UNIVERSIDADE DO VALE DO ITAJAÍ
CURSO DE MESTRADO EM COMPUTAÇÃO APLICADA

Klaus Dieter Kupper

A Comparative Study of Low-Cost LiDAR and Ultrasonic Sensors for Water Level Gauging using LoRa Technology in Regional River Basins

Itajaí
2025

Klaus Dieter Kupper

A Comparative Study of Low-Cost LiDAR and Ultrasonic Sensors for Water Level Gauging using LoRa Technology in Regional River Basins

Trabalho de Conclusão de Curso de Mestrado em Computação Aplicada da Universidade do Vale do Itajaí como requisito para a obtenção do título de Masters in Applied Computing.
Supervisor:: Prof. Dr. Jordan Sausen

Itajaí
2025

Ficha de identificação da obra elaborada pelo autor,
através do Programa de Geração Automática da Biblioteca Universitária da UFSC.

Kupper, Klaus Dieter
Estudo e Implementação de um Sistema Web para Vendas e Pagamentos / Klaus Dieter Kupper ; orientador, Carlos Roberto Moratelli, 2023.
52 p.

Trabalho de Conclusão de Curso (graduação) - Universidade Federal de Santa Catarina, Campus Blumenau, Graduação em Engenharia de Controle e Automação, Blumenau, 2023.

Inclui referências.

1. Engenharia de Controle e Automação. 2. Internet of Things. 3. Automação de Pedidos. 4. Desenvolvimento Web. 5. Sockets. I. Moratelli, Carlos Roberto. II. Universidade Federal de Santa Catarina. Graduação em Engenharia de Controle e Automação. III. Título.

Klaus Dieter Kupper

A Comparative Study of Low-Cost LiDAR and Ultrasonic Sensors for Water Level Gauging using LoRa Technology in Regional River Basins

Este Trabalho de Conclusão de Curso foi julgado adequado para obtenção do Título de “Masters in Applied Computing” e aprovado em sua forma final pelo Curso de Graduação em Engenharia de Controle e Automação.

Itajaí, 10 de July de 2025.

Banca Examinadora:

Prof. Dr. Carlos Roberto Moratelli
Universidade Federal de Santa Catarina

Prof. Dr. Jordan Sausen
Universidade Federal de Santa Catarina

Prof. Dr. Ciro André Pitz
Universidade Federal de Santa Catarina

Este trabalho é dedicado aos meus colegas de classe, a
minha namorada e aos meus queridos pais.

ACKNOWLEDGEMENTS

Gostaria de expressar minha profunda gratidão ao meu professor orientador, pela sua orientação acadêmica e apoio ao longo deste trabalho. Suas orientações sábias e paciência foram fundamentais para o seu desenvolvimento.

A todos os professores que tive ao longo da minha jornada acadêmica, sou imensamente grato. Cada aula, conselho e palavra contribuíram para o meu crescimento pessoal e profissional. Em especial, agradeço por terem despertado em mim o interesse pela engenharia e tecnologia, que hoje são a minha paixão e a área em que atuo.

Agradeço também aos meus pais, cujo amor, apoio incondicional e crença em mim foram essenciais para que eu chegasse até aqui. Vocês foram minha inspiração e força motriz em todos os momentos desafiadores.

Aos meus colegas, expresso minha gratidão pelo apoio, compreensão e companheirismo ao longo dessa jornada. Nossos momentos de estudo, discussões e desafios compartilhados foram fundamentais para o meu crescimento e formação.

Por fim, gostaria de estender meu agradecimento a todos que, de alguma forma, contribuíram para a minha formação. Cada gesto e palavra de apoio foram importantes para o meu crescimento como pessoa e profissional.

"O computador é a bicicleta da mente." (Steve Jobs, 1985)

ABSTRACT

Accurate and timely river water level data is crucial for flood prediction, water resource management, and ecological monitoring. This Master's project focuses on the development and comparative assessment of a LoRa-based Wireless Sensor Network (WSN) for robust river stage monitoring. The research critically evaluates the performance of four non-contact sensor technologies: two LiDAR sensors (TF-Luna, TF-Nova) and two ultrasonic sensors (JSN-SR04T, HC-SR04), integrated with a microcontroller-based node. The study methodology includes rigorous laboratory testing to determine sensor accuracy, precision, range limitations, and susceptibility to common interferences, reflecting findings often highlighted in foundational sensor studies [e.g., observations related to sensor physics from your list]. Subsequently, field trials will be conducted in a representative riverine environment to assess sensor reliability, power efficiency, and data transmission success via a LoRa network covering an extensive regional area. This research aims to address challenges noted in literature, such as optimizing sensor choice for specific environmental conditions and communication robustness in LPWANs [e.g., observations on LoRa performance or sensor limitations from your list]. The outcomes will provide empirical evidence to guide the selection of cost-effective and dependable sensor solutions for scalable hydrological monitoring networks, contributing to improved water management strategies.

Palavras-chave: Ultrasonic; Sensors; LiDAR; Cameras; Hydrological Monitoring; Remote Sensing.

