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IoT technologies and cold supply chain

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Master's in Computer Science and Business Management

Supervisor:
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Iscte-Instituto Universitário de Lisboa

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TECNOLOGIAS
E ARQUITETURA

Department of Information Science and Technology

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Machines take me by surprise with great frequency.
- Alan Turing

Acknowledgment

Since the finalization of my bachelor degree in business management, I felt that it was necessary to complement my knowledge with IT side of business. As such, after 6 years of academic break, and with the opportunity of complementing my knowledge with the Master's in Computer Science and Business Management, this adventure begins. I want to thanks in first place, professor Carlos Coutinho for all the support and counselling given in the making of this work.

I would also thanks my family, friends an co-workers for all the help and support when this task became more difficult and strength necessary to continue was given by them.

Resumo

Com um número cada vez maior de mercadorias transportadas em torno do globo, aumenta a necessidade de soluções mais sofisticadas para monitorizar esses movimentos e em que condições esses são realizados. Assim, este trabalho tem como objetivo criar uma solução baseada na tecnologia Long Range (LoRa) para a monitorização dos valores de temperatura, humidade e de aceleração no transporte de mercadorias refrigeradas na cadeia logística de frio. A solução a ser desenvolvida é dividida em 3 camadas, nomeadamente uma camada sensorial responsável pela recolha dos dados de monitorização, uma camada de comunicação responsável pelo transmissão entre a camada sensorial e aplicacional, e de uma camada aplicacional responsável pelo registo e visualização de dados recolhidos e alertas. Esta solução tem como intenção a redução do número de desvios de parâmetros ideais no transporte, que poderá levar à redução de mercadoria deteriorada. Para alcançar os objectivos propostos é empregado o uso da metodologia Design Science Research (DSR) com a finalidade de dar conta do estado da arte das atuais soluções, bem como reger o processo de desenvolvimento da solução.

Palavras-chave **— IoT, LoRa, Frio, Logistica, Transporte, Rastreabilidade**

Abstract

With the ever growing number of merchandising being transported around the globe, the need for more sophisticated solutions to keep track of these movements and in what conditions those movements are made is increasing. The objective of this work is to create a solution based on Long Range (LoRa) technology for monitoring the values of temperature, humidity and acceleration of the transport of refrigerated goods in the cold logistics chain. The solution to be developed is comprised of 3 layers, namely a sensing layer responsible for collecting the monitoring values, communication layer responsible for transmission of data between the sensing and application layers, and an application layer responsible for recording and visualizing of the collected data and generating alerts. This solution aims to reduce the number of deviations from ideal environmental parameters in transport, which could lead to a reduction in spoiled goods. To achieve the proposed objectives, the DSR methodology is used with the goal of reporting the state of the art of current solutions, as well as governing the process of development of the solution.

Keywords **— IoT, LoRa, Cold, Logistics, Transport, Tracking**

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List of Acronyms

AI: Artificial Intelligence
API: Application Programming Interface
ARM: Advanced RISC Machines
CDMA: Code Division Multiple Access
CSV: Comma-separated values
DSR: Design Science Research
GPRS: General Packet Radio Service
GPS: Global Positioning System
GSM: Global System for Mobile Communications 2G
IoT: Internet of Things
JSON: JavaScript Object Notation
LCD: Liquid-Crystal Display
LoRa: Long Range
LTE: Long Term Evolution
MQTT: Message Queuing Telemetry Transport
NFC: Near Field Communication
QR: Quick Response
RAM: Random-Access Memory
RF: Radio Frequency
RFID: Radio-frequency identification
SLR: Systematic literature review
SMTP: Simple Mail Transfer Protocol
SQL: Structured Query Language
TTI: Time Temperature Integrators
UV: Ultraviolet
Wi-Fi: Wireless Fidelity
WSN: Wireless Sensor Networks
XML: Extensible Markup Language

CHAPTER 1

Introduction

In supply chain, we see an increasing demand for technological solutions to dematerialize labor intensive processes. With the constant movement of tons and tons of goods around the world, it becomes very hard to track where and in what conditions those goods are being transported. Given this, one can point various examples of human error, like failure in putting away a pallet of product and, after some time, no one will know the location of the merchandise, causing possible losses to the business. One can also point equipment failures, like the malfunction of a refrigeration unit, causing the product to become unusable, which in turn will outcome in losses to the business. Given the examples above, the application of technologies like Internet of Things (IoT), Cloud and Radio-frequency identification (RFID), can contribute to the mitigation of human error, and in case of equipment malfunction, intervention before any loss can occur.

With the application of the technologies previously mentioned, it is possible for companies to start transforming their business, so they can bring more productivity, less human error and the reduction of the negative consequences of those errors. Production wise, the industry could benefit with the automation of processes, eliminating repetitive and equal tasks, the employees could shift their focus on problems were their skills are essential. In the aspect of losses, with real time monitoring, and per consequence, automated reports when things go wrong, could see a reduction of merchandise loss, either by reducing the number of pallets missing in transport or storage, or by putting the products in an environment that will cause it to spoil.

My interest in the area, is, on one hand, the fact that I like to explore new technologies, not just by learning about them, but also by experimenting with them in a real context and understanding how they work and how can they have practical applicability in a real business. On the other hand, since I have constant contact with the supply chain industry, I have the interest in knowing how the application of these technologies can impact this business, where I know there are multiple problems regarding inefficiencies and errors and malpractices.

With this work I hope to learn and experiment first-hand with emerging technologies like cloud computing and IoT, and how they can impact in terms of boosting productivity and reducing inefficiencies in the supply chain industry, where the margin of profit is very low. With the knowledge and experience gained, either by experimenting with the technologies or exploring how they work, I believe that I can get prepared to future, and bring the so much needed digital transformation in this industry.

Regarding the benefits that I hope this work will bring to the industry, is the possibility for companies to start transforming their business, using the technologies studied, so they can enable more productivity, less human error and the reduction of the negative consequences of those errors. Production wise, I hope that with automated processes, eliminating repetitive and equal tasks, the employees could shift their focus to problems where their skills are essential. In the aspect of losses, with real time monitoring, and per consequence, automated reports when things go wrong, we could see a reduction of merchandise loss, either by reducing the number of pallets missing in transport or storage, or by putting the products in an environment that will cause it to spoil.

1.1. Research questions and hypothesis

In this section a research question was defined to focus and conduct the objectives of the current research.

RQ: How can we build a solution to ensure that the temperature conditions of refrigerated goods are met during the transport?

To give an answer to this question, a set of hypotheses where enumerated, which will then be subject of analysis, investigation and validation in the remaining sections of this dissertation.

H1: Building an IoT-based solution with LoRa technology that registers the temperature of the goods may be a solution to this problem.

H2: Promoting the use of insulated bulkheads may be a solution to this problem

1.2. Document structure

Chapter 1 presents an introduction and contextualization to the necessity of a solution for the monitoring of the environmental conditions during the transport of refrigerated goods throughout the supply chain. Chapter 2 defines the methodologies that conduct this study, and rule the disclosure of the state of the art. Chapter 3 presents the state of the art for the theme in discussion, using the methodology chosen. In chapter 4, following the DSR methodology, defines what are the objectives and requirements of the solution. In chapter 5 is presented the development of the artefact, an demonstration of its functionalities, followed by the evaluation of said artefact in achieving the proposed objectives. Chapter 6 presents an report of the findings and an proposition of future work.

CHAPTER 2

Research methodology

In this section is defined the methodology that will conduct the analysis and investigation of this dissertation.

2.1. Research methodology

For the conduction of this dissertation we use the DSR methodology. The main objective of this methodology is to present solutions for problems by the creation of innovative artifacts and the generation of design knowledge [**1**]. It comprises of 3 main cycles, starting with the identification of the problem, its contextualization and establishment of hypothesis; passing through a designing and testing cycle, where we construct a solution for the problem; and ending with the validation of the solution and verification of the hypothesis.

