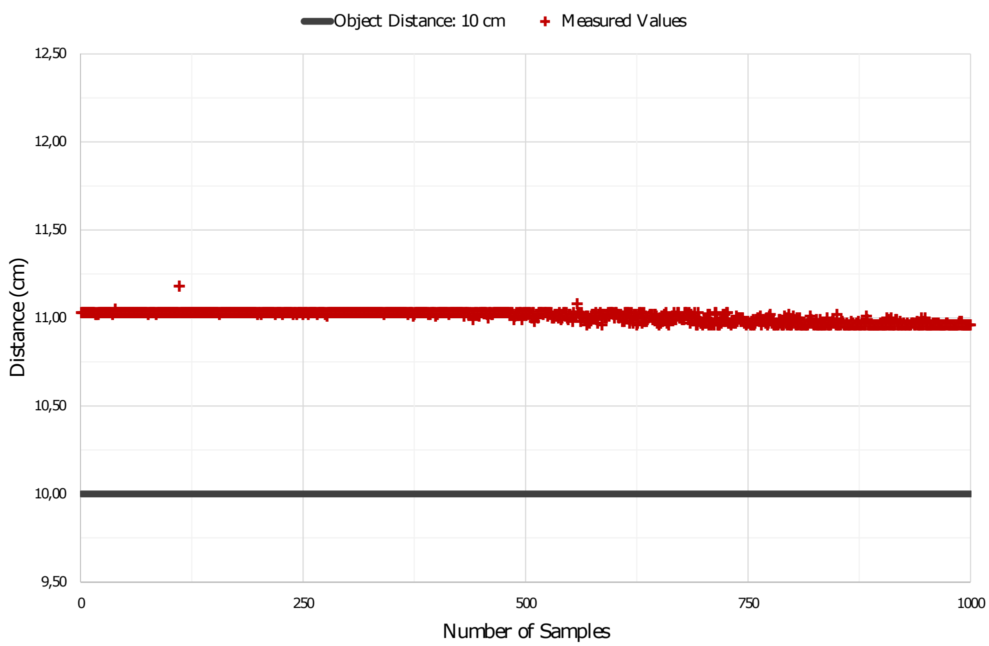


Figure B.17: Analysis #2; Object Distance: 10 cm.

B.3 Temperature Influence

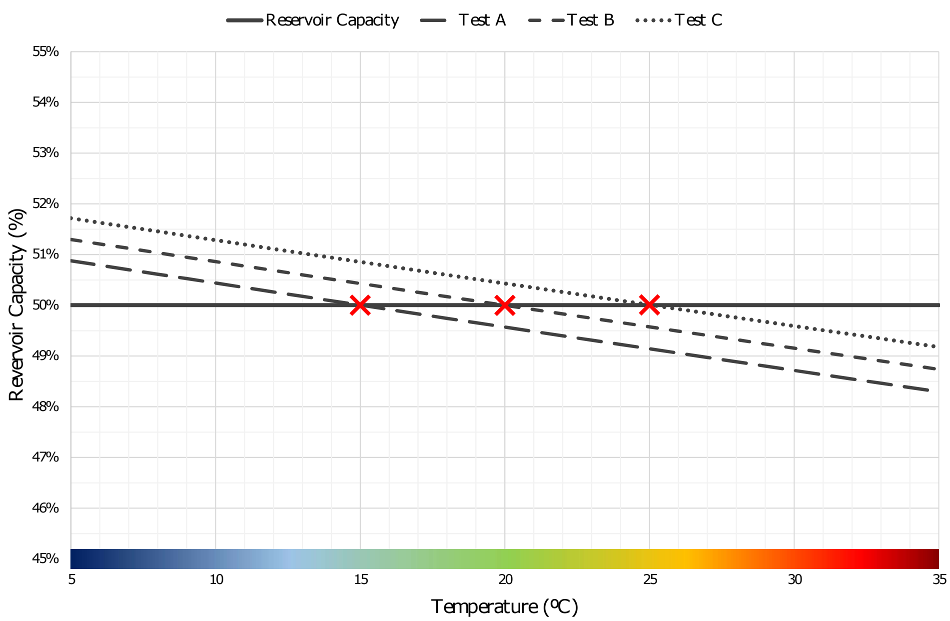


Figure B.18: Reservoir Capacity: 50 %; Test A: 15°C; Test B: 20°C; Test C: 25°C.