ABSTRACT

Dados precisos e oportunos sobre o nível da água dos rios são cruciais para a previsão de cheias, gestão de recursos hídricos e monitoramento ecológico. Este projeto de Mestrado foca no desenvolvimento e avaliação comparativa de uma Rede de Sensores Sem Fio (RSSF) baseada em LoRa para o monitoramento robusto do nível de rios. A pesquisa avalia criticamente o desempenho de quatro tecnologias de sensores sem contato: dois sensores LiDAR (TF-Luna, TF-Nova) e dois sensores ultrassônicos (JSN-SR04T, HC-SR04), integrados a um nó baseado em microcontrolador. A metodologia do estudo inclui rigorosos testes em laboratório para determinar a exatidão, precisão, limitações de alcance e suscetibilidade dos sensores a interferências comuns, refletindo achados frequentemente destacados em estudos fundamentais de sensores [ex.: observações relacionadas à física dos sensores da sua lista]. Subsequentemente, testes de campo serão conduzidos em um ambiente fluvial representativo para avaliar a confiabilidade dos sensores, eficiência energética e sucesso na transmissão de dados através de uma rede LoRa cobrindo uma extensa área regional. Esta pesquisa visa abordar desafios observados na literatura, como a otimização da escolha do sensor para condições ambientais específicas e a robustez da comunicação em LPWANs [ex.: observações sobre o desempenho do LoRa ou limitações dos sensores da sua lista]. Os resultados fornecerão evidências empíricas para orientar a seleção de soluções de sensores econômicas e confiáveis para redes de monitoramento hidrológico escaláveis, contribuindo para melhores estratégias de gestão da água.

Keywords: Ultrasonic; Sensors; LiDAR; Cameras; Hydrological Monitoring; Remote Sensing.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

CONTENTS

1 INTRODUCTION

Floods, particularly flash floods, are among the most impactful natural disasters worldwide, causing substantial economic losses, infrastructure damage, and fatalities (**jonkman__2005__global**; **santos__2014__indstria**). These events are characterized by their sudden onset and rapid development, often occurring at the outlet of small catchments in response to intense localized rainfall, with response times of only a few hours (**borga__2014__hydrogeomorphic**) . Compounding the issue, climate change is intensifying the global hydrological cycle, leading to an increase in the frequency and severity of extreme weather events, including floods. This reinforces the need for improved flood monitoring, risk management strategies and alert systems to safeguard communities (**hall__2014__understanding**; **bragana__2024__anlise**).

Flash floods and debris flows often escape conventional hydrometeorological monitoring due to their spatial and temporal unpredictability (**borga__2014__hydrogeomorphic**; **hall__2014__understanding**). Accurate and real-time data collection becomes essential to calibrate hydrological and hydrodynamic models such as rainfall–runoff systems, flood discharge and water supply volumes which serve as the foundation for effective early warning systems (**lin__2020__semantic**; **lo__2015__visual**; **iqbal__2021__how**). In addition to instrumental data, combining systematic flood observations with historical and documentary records has been highlighted as a valuable approach to better understand long-term flood regime dynamics, including the detection of flood-rich and flood-poor periods influenced by natural variability (**borga__2014__hydrogeomorphic**; **hall__2014__understanding**; **iqbal__2021__how**; **bragana__2024__anlise**).

However, monitoring natural disasters presents substantial technical challenges. The vast scales involved, coupled with harsh environmental conditions and the need for real-time data, demand robust, cost-effective, and scalable technological solutions. In this context, Wireless Sensor Networks (WSNs) have emerged as a promising tool, offering significant advantages in terms of deployment flexibility, rapid response capabilities, and affordability compared to traditional monitoring infrastructures. WSNs enable dense spatial sampling and continuous data collection, which are critical for disaster monitoring applications.(**chen__2013__natural**; **ferreira__2023__conception**; **pule__2017__wireless**)

To further enhance WSN capabilities in remote and large-scale environments, Low Power Wide Area Networks (LPWAN) like LoRaWAN have gained prominence. LoRaWAN is specifically designed for transmitting small amounts of data over long distances with extremely low power consumption, enabling sensor nodes to operate autonomously for up to 10 years . This makes it particularly suitable for hydrological monitoring systems in regions with limited infrastructure (**pule__2017__wireless**; **chen__2013__natural**; **ferreira__2023__conception**).

This Master's project aims to develop a WSN for river water level monitoring using LoRa technology, focusing on the performance comparison of low-cost LiDAR and ultrasonic sensors. The project will involve designing and implementing a microcontroller-based sensor node capable of interfacing with various sensors, including TF-Luna, TF-Nova, JSN-SR04T, and HC-SR04.

1.1 OBJECTIVES

The primary objective of this Master's project is to design, implement, and rigorously evaluate a LoRa-based WSN for river water level monitoring, focusing on a comprehensive performance comparison of selected low-cost LiDAR and ultrasonic sensors.

1.2 SPECIFIC OBJECTIVES

1. To develop a microcontroller-based sensor node capable of interfacing with TF-Luna, TF-Nova, JSN-SR04T, and HC-SR04 sensors;
2. To implement robust firmware for synchronized data acquisition, local data processing, and efficient LoRa/LoRaWAN data transmission.
3. To conduct laboratory experiments to quantify and compare the accuracy, precision, range, resolution, and susceptibility to common interferences (e.g., temperature shifts, target surface variations, water conditions) of each sensor;
4. To deploy the developed sensor nodes in a real environment, assessing their performance, data integrity, and operational resilience against ambient environmental conditions;
5. To analyze the collected field and lab data to provide a assessment of the sensors, identifying their respective strengths, weaknesses, and optimal operational conditions for river stage monitoring;
6. To offer evidence-based recommendations for sensor selection, node design, and LoRa network deployment strategies for scalable and cost-effective hydrological monitoring systems in similar regional contexts;

1.3 STRUCTURE OF THE WORK

This thesis is structured as follows:

- **Chapter 2: Literature Review** - A comprehensive review of existing literature on WSNs, LoRa technology, and sensor technologies for hydrological monitoring.
- **Chapter 3: Materials and Methods** - Detailed description of the hardware and software design, sensor selection criteria, experimental setup, and data analysis methods.