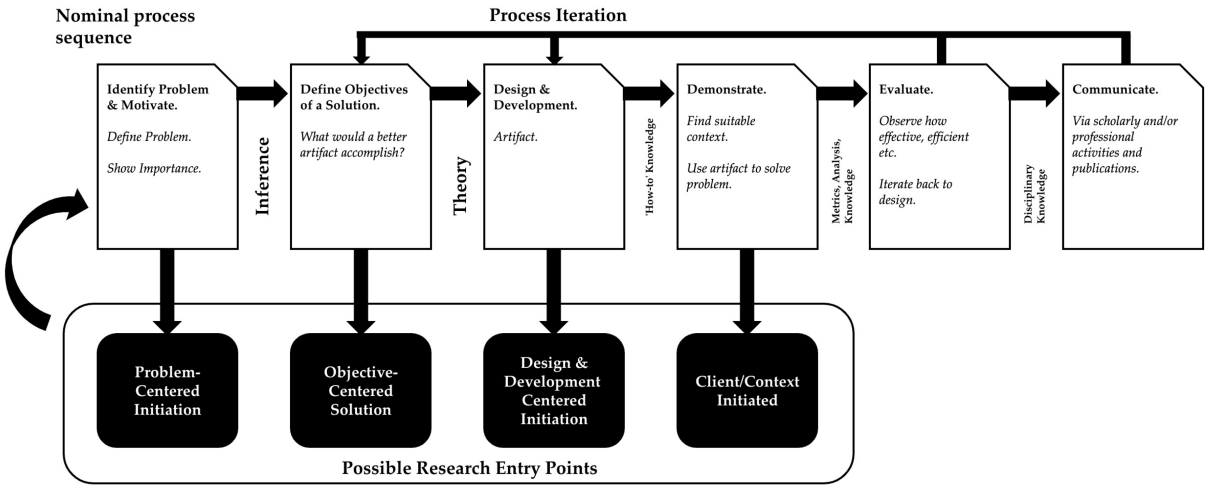


FIGURE 2.1. DSR methodology activities

This methodology comprises of 6 activities, beginning with the **identification of the problem to solve**, approached in chapter 1, where we define what is the problem we are trying to solve, and the value of a possible solution. Then we **define the objectives for a solution**, developed in chapter 4, where we measure how the artefact should solve the problem identified in the first step. The next step, denominated **design and development**, performed in section 5.2, we proceed with the creation of the artefact that will try to became the solution to our problem. Then, we will move to the **demonstration** step, approached in section 5.3, where we will use the artefact created before to solve the identified problem. After that, we will, in section 5.4, **evaluate** the artefact, regarding the capability of the created artefact in resolution of the problem identified. At this point,

we can go back to the development step with the intent of improve the effectiveness of the artefact. In the last step of this methodology, we will **communicate** in chapter 6 the results and the effectiveness of the artefact in the resolution of the problem identified.

2.2. State of the art methodology

For the state of the art of this work we use the Systematic literature review (SLR) methodology, with the goal of exploring and analyse in a structured and systematical manner the existing papers regarding the application of IoT devices in Supply Chain.

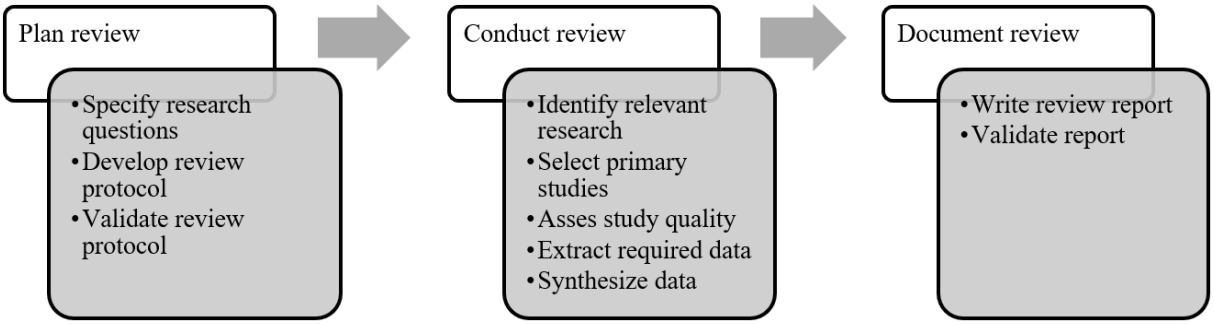


FIGURE 2.2. SLR methodology

The first step of the methodology is the definition of the research question, which will be answered with the knowledge retrieved form the works already published. With the research question defined, we elaborate the review protocol, where we define a search string and inclusion and exclusion criteria, with the propose of selecting relevant papers. The next step is the application of the previously defined search string on the various paper's data bases, and, with the application of the defined criteria, select the most relevant papers to analyse. With the works selected, we extract the relevant data from the papers that comply with all of the points fixed in the protocol, witch in terms answers the question defined in the planing stage. With all the information extracted from the papers, we report all the findings, in a structured manner [**2**].

CHAPTER 3

State of the art

In this section of the document we use the SLR methodology to report the state of the art regarding the use of technological solutions to monitor the transport of refrigerated goods. To do so, the first step is to define the protocol to be followed during the conducting of the review. Finally we present in a systematic manner the relevant findings identified in the previous step.

3.1. Planning

For this the first step of the SLR methodology, where we approach the need for the review, its objective and define the review protocol.

3.1.1. Objective

The objective of this review is to provide with a vision on the current condition regarding the solutions available for problematic identified.

3.1.2. Review protocol

For the conduction stage of this chapter it is necessary to define keywords and a search string to be use across the various scientific databases chosen to the work. Table 3.1 presents the keywords and search string to be used in the scientific databases. The scientific databases to use are Scopus, IEEE, WOS and ACM. To reduce the number of articles, and select the ones that are more appropriated to the study, we apply the filters defined in table 3.2, taking also in account the criteria establish in table 3.3.

Keywords	Cold, Logistics, Transport, Monitoring, Technology
Search string	Cold AND Logistics AND Transport AND Monitoring AND Technology

Table 3.1. Keywords and Search string

ID	Filter
1	Full text
2	Abstract
3	Duplicated
4	Inclusion and exclusion criteria

Table 3.2. Filters

Inclusion criteria	Electronically available
	Relevant to the study
	Writen in english
Exclusion criteria	Not electronically available
	Not relevant to the study
	Not writen in english

Table 3.3. Inclusion and exclusion criteria

3.2. Conduction

In this section is presented the second step of the SLR methodology where, following the protocol previously established, the relevant articles are selected, and an systematic analyses of the selected article is preformed.

3.2.1. Article selection

Following the established protocol, the author identified 5185 articles across the four scientific data bases, where the keywords defined are present in full text. Applying the first filter at the level of the abstract, the number of articles are reduced to 46. Then, it is identified that some of the articles are repeated in the different scientific databases. As such, ignoring the repeated articles, the author identified 31 different articles. With the application of the last filter defined in the protocol, which removes articles that are not publicly available, not written in English, and not relevant to the study in question, the author selected a total of 19 articles to be analysed. Table 3.4 shows the distribution of the articles for each scientific database, an the evolution of the number of articles by the application of each filter.

Data Base	Filter 1	Filter 2	Filter 3	Filter 4
IEEE	1153	4	3	3
Scopus	2220	16	13	4
WOS	45	18	9	7
ACM	1767	8	6	5
Total	**5185**	**46**	**31**	**19**

TABLE 3.4. Article distribution by scientific data base

3.3. Review

Kai et al. [**3**] address a solution that uses General Packet Radio Service (GPRS) and Beidou satellites in a system comprising of 4 acquisition nodes that measures the temperature and humidity inside of the cargo box, and using Si4432 wireless communication, transmits that data to a master node. This data is then processed in the master node, based on a STC12C5A60S2 micro-controller, where it is paired with the position data from Beidou satellites, a Chinese satellite navigation system. This node then transmits data to a monitoring center server using GPRS technology. With this information, the user can log to the server and visualize the location of the vehicle on a map and the temperature and humidity values of transport. The solution also supports a Android client where the user can also see the previous mention data. It also has a features that alerts the user when the temperature or humidity levels cross a defined value.

Li et al. [**4**] also describes a similar solution with the objective of monitoring in real-time *Tricholoma matsutake*, a type of editable fungus sensible to changes of temperature and humidity. In this solution temperature, humidity and gas sensors are used to feed a information gathering node. This node then uses GPRS as means of transmitting the data collected to a application layer based on the TLINK Cloud Services Platform, which provides real-time connection to multiple sensing nodes. It also supports Application Programming Interface (API) as a means of treating and develop data, and also enables standard integrations of IoT like Message Queuing Telemetry Transport (MQTT).

Liu et al. [**5**] mentions the use of a TP501V2.0 monitoring device with a temperature sensor and Global Positioning System (GPS) system to record, and visualize through a smartphone in real time the temperature and location of an cold storage box that is used to ensure the quality and preservation of food, drugs and biological samples.

Bijwaard et al. [**6**] also employs the use of sensing nodes, consisting of tags with RFID technology called SmartPoints, containing a Chipcon CC2430 chip, that can host temperature and humidity sensors. Then, with the use of micro-routers and gateways, is created a wireless infrastructure that provides the means of the SmartPoints to transmit their data. When the SmartPoints are not in range of a Wireless Sensor Networks (WSN), they are capable of logging the date until they are in range of one. Then, the employment

of a ConnectBox permits the remote monitoring of the environment of the cargo box during the transport using GPRS. In cases of interruption of communication, the ConnectBox buffers the data, and when the connection is re-established, resumes communication and forwards the buffered data. This solution, regarding the application layer, in addition of having an AmbiLink, a proprietary architecture that allows the remote monitoring, it has also in place an API that permits the communication with third party systems using Extensible Markup Language (XML).

