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# Monitoring solution for cold chain logistic transport based on LoRa technology

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**Abstract**—With the ever growing number of merchandising being transported around the globe, the need of more sophisticated solutions to keep track of these movements and in what conditions those movements are made is increasing. As such, this work aims to research the available technologies applied in the monitoring of the environmental conditions of the transport of refrigerated goods in the cold logistics chain, by reviewing relevant articles about the theme in question. With the insight of the state of the art regarding the accomplished by the review of the relevant articles, a solution based on Long Range (LoRa) communication technology is developed to achieve a set of objectives and requirements. The article also presents a demonstration of the developed solution regarding its functionality.

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

## I. INTRODUCTION

In supply chain, we see an increasing demand for technological solutions to dematerialise labour 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, we 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. We 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 the 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 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.

## II. STATE OF THE ART

For the purpose of tracking logistical vehicles and recording and monitoring the environmental conditions of goods that are required to be kept at a defined range of temperature and humidity, there are today in some solutions to accomplish this requirement. Kai et al [1] makes reference to the use of an solution based on General Packet Radio Service (GPRS) and Beidou satellites comprising of 4 acquisition nodes that measures the temperature and humidity inside of the cargo box. This data is then to a master node via wireless communication to be processed and sent to a monitoring center server using GPRS technology. 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. It also has its disposal an Android application to visualise the previously data mentioned data. The solution described by the author also provides an automated alarm that is triggered when a predetermined threshold is exceeded.

Li et al. [2] also describes an similar solution with the objective of monitoring in real-time *Tricholoma matsutake*, a type of edible fungus sensible to changes of temperature and humidity. In this solution are employed temperature, humidity and gas sensors that feed an information gathering node. This node then uses GPRS as means of transmitting the data collected to an application layer based on the TLINK Cloud Services Platform, which provides real-time connection to multiple sensing nodes. It also supports API as a means of treating and develop data, and also enables standard integration's of IoT like Message Queuing Telemetry Transport (MQTT).

Bijwaard et al. [3] also employs the use of sensing nodes, consisting of tags with RFID technology called SmartPoints, that can host temperature and humidity sensors. Then, with the use of micro-routers and gateways, it is created a wireless infrastructure that provides the means of the SmartPoints to

transmit their data. When the SmartPoints are not in range of an 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 reestablished, resumes communication and forwards the buffered data. This solution, regarding the application layer, in addition of having a AmbiLink, a proprietary architecture that allows the remote monitoring, it has also in place an Application Programming Interface (API) that permits the communication with third party systems using Extensible Markup Language (XML).

Still on the subject of RFID technology, Cao et al. [4] describes 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.

Bapatala et al. [5] describes a solution with end nodes based on the ESP8266 micro-controller, with temperature, humidity, light and Global Positioning System (GPS) sensors to collect the environmental data. It also incorporates actuators that aid in the controlling of the environment. This solution communicates through the internet with a edge node based on a Raspberry PI, that act also as a blockchain network node, permitting that the data being transmitted is put in an chain, ensuring that the data is 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 that the safety of products. Using blockchain also permits a shared ledger, that inhibits centralized control of the data.

Sergi et al. [6] 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 Wireless Fidelity (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.

Ou et al. [7] 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.

Another author, Luo et al. [8], 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.

As a less technological system, Jedermann et al. [9] 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.

### III. SOLUTION OBJECTIVES AND 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's required to be possible to set by the users, different trigger points for the alert functionality, for the different types of products being transported.

### IV. SOLUTION ARCHITECTURE

The solution to be developed is comprised by an sensor layer, and communication layer and a application layer. Figure 1 schematises the three different layers and how they interact with each other.

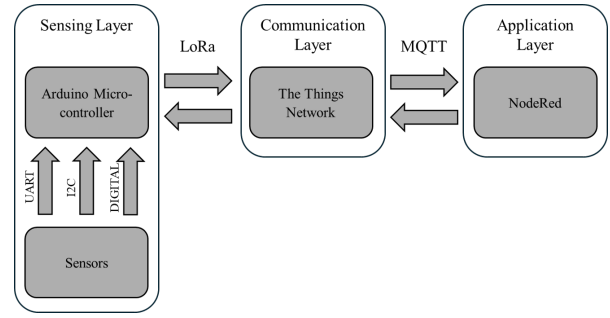


Fig. 1. Solution architecture

The sensing layer is composed by multiple modules responsible to capture data regarding the environment in which they are placed, and it's location. To capture the environmental data it is employed an temperature/humidity sensor and an accelerometer. For capture the location of the truck it is used an GPS module. The sensors and modules are then connected to the micro-controller with is responsible for controlling such modules, and transmitting and receiving data to the application using it's LoRa capability. It is also responsible to encode and decode the data to and from the communication layer.

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.