- **Chapter 4: Laboratory Experiments** - Presentation and analysis of laboratory results comparing the selected sensors under controlled conditions.
- **Chapter 5: Field Deployment** - Description of the field deployment process, network setup, and performance evaluation in a real riverine environment.
- **Chapter 6: Discussion and Conclusion** - Summary of findings, implications for future research, and recommendations for practical applications in water level monitoring.

2 LITERATURE REVIEW

This study proposes the development of a water level monitoring system using LoRa-based WSNs and evaluating different non-contact measurement methods. The choice for a wireless and non-contact reading sensor node is the most recommended in the sensing application of unhealthy and harsh environments because it has independent processing and wireless signal transmission. They have a significant advantage over traditional wired sensors, which are not a cheap and viable option for this type of application (**bhuyan_2010_intelligent**).

——— General LORA REVIEW MENTIONS —— GENERAL FLOOD REVIEW MENTIONS —— ?? maybe put on fundaments chapter

Previously ultrasonic was defined as viable option to monitor water levels in river and channels using the sensor model GY-Us42, with results indicating that the device's average error is below 3% (**mohammadrezamasoudimoghaddam_2024_a**). Other work concludes that the ultrasonic sensor model HC-SR04 is a technically and economically viable alternative to monitor water levels (**pereira_2022_evaluation**), and the same sensor model is also praised as a good option for education, citizen science, and research due to low cost (**bresnahan_2023_a**).

In previous research, LiDAR was explored as a cost-effective sensor for measuring water leves from bridges, with lab and field tests indication a good accuracy with 0.1% error, but significant variations caused by sensor temperature and water roughness (**paul_2020_a**). LiDAR sensors installed on river banks for flash flood monitoring were also tested with good results, and indication that different amounts of small suspended particles on water could impact the results, and that the sensor could also be used to monitor these suspended particles (**tamari_2016_flash**). Another study explored how the LiDAR sensor model TF-mini compared to linigraph pressure sensors, showing the benefits of a non-contact measurement method of the LiDAR compared to a contact one with the linigraph and validating the LiDAR as an excellent choice among fluid level measurement technologies compared (**santana_2024_development**).

The contribution of this work is exploring more of the two different methods of non-contact water level measurement, comparing and definig best applications for each one. Adding to it, this work will also explore creating a low-cost, low-power, and long-range water level monitoring system using LoRaWAN technology. The system will be designed to operate in challenging environments, such as flood-prone river systems, where other more traditional monitoring methods may be impractical or too expensive.

3 THEORETICAL FRAMEWORK

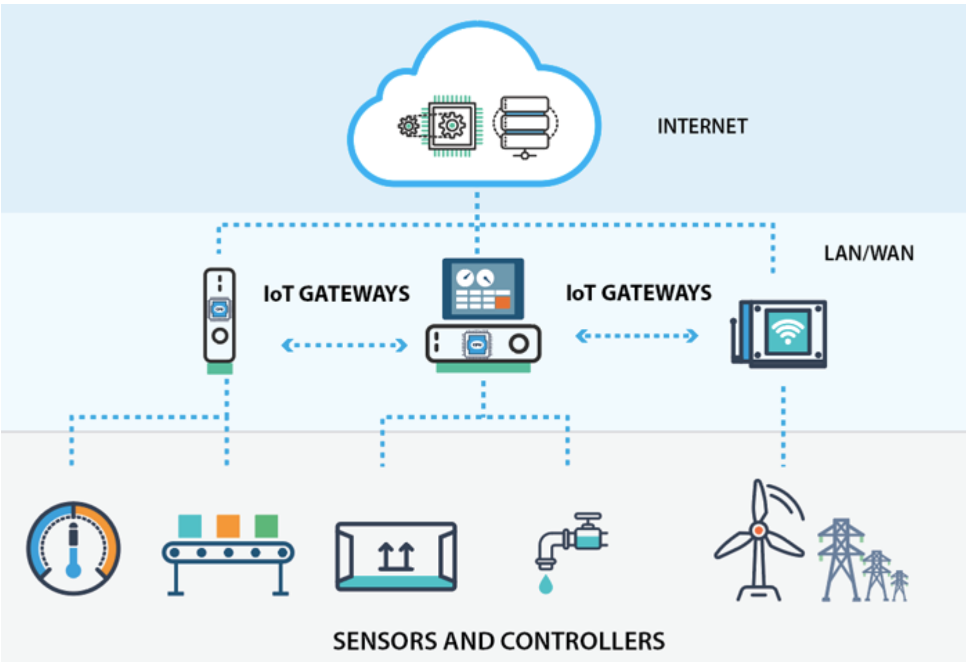
This chapter presents the theoretical foundation underpinning the development of the proposed water level monitoring system. It discusses the essential technologies and concepts, including the IoT (Internet of Things), long-range wireless communication (LoRa (Long Range)/LoRaWAN), distance measurement methods such as LiDAR (Light Detection and Ranging) and ultrasonic sensors, and embedded systems. These topics establish the context and technical justification for the architecture adopted in this work.

3.1 IoT (Internet of Things)

The IoT encompasses a network of interconnected physical objects that are equipped with sensors, processors, and communication interfaces, allowing them to collect, process, and transmit data without human intervention . The proliferation of IoT has enabled the deployment of intelligent systems in areas such as agriculture, industrial monitoring, and environmental surveillance. (**Madakam:2015**; **javaid_2021_sensors**)

In this project, IoT concepts are applied to create an autonomous and distributed sensor network capable of collecting hydrological data and transmitting it remotely for analysis and visualization. The figure **??** illustrates how various devices connect to the internet through IoT, enabling data exchange and interaction between the physical and digital worlds. (**javaid_2021_sensors**)

Figure 1 – Internet of Things.