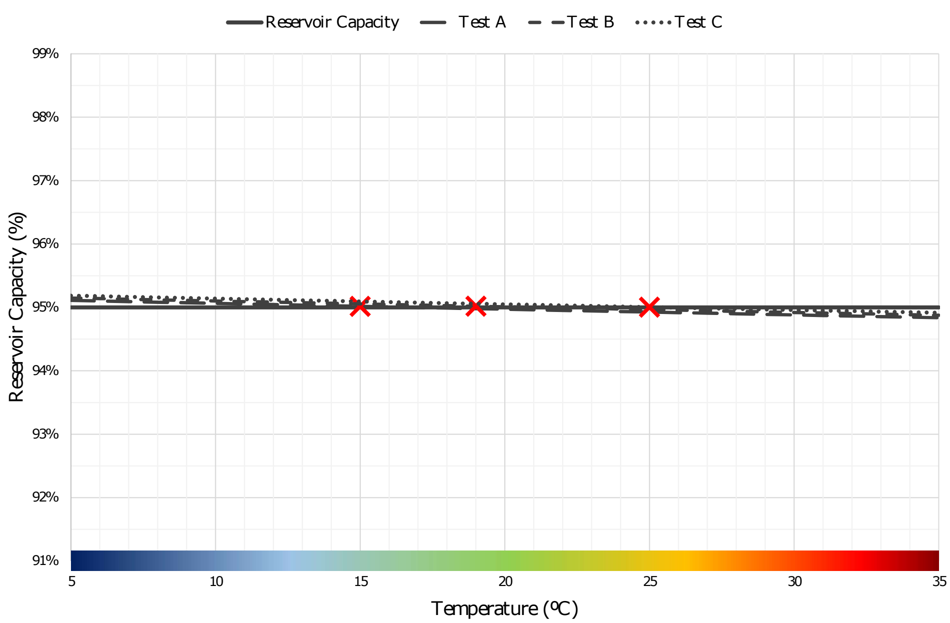


Figure B.19: Reservoir Capacity: 95 %; Test A: 15°C; Test B: 20°C; Test C: 25°C.

Appendix C

Summary of the Technical Drawings and Developed Codes

In this appendix, the Section C.1 illustrate the technical drawings regarding the development of the 3D device through the SolidWorks software.

Already, for the section C.2, it provides the link for the GitHub, where the user can find the documents developed. The files are divided as follows:

- The *api* file contain all the Appication Program Interface developed using PHP programming language.
- Already for the *application* file, it gives the access to the Front End application, where can be found the HTML/CSS and JavaScript codes.
- In *esp32_code* file, it is found the code structure developed using Arduino IDE in C programming language.