Bapatala et al. [**7**] mentions the use of end nodes based on the ESP8266 microcontroller, with temperature, humidity, light and GPS sensors to collect the environmental data. It also incorporates actuators that aid in the controlling of the environment. This board communicates through the internet with a edge node based on a Raspberry PI, that acts also as a blockchain network node, permitting that the data being transmitted is put in a chain, ensuring that the data received in the other end was not manipulated in any way. This chain contains any discrepancy regarding the values of the transport and the recommended range. This data can be accessed by the consumer verifying the safety of products. Using blockchain also permits a shared ledger, that inhibits centralized control of the data.

Zhu [**8**] mentions the use of RFID technology to not only identify objects, but also to retrieve important sensory information through the integration of an WSN. With this conjunction, information can be received by the user by means of a multi-hop network, improving the RFID communication distance. The WSN is mostly composed of various sensors with the main objective of collecting processing and transmitting data. The author also identifies the use of smart RFID tags with the goal of monitor temperature and relative humidity, the use of Bluetooth paired with sensors in WSN to monitor the environment of a refrigerator truck, the application of a ZigBee based WSN to monitor in real-time the temperature and humidity in the cold chain and the development of a printable photochromic time and temperature indicator activated by Ultraviolet (UV) light. It is referred that traditional RFID by itself cannot provide monitoring capabilities of the environment of the products. As such, using a system based on ZigBee and high frequency RFID technology permits the full tracking of information, with the advantage of low power consumption, long distance transmission and high flexibility. The author points out that the evolution of computer and hardware and software knowledge allowed for the transition from manual measurement and paper records to systems that enable real-rime collection and transmission, providing an early warning of environmental data. Regarding the merging of RFID and WSN technology, it can be divided in two types. On one hand, the merging of RFID tags with the WSN allows the tag to not only act as an ordinary tag read by a scanner, but providing the measure of parameters like temperature and humidity. This system comprises a sensor, an analogue to digital converter, Random-Access Memory (RAM) , a microprocessor, a RFID tag, a RFID reader, and a host computer. The tag is powered by a lithium battery and controlled by a timer which

enables it to collect data periodically, regardless of being in range of an reader. On the other hand, the WSN can be paired with the RFID readers. In this case RFID readers are connected to Radio Frequency (RF) transceivers with routing capabilities enabling the forwarding of information to each other. For the sensing layer, sensor nodes called smart nodes, are employed. These are comprised of sensors, a battery, an RF transceiver, a micro-controller and an RFID reader.

Zhang et al. [**9**] allude to the use of D-Bus technology for communication as an end-to-end technology to ensure the communication between sensor nodes and general devices can be carried normally. Regarding transmission protocols, it is mentioned the use of XML, JavaScript Object Notation (JSON) and Thrift, pointing that JSON has advantages over XML like having a simpler data format, faster parsing density, better readability and the resulting file after serialization is smaller. It's pointed out that in a cold chain traceability system, due to problems like poor network conditions and the amount of real-time data generated due to the large number of sensor nodes use, some error data will be produced. As such, data error correction is required. For device access technology, the author presents the use of technology such as Wireless Fidelity (Wi-Fi), Bluetooth and ZigBee.

Cui [**10**] states that in general, bar codes RFID and sensors are used to identify and collect logistical information, that are stored and processed with the use of micro-controllers which is transmitted along with the use of wireless networks to service personnel. Is also mention the utilization of GPS technology as the means of location distribution vehicles. This information allows the efficient and optimal management of the logistics system, leading not only to costs and resources consumption reduction, but also the reduction of carbon emissions. At the same time, the monitoring of the transport allows an early automatic warning of anomalies. Regarding the use RFID it's salient that one possible problem of using multiple tags is the possibility of when more than one tag sends data, tag collision will occur, causing in failure of reading the data by the reader.

Sergi et al. [**11**] proposes a system based on Microsoft Azure Sphere platform. This solution comprises of a Smart Box, based on a MT3620 micro-controller, which is specially designed to work with the Azure platform. This platform permits a fast prototyping of solutions, in some cases, micro-controllers having sensors already embedded in them, like barometric and acceleration , and communication modules like Wi-Fi. The Smart Box is responsible to collect the environmental data thru temperature and humidity sensors. For the communication it is used an Wi-Fi connection to an Azure IoT hub that enables a secure two-way communication between the device and the back-end application. It is mention by the author that the Wi-Fi communication is used for prototyping reasons, but for a future stage, it must have 4G connectivity. To minimize the possible data loss, the device checks if there is a connection established, and if not, it buffers the data in a internal memory. Due to the limited capacity of this memory, when the maximum capacity is reached, it discards the older data and keeps the most recent one. Once a

connection is available, the data stored is sent to the IoT hub. In the back-end, it is used the Azure cloud services, which in terms saves the data to an Structured Query Language (SQL) data base, using an Azure stream analytics job.

Guan et al. [**12**] mentions the use of sensor devices in the cold chain logistics transport chain, permitting the gathering of temperature and humidity data in a real-time matter. This data is then transmitted to the cloud, which provides supervisors with useful information, that can be used for monitoring the of the transport conditions, permitting corrective actions to keep the environmental condition right, therefore assuring the quality and safety of the products. The data can also be used in calculating shelf live and thus, creating a better decision process in the cold supply chain. It is also mentioned that the collection of data like temperature fluctuating, vehicle trajectory and traffic conditions, combined with the application of big data and Artificial Intelligence (AI), enables the optimization of distribution paths and provides a better efficiency of the resources available, leading to a reduction in costs and minimizing the delivery times.

Ou et al. [**13**] makes use of an WSN and 3G and Near Field Communication (NFC) technology to achieve real time monitoring of the environment data, such as temperature and humidity, in the transport of refrigerated goods. To accomplish it, the author uses an DHT22 module do measure the environmental data, with is paired with an Arduino micro-controller. Then, with the use of an android application running in a smartphone and an HC-05 Bluetooth module in the micro-controller, is established a short distance connection that permits the transmission of the collected data. The application is then used to forward the environmental and position data to a server, making use of the 3G capability of the smartphone, that records it using a MySQL database. Is also mentioned by the author the use of 4G Long Term Evolution (LTE) technology with the benefit of improving the transmission speed and the efficiency.

Luo et al. [**14**] also makes use of an WSN as the means of collecting various parameters such as temperature, humidity and physical location of the goods. For such, it is used the Zigbee protocol as the means of transmitting the data between the wireless nodes and router. For the sensing nodes it is used an SHT11 temperature sensor with is paired an LM3S811 micro-controller and an CC2420 wireless transmission module for the Zigbee communication. As Zigbee uses the 2.4Ghz frequency range, it is not required to be registered with communication authority. This WSN can achieve a range of transmission between 10 to 75 meters, at a speed of 10 to 250 Kb/s. For the communication between the WSN and application layer is used 3G and 4G mobile telecommunication networks. It is also mentioned the use of GPRS, regarding the possibility of underdeveloped mobile telecommunications networks, ensuring a good coverage. The application layer will then process the received data using servers installed in a remote monitoring center, which can be displayed in the real-time status in an Liquid-Crystal Display (LCD). In case of the detection of an anomaly, the application can generate alerts to the on site personal, allowing them to take corrective measures. A web-server allows producers, customers

and transporters to access the real time and the historic data, with is kept in a database server, data through the internet.

Mohsin et al. [**15**] also refers the use of sensing nodes in a truck, with temperature and humidity sensors, as the means of retrieving data about the environmental conditions of the cargo being transported. A base station, based on the ARM7 micro-controller chip LPC2148, collects the data from the sensing nodes and pairs it with GPS data. This data is then transmitted to a cloud service that acts as a host for the data collected.

Renko et al. [**16**] refers to RFID tags as a mean of automatically capture a range of information regarding the product identity, and proprieties like temperature history. The author points the evolution in the field of temperature monitoring systems from conventional thermometry, to electronic data loggers and wireless communications systems such as like WSN and the combination of RFID technology with temperature sensors. It is pointed as advantages of using technology solutions in temperature tracking the reduction of logistical operation costs and the reduction of product losses. The author also mentions the use of printers that are connected to the cooling device of the vehicle, that can produce a receipt with the temperature level of every hour during the transport.