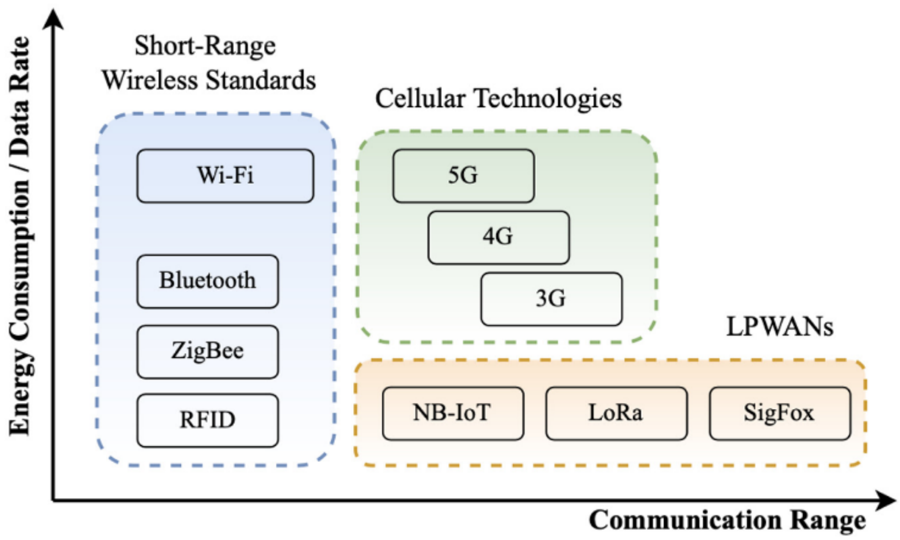
Source: (**iot123**).

3.2 LORA AND LORAWAN

LoRa (Long Range) is a proprietary spread spectrum modulation technique on the basis of CSS (Chirp Spread Spectrum), which is resilient and robust against interference and noise, it also provides a solution for long-range and ultra-low power-consumption transmission, using unlicensed radio bands such as 868 MHz (Europe) and 915 MHz (Americas) (**sun__2022__recent**).

LoRaWAN (Long Range Wide Area Network) is the MAC (Medium Access Control) protocol built on top of LoRa, specifying how end-devices communicate with central gateways and application servers, defining a typical star-topology network architecture and its bi-directional communication protocol. The technology has been designed for applications that need to send small amounts of data over long distances a few times per day. Its low power features offers the capability to achieve autonomy of up to 10 years. (**pule__2017__wireless**; **sun__2022__recent**). Such long-range and energy-efficient communication demands have inspired the emergence of Low Power Wide Area Networks (LPWANs) as a new IoT paradigm, which fills the gap of legacy wireless communication technologies shown in Figure **??**.

Figure 2 – Comparison with legacy wireless communication technologies.

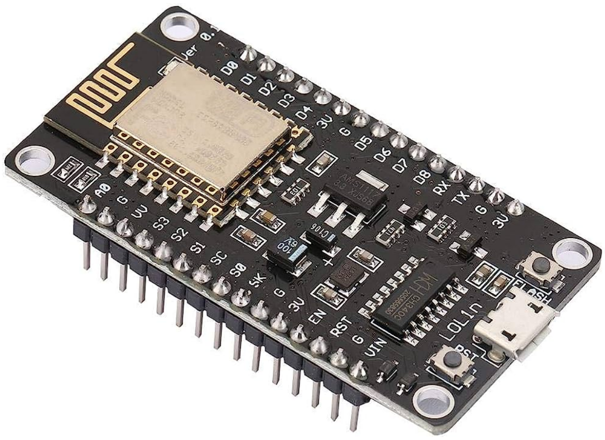


Source: (**sun__2022__recent**).

3.3 MICROCONTROLLER ESP8266

Embedded systems are specialized computing systems designed to perform dedicated functions within larger systems, often under real-time constraints. The NodeMCU ESP8266 is a microcontroller based on the ESP8266 platform, which features integrated Wi-Fi connectivity. It is widely used in IoT projects due to its ease of programming, low cost, and advanced features. The ESP8266, shown in Figure **??**, is particularly suitable for such applications due to its ability to operate at low power, which is crucial for battery-powered devices, and its capability to connect to Wi-Fi networks, enabling communication with the internet and other devices on the network (**Kolban2016**).(**datasheet__2023__esp8266ex**)

Figure 3 – ESP8266 NodeMcu.