C.1 Technical Drawings

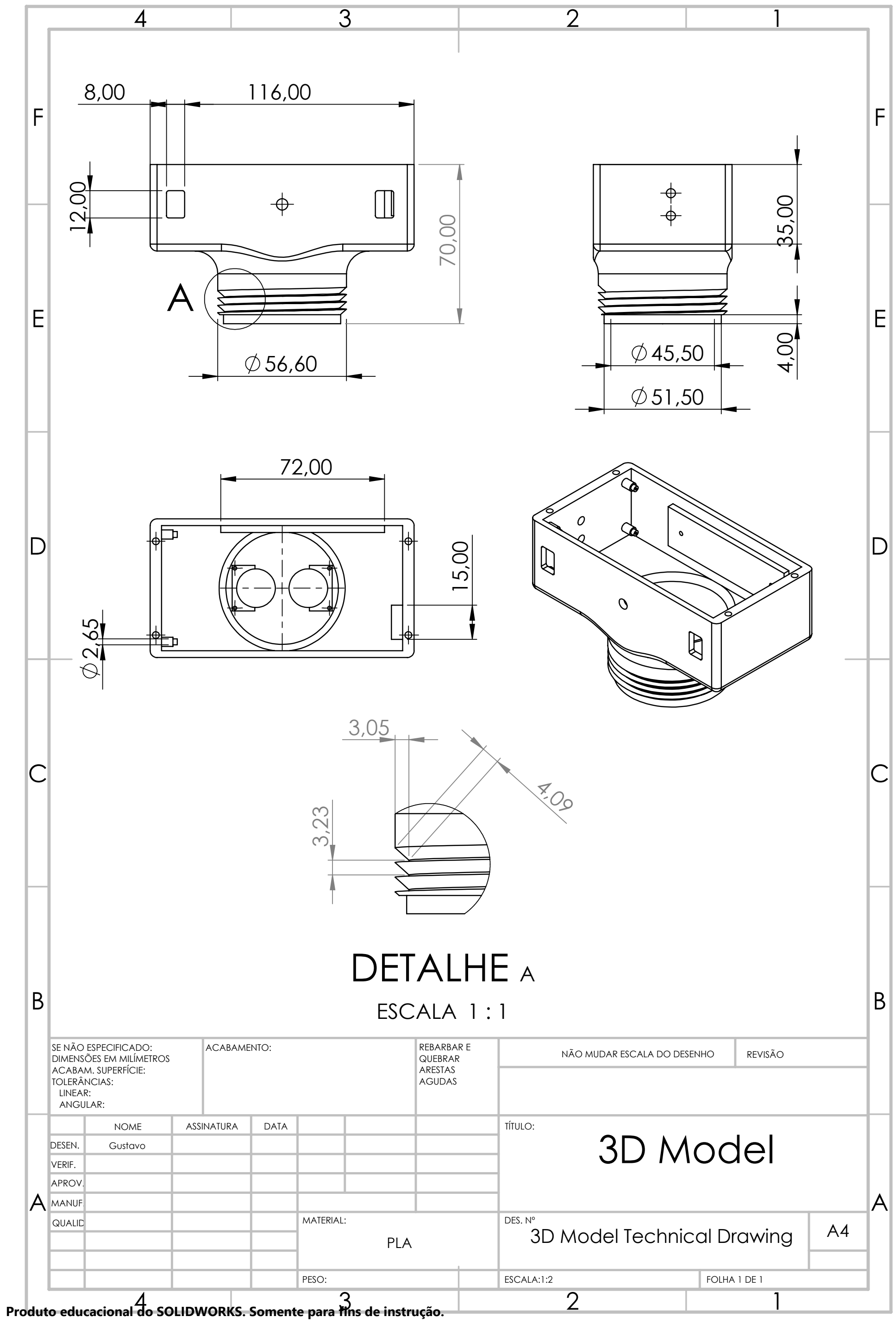


Figure C.1: Technical drawing of the 3D printed model.

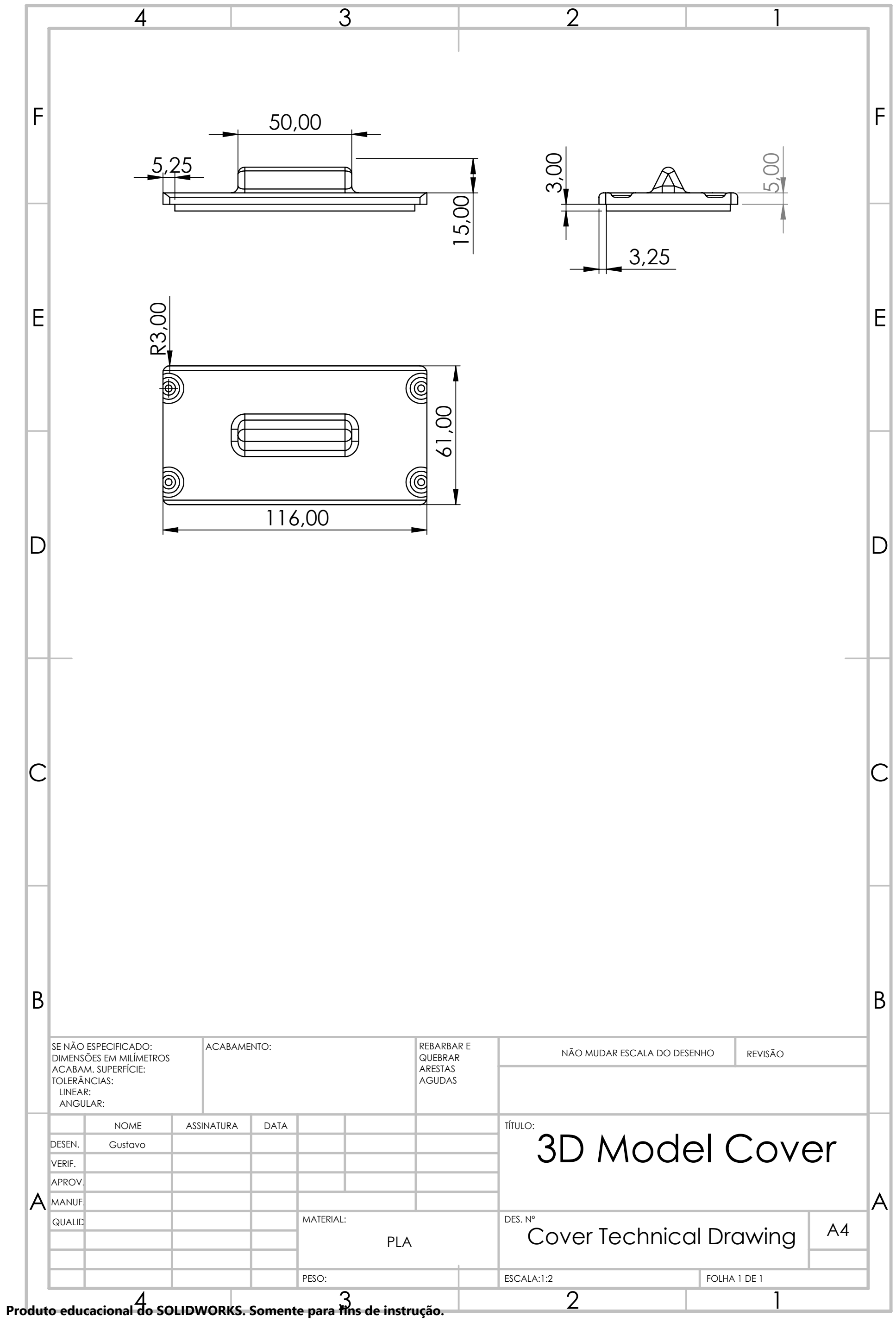


Figure C.2: Technical drawing of the 3D printed cover model.

C.2 Developed Codes

Link for GitHub, where can be found the files with the codes applied:

`https://github.com/gustavogoncalvescoelho/`
`IoT-Solution-For-Industrial-Washing-Machines`