Jedermann et al. [**17**] mentions a Time Temperature Integrators (TTI) as the first device indication of an product been exposed at incorrect temperature settings. Usually a sticker, it gives colour indication based on the temperatures it was subject to, and it is referenced against a scale. Giving only an visual indication, it can only be read by manual, blocking the possibility of integrating with automated systems. They also have an limited accuracy, and can´t pinpoint in the where the deviation occurred. The author then refers the use an smart sensor tag containing temperature, pH, humidity and gas sensors, with allied with RFID technology could be read wirelessly. A system denominated "intelligent container" makes uses of an WSN inside or on top off pallets to monitor the temperature and other parameters, an supervision unit to evaluate the collected data, an telematics unit for the transmission of the collected data using Global System for Mobile Communications 2G (GSM) or satellite networks, and a remote web-server to web access of the data and integration with company databases. Regarding the type of communication, the author mentions if a reliable transfer could be guaranteed by a single-hop communication system, this should be the preferred against a multi-hop system, since a simpler radio protocol provides more battery life. To avoid confusion with proprietary systems, the network protocols should be based on open standards.

Li et al. [**18**] enumerates, as the technologies used to create a solution to monitor the environment of refrigerated goods on transport RFID, WSN, GPS and GPRS. As the parameters to monitor, the author mentions the use of temperature, humidity, gas and location sensors. He also mentions the use of LoRa in the device, a low power modulation technology, as the means of pushing the data to a communication gateway, and send it to the cloud. The cloud platform can provide dynamic tracking, environment monitoring, statistics analyses and alerts for abnormal environment conditions.

Cao et al. [**19**] approach a solution based on RFID tags for the monitoring of temperature conditions of tuna throughout the cold logistics chain. When the tuna is cached, with the use of an handheld device, a RFID tag is placed in the fish, and data like local of catch and species is printed and registered on the tag. These tags incorporate a temperature sensor and memory that senses and records the temperature of the tuna. In key points of the logistic circuit, like the unloading for storage, are placed RFID tag readers that extract the data from multiple tags at a time, saves it to a database and resets its memory, ensuring that the tag wont ran out of memory. At the end of the circuit, customers can, with the use of the handheld device, verify the data of the product, and confirm if there was a variation in temperature during the entirety of the supply chain. With this data, customers can assess and decide whether or not to accept the product. For this solution it is utilized SQL Server as the database layer, and Visual C as the application layer.

Zhang et al. [**20**] says that the logistical vehicle component is comprised of three parts, the vehicle terminal, the server and the monitoring center. The main objective of the vehicle terminal is to collect the data. This terminal is based on Advanced RISC Machines (ARM) processor. This processor consolidate an GPS module, an RFID module with a working frequency between 840Hz and 960 Hz and an standard 8dBi antenna, enabling a reading distance of 10m, multiple sensor modules, and thru an Code Division Multiple Access (CDMA) module, which is capable of two way communication, such as sending and receiving short messages, voice calls and data transmission to a server. It provides a mean of collecting data like cargo information and vehicle position and transmit it to the monitoring center in real-time. It also incorporates a means of interact with the vehicle driver via the use an LCD screen. This author equates the use of labels with a Quick Response (QR) code, with the consumer can scan, permitting the query of the traceability data, and the use of RFID labels, permitting the same query at a distance, but with a higher cost.

Jedermann et al. [**21**] also addresses the uses RFID tags with environmental sensors as the means of registering the temperature and humidity data. It is mentioned that there is no need of continuously sending the full sensor data over mobile networks, transmitting only alarm notifications when values cross define, and state flags. This permits a reduction in used bandwidth and communication costs. The use of semi-passive tags, which makes use of an battery for the recording logic, enables the tag to be read up to distances of 100 meters.

3.3.1. Synthesis of the extracted data

With the analysis and review of the articles resulted of the application of the methodology, table 3.5 summarizes the identified technologies used to monitor the environmental conditions of the transport in cold chain logistics.

Author	GPS	GPRS	RFID	Wi-Fi	LoRa	MQTT	LTE	AI
Kai et al.	X	X						
Li et al.	X	X	X		X	X		
Liu et al.	X							
Bijwaard et al.		X	X					
Bapatala et al.	X							
Zhu			X					
Zhang et al.	X		X	X				
Cui	X		X					
Sergi et al.				X			X	
Guan et al.								X
Ou et al.							X	
Luo et al.		X					X	
Mohsin et al.	X							
Renko et al.			X					
Jedermann et al.		X	X					
Li et al.	X	X	X					
Cao et al.			X					
Zhang et al.	X		X					
Jedermann et al.			X					

TABLE 3.5. Summary of technologies used in the monitoring of cold chain logistics

3.3.2. Technology selection

For the development of the solution it is used as a mean of sending data between the sensing node and application node LoRa technology. One of the factors that lead to this choice is the capability of transmitting messages at long distances. Another characteristic that influenced this choice is the existence of a community with gateways, providing a large network for transmitting and receiving the messages of the solution. As this community provides gateways in a shared basis it allows for a more cost effective solution, when compared with other technologies.

CHAPTER 4

Solution objectives and requirements

In this section the objectives and requirements of the solution to be developed, tested and evaluated regarding the efficacy in solving the previously approached problem are defined.

4.1. Metrics

To verify if the solution to be developed provides a benefit on responding to the research question, it is necessary to identify some metrics regarding the theme in question. These metrics are quantified before the application of the developed solution to serve as a baseline of the actual situation regarding the subject. As such, for the topic addressed in this work, the identified metrics are the ratio between the number of deviations in a year and the number of loads carried out in the same period. Consequently, it is consulted an company that handles refrigerated goods regarding the metrics identified above, before the implementation of the solution. Table 4.1 summarizes the metrics registered by the consulted company.

Description	**Value**
Number of loads with deviation	3
Number of loads handled	235
Percentage of incidents	**1,23%**

TABLE 4.1. Metrics before the implementation of the solution

4.2. Solution objectives

The main objective of the solution to be developed is to reduce the number of deviations in temperature and humidity conditions occurred during the transport of goods that need refrigeration and, in case of an deviation, the minimization of the effects on the products due to exposure to inadequate environmental conditions.

4.3. Solution requirements

The main objective for the solution to be produced is to monitor the environmental conditions, as temperature, humidity and acceleration of refrigerated goods, and in case of deviation of the normal parameters, give early warning of such conditions and where in time and location happened. As such, the first requirement is the ability of capturing the previously mentioned data. Another requirement is the ability to alert via an notification,

all parties involved in the process, such as drivers, shippers and clients, of any anomaly regarding the environmental conditions of the product been transported. It is also required that data captured to be stored and available in real time to the involved parties, allowing for the following and reviewing of the shipment data. Since different cargos required different temperature and humidity set points, it is required to be possible to set by the users, different trigger points for the alert functionality, for the different types of products being transported.

4.4. Solution parameters

The parameters to be monitored during the transport are important to maintain the preservation of the merchandise being transported. One of the key parameters that allows for the preservation of the goods is the temperature, since it is linked with the formation of microorganisms. A low temperature prevents the reproduction of such microorganisms like bacteria and mold. Humidity is also an important aspect too keep track during the transport. For cargos composed of dry foods, a low humidity ensures that this type of cargo wont absorb water creating moisture in the cargo. For fresh items, like fruits and vegetables, an high humidity environment allows for a retention of moisture in the cargo, prolonging the shelf life of the products. For fragile goods, the vibrations that they are subjected is a important factor to keep in consideration, since a high level of vibration can lead to damaged goods. As such, the measure of acceleration values of the transport can give a picture of the levels o vibrations the merchandise was subjected.

CHAPTER 5

Solution design and development

This chapter defines the architecture and functionality of the solution developed, and describes in synthesis the different layers of the solution.

5.1. Architecture definition

The solution to be developed is comprised by a sensor layer, communication layer and an application layer. Figure 5.1 schematises the three different layers and how they interact with each other.