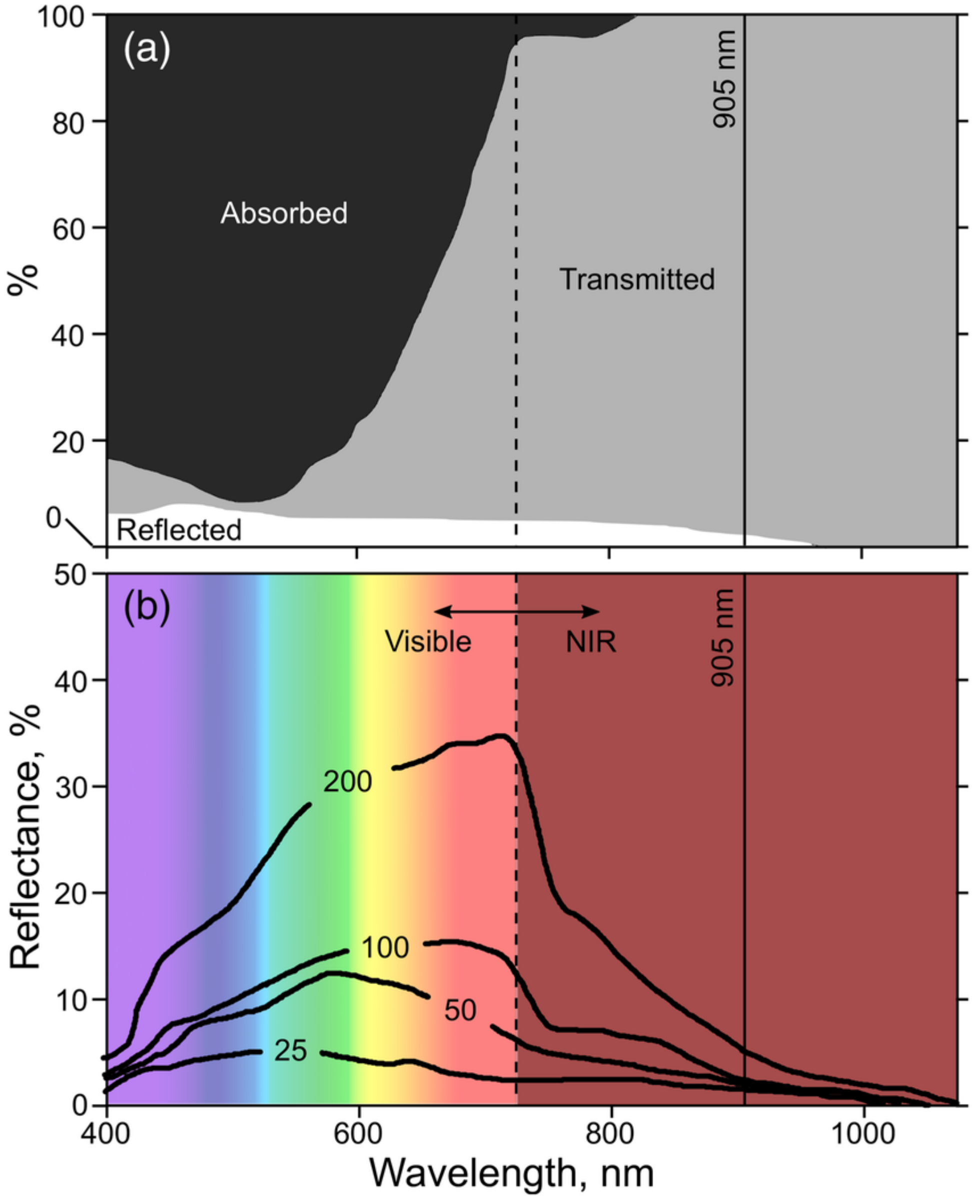
Source: (**nodemcu**).

3.4 LIDAR

LiDAR (Light Detection and Ranging) technology enables the accurate determination of an object's distance (and velocity) information. LiDAR technology is widely used in metrology, environment monitoring, archaeology, and robotics. Compared with more mature RADAR (Radio Detection and Ranging) technology, LiDAR makes use of optical wave, which is at shorter wavelength regime compared with radio wave, and hence has potential to achieve higher precision in 3D sensing.(**li__2022__a**; **lednev__2013__remote**; **behroozpour__2017__lidar**; **javaid__2021__sensors**).

The principle of lidar ranging relies on the rugosity of the reflective surface to generate nonspecular reflection (i.e., scattering) of the incipient laser beam. As with radar, lidar ranging measures time of flight, but it uses higher frequency waves for greater pulse intensities. Near-infrared (NIR) light is most commonly used for this purpose, typically over wavelengths of 900–1,100 nm (270–330 THz) due to the low cost of lasers operating in this wavelength range and lower energy density than the visible spectrum.(**li__2022__a**; **fernandezdiaz__2014__early**; **smart__2009__river**; **behroozpour__2017__lidar**). The laser wavelength is a critical factor in determining the sensor's performance, as it influences the interaction with water and suspended particles. Figure **??** illustrates the spectral character of clear still water as a function of laser wavelength and the influence of suspended sediment concentration on reflectance in rivers (**lednev__2013__remote**; **milan__2010__mapping**; **paul__2020__a**).

Figure 4 – (a) Spectral character of clear still water as a function of laser wavelength (**lednev_2013_remote**; **milan_2010_mapping**). (b) Influence of suspended sediment concentration (curves: units of mg L(-1)) in river upon reflectance (**paul_2020_a**; **milan_2010_mapping**)



Source: (**lednev_2013_remote**; **milan_2010_mapping**; **paul_2020_a**).

The three sensing schemes most commonly used in LiDAR sensors are: pulsed TOF (Time Of Flight), AMCW TOF, and FMCW. (**li_2022_a**; **behroozpour_2017_lidar**). For this work the most important ones are the pulsed TOF and AMCW TOF, which are described below.

3.4.1 Pulsed Time of Flight (TOF)

The pulsed TOF LiDAR works based on the time delay of an optical pulse emitted by the TX, reflected from the sensing object, and received by the RX. The sensing distance can be expressed using the following equation (**li__2022__a**).

$$d = \frac{c \cdot \Delta t}{2} \tag{1}$$

where d is the distance to the object in meters, c is the speed of light, and Δt is the time delay between emission and reception of the optical pulse in seconds.

3.4.2 Amplitude Modulated Continuous Wave (AMCW) Time of Flight (TOF)

AMCW TOF LiDAR uses a continuous wave laser that is modulated in amplitude. The phase difference between the transmitted and received signals is measured to determine the distance to the object. The distance can be calculated using the following equation (**li__2022__a**).

$$d = \frac{c \cdot \Delta\phi}{4\pi f} \tag{2}$$

where d is the distance to the object in meters, c is the speed of light, $\Delta\phi$ is the phase difference between the transmitted and received signals, and f is the modulation frequency in Hz.

3.5 ULTRASONIC SENSORS

Ultrasonic sensors estimate distance by transmitting high-frequency acoustic waves and measuring the echo delay. Common models like the HC-SR04 and JSN-SR04T are widely used in academic and industrial applications due to their low cost and simplicity (**bresnahan__2023__a**; **akhileshnagpure__2022__water**; **mohammadrezamasoudimoghaddan**

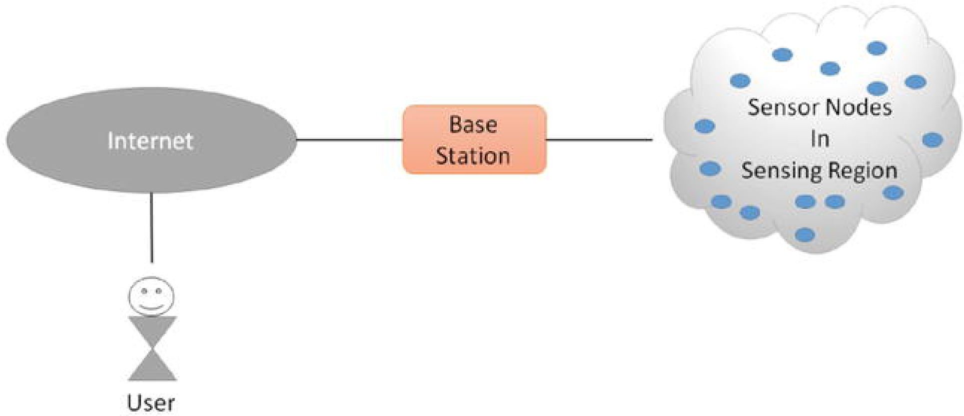
The basic principle of ultrasonic distance measurement is based on the time of flight (TOF) of sound waves. The sensor emits a high-frequency sound wave, which travels through the air, reflects off an object, and returns to the sensor.

3.6 WIRELESS SENSOR NETWORK (WSN)

WSN (Wireless Sensor Network) are considered a promising alternative to complement conventional monitoring processes. These networks are relatively affordable and allow measurements to be taken remotely, in real-time and with minimal human intervention (**pule__2017__wireless**). A WSN is composed of spatially distributed autonomous nodes that monitor physical or environmental conditions. These nodes typically consist of a sensing unit, processing unit, communication interface, and power source. Natural disaster monitoring is very complex and imposes a number of challenges mainly due to huge scales,uncertainties, and harsh environments.

Each such sensor network node typically has many parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting (**yellampalli__2021__wireless**). An example architecture of a WSN is shown in Figure **??**. The nodes are capable of collecting data from the environment, processing it, and transmitting it wirelessly to a base station or gateway for further analysis and visualization. A WSN can be single hop, where the nodes connect directly to the base station, or multi-hop, where the nodes can send information between themselves before reaching the base station (**yellampalli__2021__wireless**).

Figure 5 – Wireless Sensor Network architecture.



Source: (**yellampalli__2021__wireless**).

WSN-based natural disaster monitoring systems excel in terms of cost, speed of response, scalability and flexibility in contrast to conventional approaches. In general, disaster monitoring with WSN manifests a typical paradigm of data-intensive application upon low-cost scalable system (**chen__2013__natural**; **pule__2017__wireless**; **ferreira__2023__conception**). In this work, the WSN architecture facilitates distributed hydrological data collection and centralized data aggregation through LoRa communication.

3.7 TIME-SERIES DATA AND ENVIRONMENTAL MONITORING

Time-series data represent sequential observations over time. In the context of water level monitoring, time-series analysis enables the detection of trends, anomalies, and correlations between environmental factors (**lozano__2017__sensors**). Basic statistical techniques—such as moving averages, root mean square error (RMSE (Root Mean Square Error)), and filtering—are applied to improve data reliability and reduce noise(**santana__2024__development**).

4 MATERIALS AND METHODS

To achieve the proposed objectives in this project, the work is divided into a few phases. In the first phase tests will be conducted in a controlled environment to evaluate the different sensors performance, without interferences form the network connection elements or variations in environmental conditions. In this phase the sensors will be integrated into a microcontroller-based sensor node and classified to define the best sensor for the application in monitoring a large river, such as the Itajaí-Açu river, and the most cost efficient solution for a smaller channel/river. In this phase the sensors will be tested, with the goal of evaluating their performance in terms of accuracy, precision, range, resolution, and susceptibility to common interferences such as temperature shifts, target surface variations, and water conditions.

On a second phase, the sensor nodes will be connected to a LoRa / LoRaWAN network, and the data will be transmitted to a backend database for storage and visualization. The network will be designed to operate in a star topology, with one central gateway and multiple sensor nodes. The sensor nodes will be programmed to periodically make multiple readings on the distance data, process it and send to the gateway using LoRa modulation.

Finally, the system will be deployed in a real environment, such as a river or water body, to evaluate its performance in terms of data accuracy, transmission success rate, energy efficiency, and resilience against ambient environmental conditions. The collected data will be analyzed to provide insights into the performance of the sensors and the overall system.

4.1 SYSTEM ARCHITECTURE

The proposed monitoring system is built around a modular WSN designed for remote water level monitoring. Each node in the network is equipped with non-contact distance sensors, LiDAR and/or ultrasonic, and a LoRa/LoRaWAN communication module. The architecture comprises the following subsystems:

- **Data Acquisition**: Utilizes LiDAR and/or ultrasonic sensors for distance measurement.
- **Processing Unit**: A low-power microcontroller (e.g., ESP32, ESP8266) reads sensor data and manages system logic.
- **Communication Interface**: Sends processed data via LoRa/LoRaWAN to a centralized gateway.
- **Power Management**: Employs rechargeable batteries and optional solar panels.

4.2 FIRST PHASE: SENSOR TESTING AND CALIBRATION

Sensors are mounted on adjustable rigs to test performance against fixed surfaces at various distances and materials. Environmental conditions like ambient temperature and lighting are controlled.