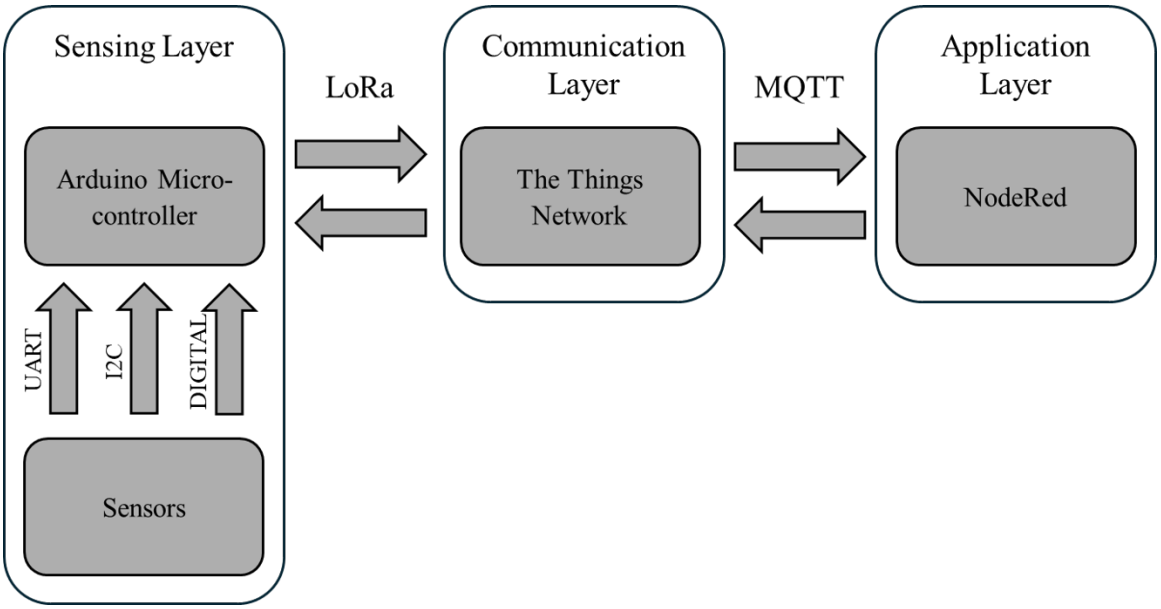


FIGURE 5.1. Solution architecture

The sensing layer is composed by multiple modules responsible to capture data regarding the environment in which they are placed, and its location. To capture the environmental data it is employed a temperature/humidity sensor and an accelerometer. With the temperature/humidity sensor we can verify if the goods being transported were kept at optimal levels to prevent the growth of pathogens or the absorption of water on dry goods. The accelerometer, responsible for register the levels of acceleration subjected by the merchandise, gives a picture regarding the levels of vibration of the cargo being transported, which is particularity important for fragile goods. To capture the location of the truck it is used a GPS module. The sensors and modules are then connected to the micro-controller which is responsible for controlling such modules, and transmitting and receiving data to the application using its LoRa capability. It is also responsible to

encode and decode the data to and from the communication layer. Table 5.1 presents the components used in the sensor layer.

Functionality	**Component**
Temperature and Humidity	Seeed DHT21
Accelerometer	MPU-6050
GPS	Seeed air 530
Micro-controller	Arduino MKR 1310

TABLE 5.1. Sensor layer components

The communication layer is responsible for sending and receiving data from the sensing layer by using LoRa technology, by encoding and decoding this data into the format necessary to enable LoRa communication and to receive and send data between the application layer using MQTT protocol.

The application layer is responsible to receive the data processed by the communication layer, storing it and display it in an organized manner to the end user. It is also responsible to generate automated alerts in case of an deviation of the set environmental parameters. This layer also provides an mean of the user to set the environmental parameters used to trigger the automated alerts.

5.2. Solution Development

5.2.1. Sensing Layer

For the fist steps of the development, is the creation of the sensing layer. As such, the select modules where connected to the Arduino micro-controller, with the use of an prototyping breadboard and jumper wired. Figure 5.2 schematizes the connections between the components.

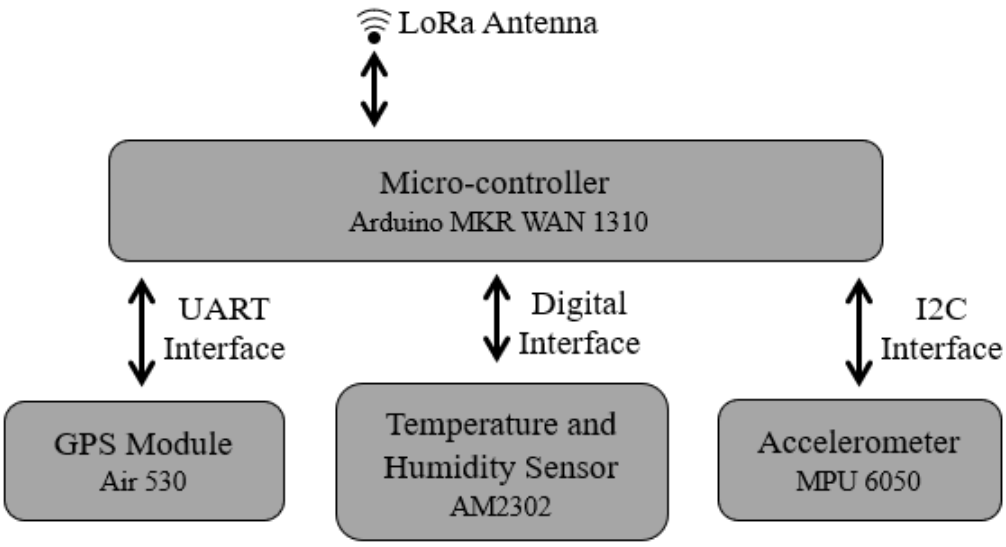


FIGURE 5.2. Connection scheme

For controlling the different applied modules, it is necessary to program the micro-controller. Therefore, it is used the Arduino IDE, an application that allows for the development of the code, using the C++ programming language, necessary to control the different components, and to compile and write the compiled code to the micro-controller. To provide functionality to the modules employed, the Arduino libraries listed in table 5.2 where installed.

Functionality	**Library**
Temperature and Humidity	DHT.h
LoRa	MKRWAN.h
GPS	TinyGPSPlus.h
I2C	Wire.h
Accelerometer	MPU6050.h

TABLE 5.2. Arduino libraries employed

With the previously chosen libraries, the code developed initializes the sensors and repeatedly retrieves the temperature, humidity, acceleration and location data in a set period of time. This data is then passed trough a constructor function to prepare the data do be sent to the application, using the LoRa capability of the micro-controller. To allow immediate alert of an deviation of optimal parameters, when an environmental value exceeds the correspondent set value, an message regarding the value in question is immediately sent. This set value can be programmed by sending a message from the application to micro-controller. The figure 5.3 presents the solution sensor layer

developed. The code developed for programming the micro-controller is available in github at https://github.com/gproo-iscte/Cold-Chain-Logistics-Tracking-Solution

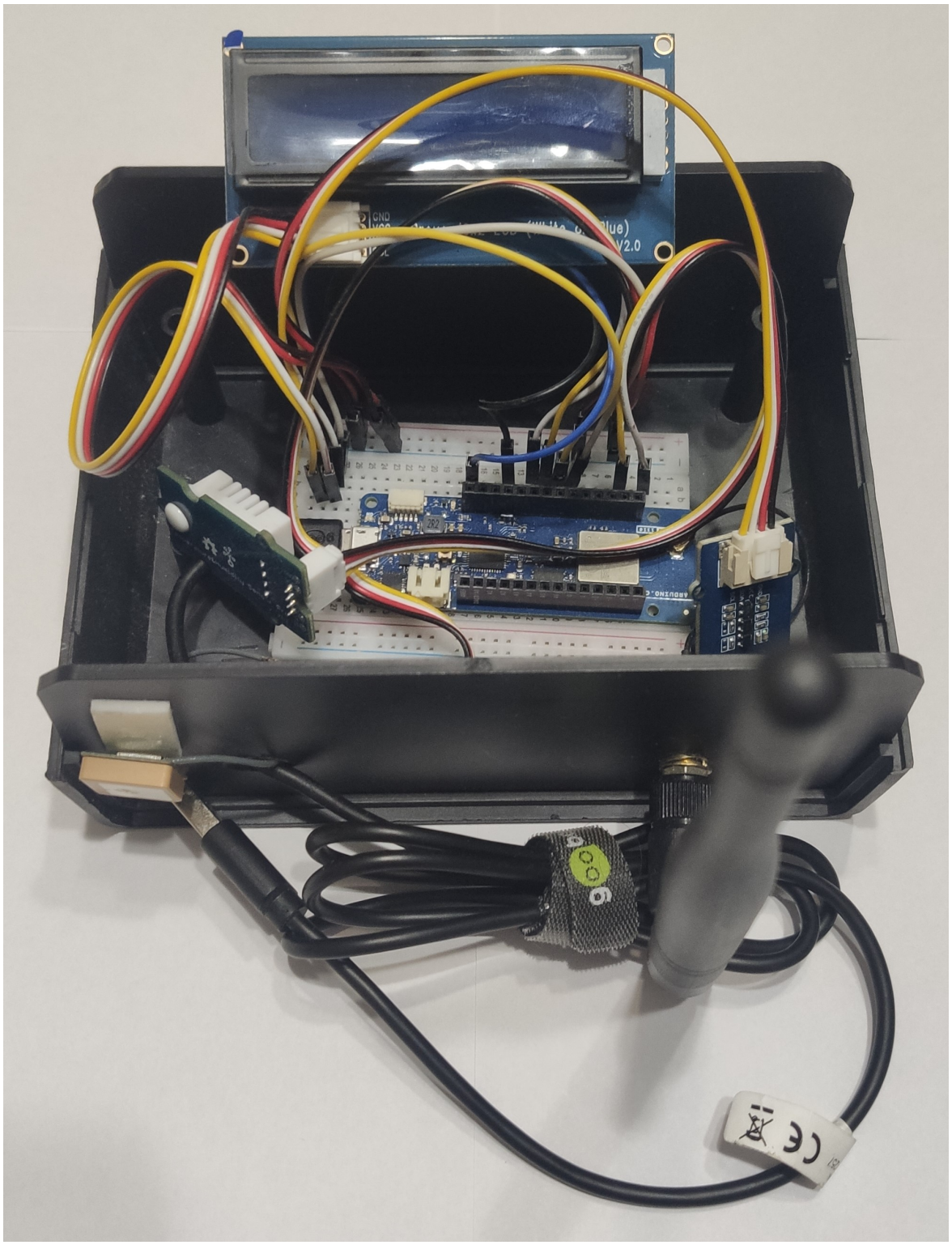


FIGURE 5.3. Solution sensor layer

5.2.2. Communication layer

For the communication layer, since the LoRa technology is to be used as the means of transmitting data, it is necessary the utilization of an communication broker. As such, the solution uses The Things Network, which provides community LoRa gateways spread across the multiple cities. The broker provides functionality for receiving, processing and forwarding of the information from the sensing layer to the application layer and vice-versa. To allow the data transmission between the communication layer and application layer, it is used the MQTT integration of the broker.

The message received from the sensing layer is encoded in a byte array, striped of its floating point values to reduce the number of bytes in the payload. To decode each of the values sensed, the communication broker contains a tool that allows for the creation of a JavaScript decoder. The decoded message is then forwarded with the sensed values attached. Figure 5.4 presents a fragment of the message processed by the communication layer, containing the payload and its decoded values.



FIGURE 5.4. Decoded message

5.2.3. Application Layer

The application layer allows the visualization of the data captured by the sensing layer. To run the application it is necessary a server with storage and a network connection. To accomplish this, it is utilized the Azure cloud services which provide these resources. A virtual machine with NodeRed, an open source low code application that provides flow programming, is used as a platform to host the application. With this, the necessary flows

to display the data received, to push the automated alarms to the users and the interface to set the parameters to trigger the alarms are created. Figure 5.5 presents and overview of the produced flow.

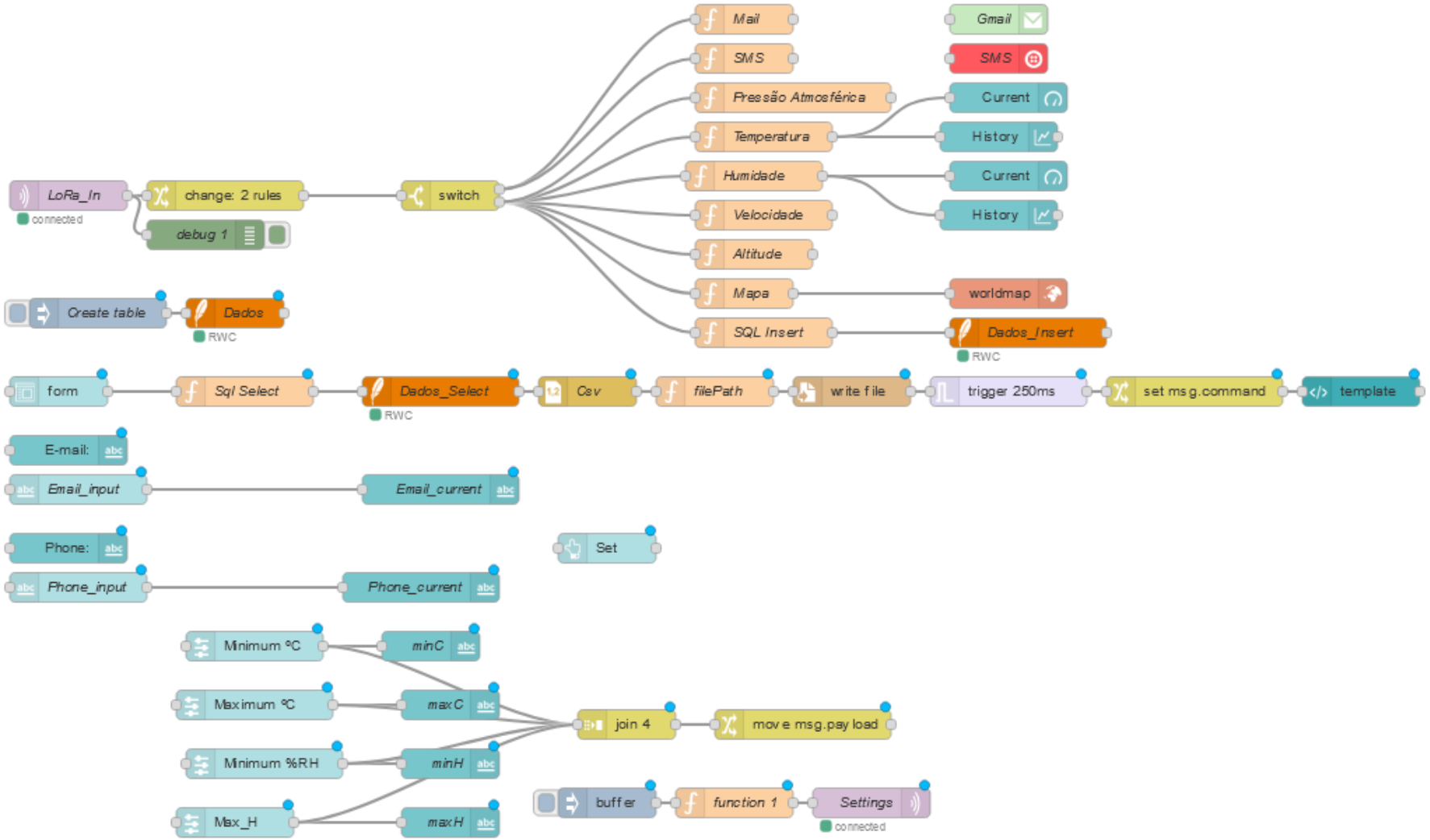


FIGURE 5.5. NodeRed Flow overview

The flow in the top of the canvas, begins with entry node of the flow and is responsible to receive the LoRa message, forwarded by the communication broker MQTT functionality. The message is then passed trough a switch that forwards the data to the display nodes of the dashboard and a SQL node to write the data, or to the notification nodes in case of an alert message.

The flow in the middle of the canvas is responsible for creating the web form, to retrieve the data that meets the criteria inputted in the form and, to generate the Comma-separated values (CSV) file with the correspondent data.

The bottom flow of the canvas is responsible to retrieve the user data regarding the trigger values of the automated alarms, and the encoding of this information to pass it via the MQTT capabilities to the sensing node.

The flow described above is also available in the git-hub repository.

5.3. Solution demonstration

This section demonstrates the functionalities of the solution, and how they can be used to possible reduce the number of deviations of the environmental conditions on the transport of refrigerated goods.

5.3.1. Data visualization

The data visualization capability of the solution enables the display of the current values of the environmental conditions of the cargo in the form of a gauge, and the past values in form of a chart. Figure 5.6 presents a view of disposable gauges and charts to the user.

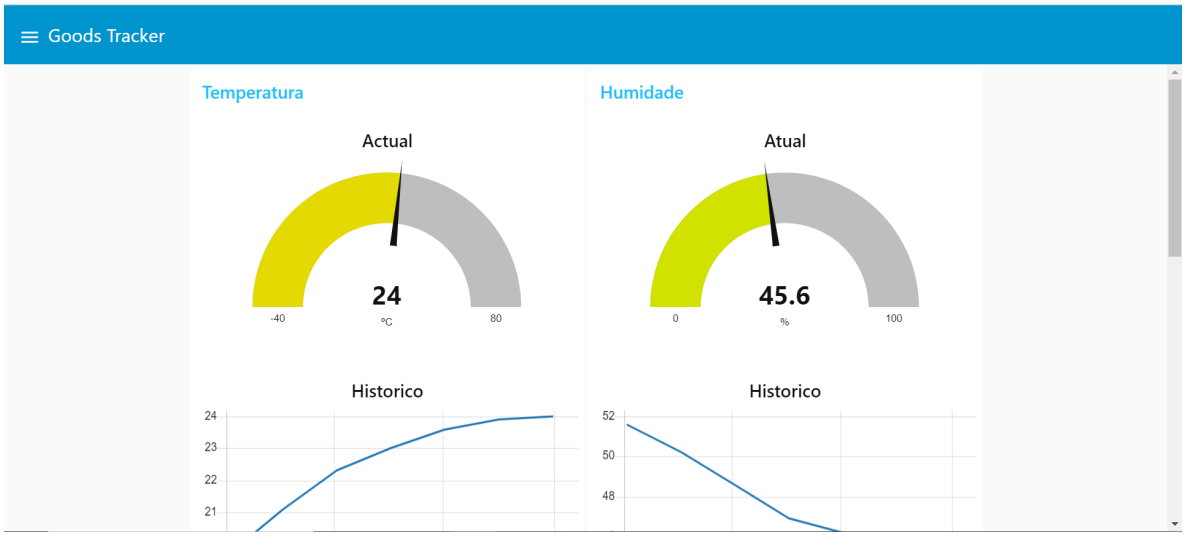


FIGURE 5.6. Data chart visualization

The application also allows for the display in a map of a sketch of the approximated route taken by the vehicle, and the correspondent environmental conditions of the cargo,

recorded at each point of communication. Figure 5.7 provides a view of the end user of the data captured by the solution in a form of a map.