4.2.1 Microcontroller Unit

A low-power microcontroller such as the ESP8266 is selected for this project due to its sufficient performance, integrated Wi-Fi, and support for external LoRa modules. The MCU interfaces with sensors using UART,I2C and digital I/O.

This microcontroller will be used throughout the project, from the first phase of testing the sensors to the final deployment in the field. It will be responsible for reading sensor data, processing it, and transmitting it via LoRa. The microcontroller will also be responsible for managing power consumption, entering a low-power sleep mode when not actively collecting or transmitting data.

4.2.2 Sensors

Four distance sensors were used to capture water level data for performance comparison:

- **TF-Luna (LiDAR)**: Compact, accurate, and low-cost, with up to 8 m range.
- **TF-Nova (LiDAR)**: Offers improved range (up to 12 m) and stability over TF-Luna.
- **JSN-SR04T (Ultrasonic)**: Waterproof, outdoor-suitable sensor with 6 m range.
- **HC-SR04 (Ultrasonic)**: Basic sensor for initial prototyping, up to 4 m range.

The four sensors will be tested in the same conditions, connected to a ESP8266 microcontroller, which will read the data and send it to a connected computer for analysis. After the tests are completed the data will be analyzed to determine the best sensor for the application, considering factors such as cost, performance, and environmental conditions.

The list of tests to be performed was defined based on the sensors specifications, the project requirements and based on some findings of previous works, (**paul_2020_a**) found that the temperature can affect the readings of the LiDAR sensors, and (**tamari_2016_flash**) mentions that future works should look to check if the number of suspended small particles in the water could impact the readings of LiDAR sensors. The tests will be as follows:

- **Distance Range Test**: Sensors are tested at various distances to detect soft and hard reading limits.
- **Precision Test**: Multiple readings are taken at fixed distances to evaluate precision.

- **Accuracy Test**: Comparing sensor readings with reference measurements to determine accuracy.
- **Light Interference Test**: Sensors are tested under different lighting conditions to assess sensitivity to ambient light.
- **Surface Material Test**: Sensors are tested on different surfaces (clean water, water mixed with earth, solid materials).
- **Temperature Variation Test**: Sensors are tested at different temperatures.
- **Environmental Interference Test**: Sensors are tested in simulated and controlled envirmental conditions with wind, rain, and other environmental factors.

4.3 SECOND PHASE: SYSTEM INTEGRATION AND COMMUNICATION

After evaluating the sensors, the selected ones are integrated into a sensor node. Besides the sensor, the node includes the LoRa transceiver, a microcontroller, and a power management system. The node is programmed to read sensor data, process it, and transmit it via LoRa. The node is designed to operate in low-power mode, waking up at set intervals to collect and send data.

4.3.1 Communication Module

A LoRa transceiver operating at 915 MHz enables long-range data transmission with minimal energy consumption. Each node sends data to a gateway(LoRa Receiver) which forwards it to a backend database for storage and visualization. Figure **??** illustrates the integration of the LoRa nodes and the receiver.

4.4 THIRD PHASE: FIELD DEPLOYMENT AND EVALUATION

4.4.1 Field Deployment

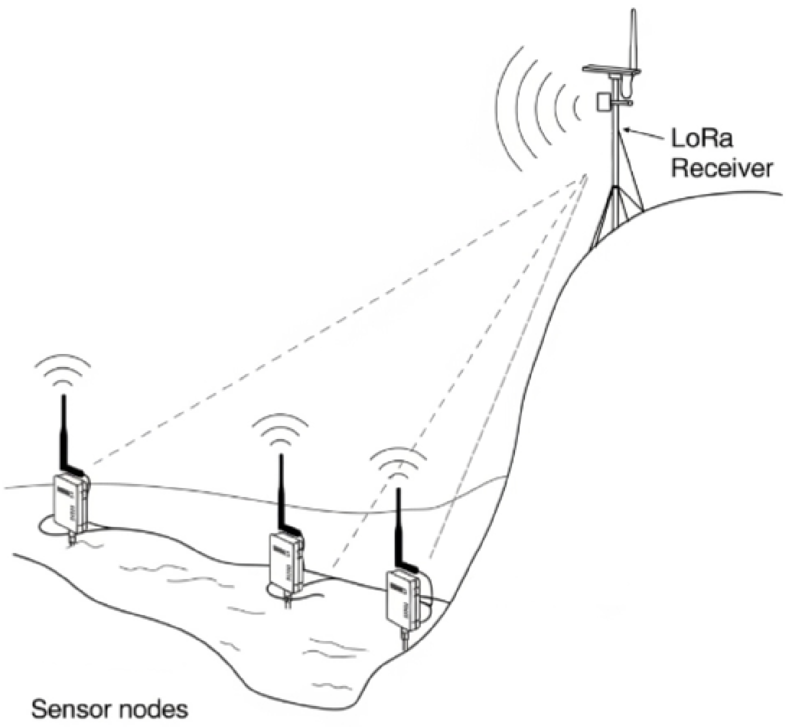
The complete system is deployed near a river or water body. Each node is securely housed and positioned above the water surface.

- Evaluation criteria: data accuracy, transmission success rate, energy efficiency, and resilience.
- Nodes report data every 15 minutes; timestamps allow trend tracking.

4.4.2 Node Software Architecture

The software architecture is designed to ensure efficient data acquisition, processing, and transmission. The main loop reads sensor data, processes it, and transmits packets via LoRa only in set intervals to conserve energy, entering a deep sleep state otherwise. The flow of the node while it is active is descrbed in Figure **??**.

Figure 6 – LoRa Nodes and Receiver integration diagram.



Source: The author.