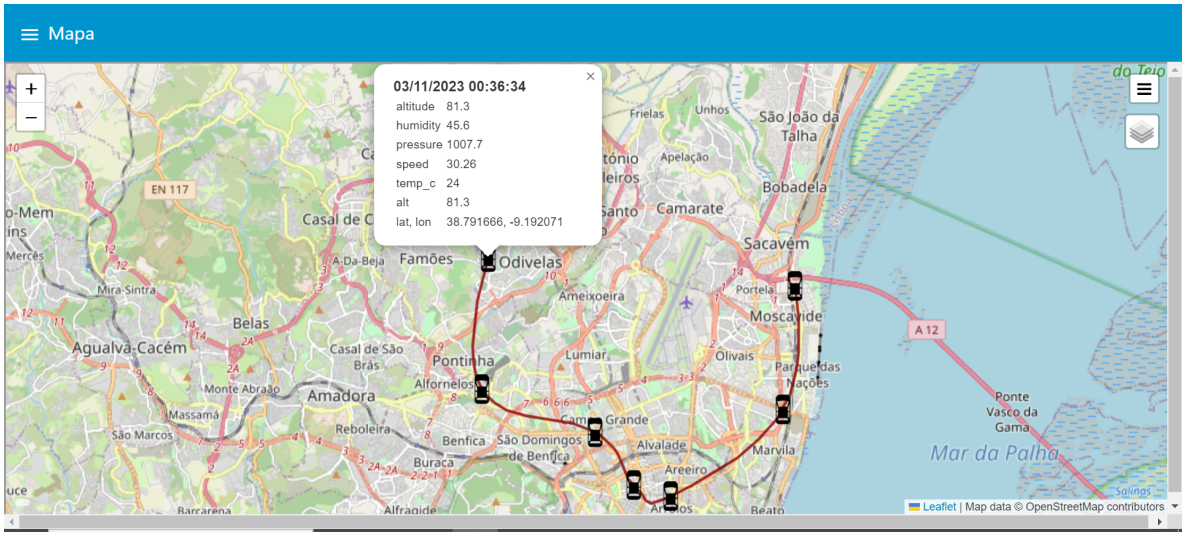


FIGURE 5.7. Data mapping visualization

5.3.2. Automated alarms

For the automated alarms, the sensing node is constantly checking if current values of the environmental conditions are in accordance with the set values. In case of the sensing values exceeding the set parameters, the sensing node will immediately send a message to the application that triggers the dispatch of an automated e-mail and text message to the configured recipients. For the email it is used an email node which uses Simple Mail Transfer Protocol (SMTP) to send the email to an existing account. Regarding the text message, it is used Twilio API to send the message to the configured recipients. Figure 5.8 presents an example of the notifications sent by the application layer.

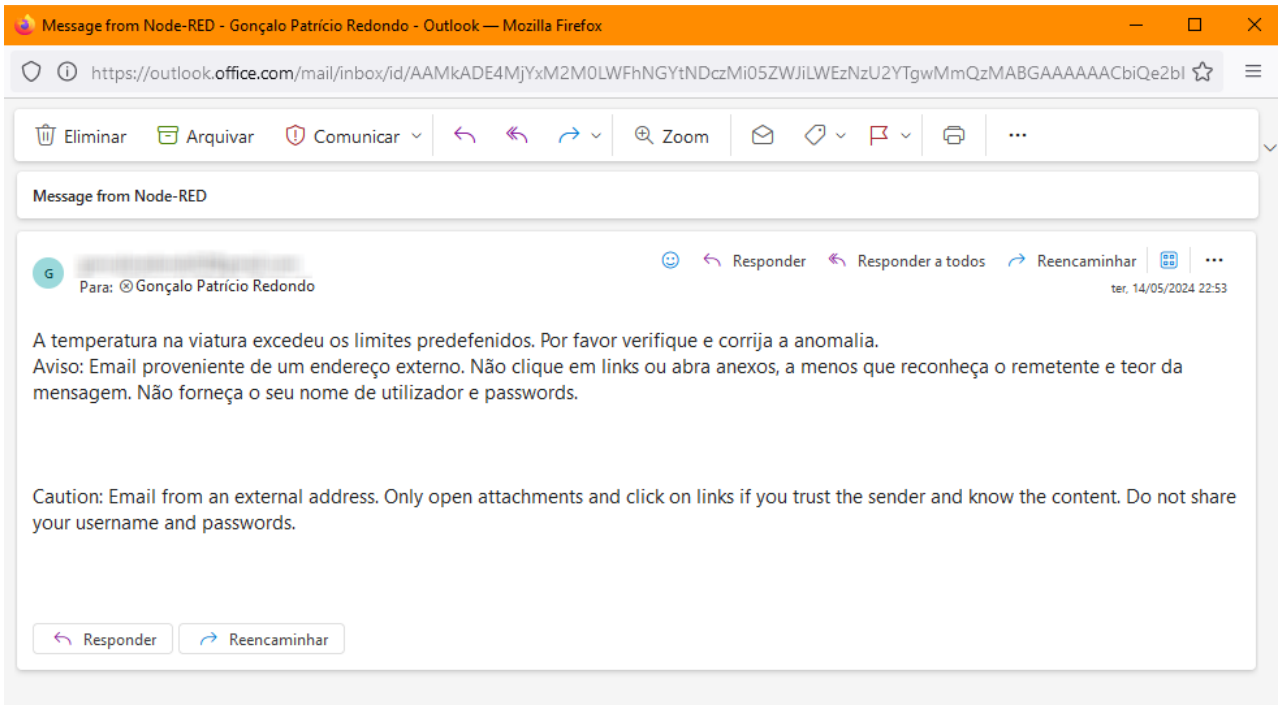


FIGURE 5.8. Notifications example

5.3.3. Parameters setting

To enable configuration of the settings for the automated alarms, such as the thresholds and the recipients of the alerts, the user has access to a settings interface where those parameters are set. This page also allows for the export of the registered values sensed by the solution. Figure 5.9 presents the aspect of the user configuration interface.