4.4.3 Data Communication and Network Topology

Each node periodically collects distance data and sends it to the gateway using LoRa modulation. The gateway relays this data to a server through Wi-Fi or cellular connection. The network is structured in a star topology with one central gateway and multiple sensor nodes.

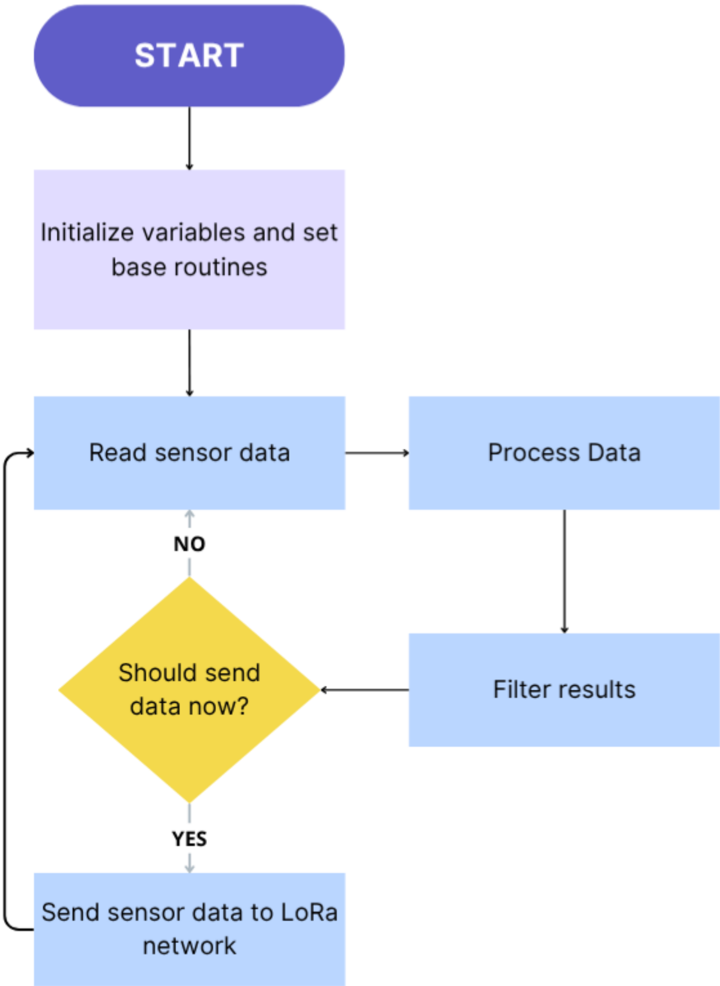
4.5 DATA PROCESSING AND STORAGE

Received sensor data is stored in a cloud database for further analysis. Time-series data is cleaned and visualized using statistical and signal processing tools. Metrics such as mean, standard deviation, and RMSE are computed.

4.6 EXPECTED OUTCOMES

This integrated system aims to evaluate the accuracy, stability, and cost-effectiveness of multiple distance sensors in real-world hydrological monitoring. The LoRa-based architecture enables remote deployment and real-time water level reporting, supporting early warning and sustainability goals.

Figure 7 – Sensor node diagram.



Source: The author.

Table 1 – Table comparing sensors.

Sensor	**Type**	**Range**	**Precision**	**Accuracy**
JNS SR04T	Ultrasonic	20 cm a 4 m	±1 cm	±1 cm
HC-SR04	Ultrasonic	2 cm a 4 m	±3 mm	±3 mm
TF-Luna	LiDAR	0,2 m a 8 m	±1 cm	±1 cm
TF-Nova	LiDAR	0,1 m a 12 m	±1 cm	±1 cm

Source: The author.

Listing 1 – Exemplo de um schema no Prisma.

```
generator client {
  provider = "prisma-client-js"
}

datasource db {
  provider = "postgresql"
  url      = env("DATABASE_URL")
}

model User {
  id        String       @id @unique @default(uuid())
  email     String
  password  String
  cpf_cnpj  String       @unique
  name      String
  role      RoleEnumType? @default(user)
  createdAt DateTime     @default(now())
  updatedAt DateTime     @updatedAt
}

enum RoleEnumType {
  user
  admin
}
```

Source: The author.

5 CONCLUSION

A proposta deste projeto foi desenvolver um sistema para automação de pedido e compras em pontos de venda, que permita integração com agentes de distribuição, de forma a automatizar todo o processo.

Com base nos resultados apresentados, pode-se concluir que o desenvolvimento do sistema obteve sucesso. A aplicação web desenvolvida permite que os usuários possam fazer seus pedidos, enquanto os funcionários dos pontos de venda têm acesso a informações precisas sobre os pedidos realizados, podendo acompanhar o status da entrega em tempo real. Além disso, o servidor de *sockets* permite que os pontos de venda possam notificar os agentes de distribuição de qualquer atualização no status dos pedidos, de forma rápida e eficiente.

Por fim, a utilização de serviços de hospedagem em nuvem garantiu a disponibilidade e a escalabilidade do sistema, permitindo que ele possa ser usado por um grande número de usuários ao mesmo tempo.

Dessa forma, pode-se afirmar que o sistema de gerenciamento de pedidos para pontos de venda desenvolvido neste trabalho é uma solução eficiente e viável para empresas que desejam aprimorar seus processos de gerenciamento de pedidos e melhorar a experiência dos seus clientes, usando automação e tecnologias web modernas.

Para trabalhos futuros deseja-se incluir melhorias na interface, principalmente para exibir mais informações sobre os pedidos, e de forma geral torna-la mais amigável. Além disso, outro ponto que pode ser trabalhado seria o desenvolvimento de agentes de distribuição, conectando o NodeMCU com uma máquina de café, por exemplo, e distribuindo realmente os produtos.