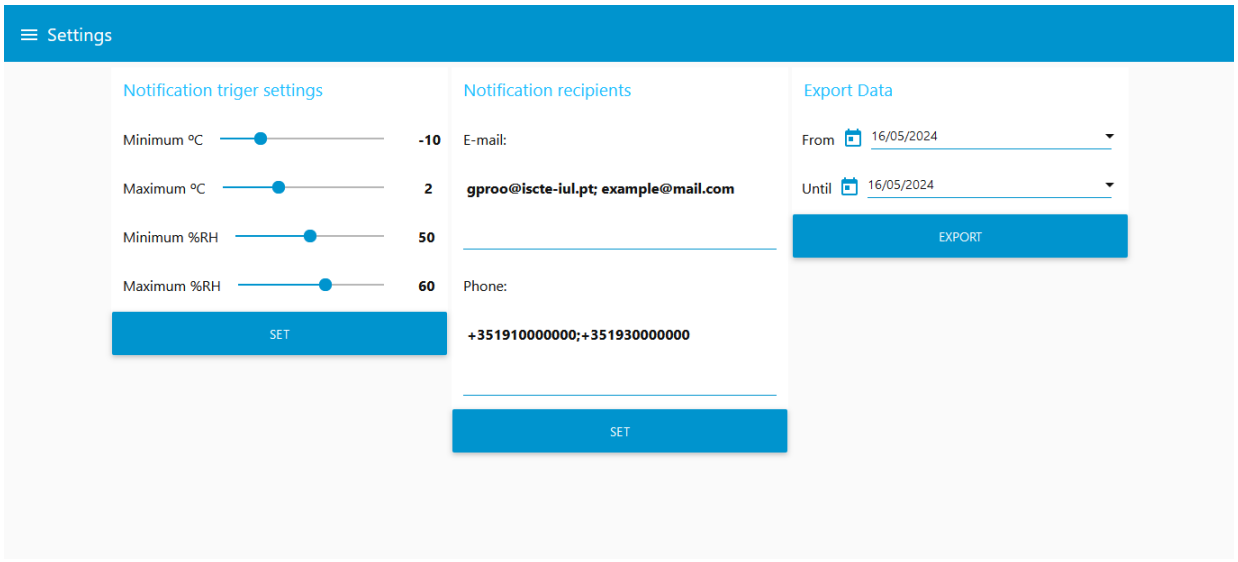
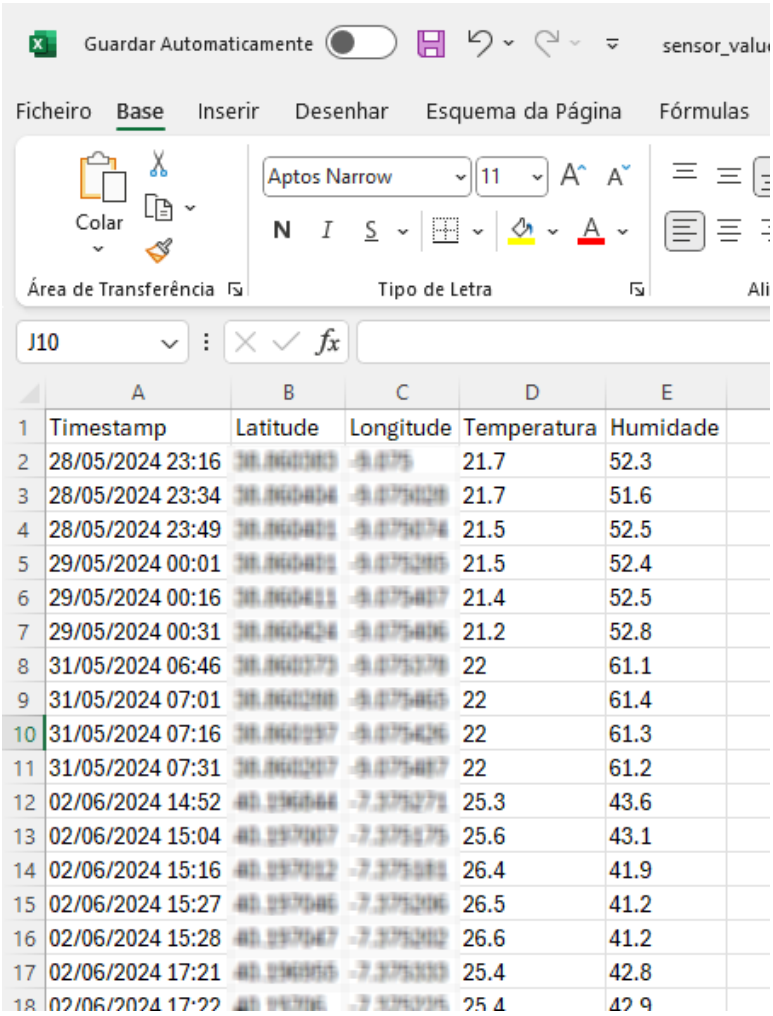


FIGURE 5.9. Settings user interface

5.3.4. Data export

Since the solution records the sensed values in a database, it is possible to retrieve this data by querying it. As such, the user settings interface allows for query the recorded data in a date interval, and returns it in CSV format. Figure 5.10 presents an example of exported data from the application layer.



	A	B	C	D	E
1	Timestamp	Latitude	Longitude	Temperatura	Humidade
2	28/05/2024 23:16			21.7	52.3
3	28/05/2024 23:34			21.7	51.6
4	28/05/2024 23:49			21.5	52.5
5	29/05/2024 00:01			21.5	52.4
6	29/05/2024 00:16			21.4	52.5
7	29/05/2024 00:31			21.2	52.8
8	31/05/2024 06:46			22	61.1
9	31/05/2024 07:01			22	61.4
10	31/05/2024 07:16			22	61.3
11	31/05/2024 07:31			22	61.2
12	02/06/2024 14:52			25.3	43.6
13	02/06/2024 15:04			25.6	43.1
14	02/06/2024 15:16			26.4	41.9
15	02/06/2024 15:27			26.5	41.2
16	02/06/2024 15:28			26.6	41.2
17	02/06/2024 17:21			25.4	42.8
18	02/06/2024 17:22			25.4	42.9

FIGURE 5.10. Exported data

5.4. Solution evaluation

This section presents an evaluation of the proposed solution to accomplish the proposed objectives, and its efficiency regarding the problematic exposed, and also if the artefact developed gives answer to the research question presented in this work. To do so, the sensing layer of the proposed solution is placed in a simulated environment, allowing for the register of the environmental values during the trip.

To create the environmental conditions of a truck cargo box, it is utilized a portable electric cooler, where it is positioned the proposed solution, along with frozen accumulators. This cooler is then transported in an aleatory path to determine if the sensing layer of the solution is capable of transmitting the conditions of the simulated environment. To

evaluate the solution capability of trigger an automated alert, the cooler is opened to the ambient conditions, simulating a fault. For the tests, the settings values were set for the following ranges:

Temperature: 5 - 10 ºC

Humidity: 40 - 50 %

Acceleration: 20 m/s^2

Periodic data transmission: 10 min

5.4.1. Test 1

In this test, the sensing layer of the solution is completely placed in the simulated environment, representing the placement of the solution inside a cargo box of an vehicle. During the course of the test, it is noted that periodically, some of the transmissions regarding the status of the environment do not reach the communication layer. Despite the solution is continuously measuring the parameters of the environment, and when the set threshold is overshoot, the lack of gateways in range can cause the failure to receive the message that triggers the automated alerts to the users in the application node. with this, it is possible to lose an event of deviation, and consequently the loss of an opportunity to correct the origin of said deviation, which can lead to the degradation of the merchandise being transported.

5.4.2. Test 2

In this scenario, the antenna of the solution is placed outside the box, representing the deployment of the antenna outside of the cargo box of an truck, and the sensors inside of the cargo box, in the attempt to eliminate some of the missing points of transmission. This configuration allowed for an improvement if the reliability of reception in the communication layer, but did not eliminate the problems observed in the previous test.

CHAPTER 6

Conclusions and future work

6.1. Conclusions

With the evaluation executed in the previous chapter, it was identified that the use of the LoRa community gateways, and its uneven distribution can lead to the loss of some points in time of the sensed values. This also can lead to the loss of an message triggered by an overshoot of set optimal values event. The loss of this type of event reflects in an missed opportunity for correcting an problem in the transport, since the end user did not received the automated alert that the application layer should have generated upon the reception of this type of message. Ultimately, the missing of this event can cause the degradation of the merchandise being transported. It is also noted that line of sight between the sensing layer solution to the community gateways is a factor that affects the transmission of data. With the placement of the antenna outside of the simulated environment it is noted a reduction in the number of points loss.

Taking in consideration the previous finding regarding the possibility of loss of data, it is not possible with the used methods an end to end traceability of the conditions. This is caused by the loss of some punctual data, which means we can lose the picture of an segment of the trip.

Due to the lack of historic continuous data, like the records of the various values registered in the transport, by the queried company, it is not possible to evaluate the produced solution in an comparative manner to the other technologies identified in the research phase.

Through the findings above mentioned, and regarding the research question established in the beginning of this work, even tough the solution is capable of sensing and transmitting the environmental data of the cargo box, with the lack of constant data transmission we can not ensure the conditions of the refrigerated goods in the entirety of duration of the transport. With this, although it was possible to developed an solution based in LoRa technology, the H1 set in the beginning of the work does not give an full answer to the research question.

With the work developed in this dissertation, in particularly, the findings about the current technologies in use, and the development and demonstration of the solution presented, this research achieved an acceptance and presentation of an article at the 4th International Symposium on Sensing and Instrumentation in IoT Era, which is pending publication at the time of writing.

6.2. Future work

Since the produced tests carried out to the solution where made in a simulated environment, one of the proposal for a future work is the subjection of the produced solution to an real world application, to verify if the produced results are in line with the outcome obtained in this work.

Another proposal for future work is the consultation of another cold chain logistic company, that could provide an different and more complete dataset. This would allow an comparison of the solution developed in this work, with the state of the art, and verifying its effectiveness in solving the problem identified in the beginning of this work.

At last, it is proposed the development of an solution that uses a different means of communication, such as 5G technology, between the sensing layer, and the communication layer. This would allow to compare different technologies in the effectiveness in pushing the sensed data to the application data. With this different technology, it is also verified, in comparison of the developed solution, the increase or decrease of the data lost between layers.

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