### V. SOLUTION DEVELOPMENT

For the development of the sensing layer it is used an Arduino micro-controller MKR 1310 with LoRa communication capabilities. The micro-controller allows for the connection of the necessary sensors to read temperature, humidity, acceleration and location of the cargo. This data is periodically read, processed and encoded by the micro-controller using the appropriated libraries for the relevant modulus and then sent to the application layer using the LoRa capabilities, via the communication layer. In case of detection of abnormal conditions, it sent an immediate message to trigger the automated alerts. Figure 2 presents an block diagram of the solution developed.

To receive and send the messages to between the sensing layer and the application layer, it is used The Things Network which is a LoRa communication broker. This service is community based and its members deploy gateways that are capable of receiving the messages of LoRa devices. To

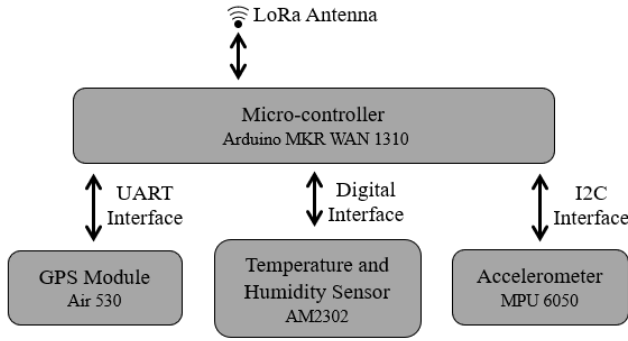


Fig. 2. Solution block diagram

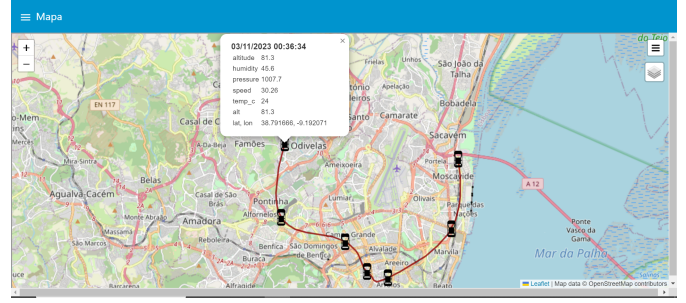


Fig. 3. Solution data visualization

provide communication with the application layer, this service provides an MQTT integration.

To develop the application layer, it is used an Virtual Machine (VM) provided by Azure cloud services, where is installed Node Red, which is an low code application based in node.js, allowing for programming based on flows. This application allows for the creation of an dashboard that presents the environmental data register by the sensor layer. Since the received data has the geographical coordinates of the sensing node, the approximated route and the environmental at the time of the transmission is displayed on an map. The application also allows for the storing the received data in a sqlite database, that can be queried by the user using an form in the application for the effect. For the automated alerts, the application upon receiving the correspondent message, pushes an e-mail to the users using Simple Mail Transfer Protocol (SMTP) protocol, and an text message using the Twilio API.

## VI. SOLUTION DEMONSTRATION

The developed solution has implemented various features that allows for constant monitoring of the environmental conditions of the cargo being transported and alert the users of an abnormal condition. For the monitoring of the transport conditions, the sensing node periodically sends the data captured by the sensors to the layer. With this data, the application layer plots in a map the approximate route taken by the vehicle, and the sensed values in points of its trip. Figure 3 presents the view of the application tracking function, and the displaying of the previously data. The application also presents the last sensed data in a form of dial, and the past values in a form of an graph.

Still in the monitoring capabilities, the solution is constantly checking if the sensed values are in range of the optimal conditions. For this, target values are set in the application layer by the user that are sent to the sensor layer, via the communication layer. In case of any deviation against the set parameters, the sensing node will trigger the transmission of an message to the application, which in turn sets in motion the dispatch of an text message and e-mail to set recipients, alerting them for the deviation of optimal environmental conditions.

The screenshot shows a spreadsheet with the following data:

|    | A                | B          | C         | D           | E        |
|----|------------------|------------|-----------|-------------|----------|
| 1  | Timestamp        | Latitude   | Longitude | Temperatura | Humidade |
| 2  | 28/05/2024 23:16 | 38.8603853 | -9.075426 | 21.7        | 52.3     |
| 3  | 28/05/2024 23:34 | 38.860404  | -9.075428 | 21.7        | 51.6     |
| 4  | 28/05/2024 23:49 | 38.860405  | -9.075424 | 21.5        | 52.5     |
| 5  | 29/05/2024 00:01 | 38.860405  | -9.075425 | 21.5        | 52.4     |
| 6  | 29/05/2024 00:16 | 38.860411  | -9.075427 | 21.4        | 52.5     |
| 7  | 29/05/2024 00:31 | 38.860424  | -9.075436 | 21.2        | 52.8     |
| 8  | 31/05/2024 06:46 | 38.860373  | -9.075378 | 22          | 61.1     |
| 9  | 31/05/2024 07:01 | 38.860286  | -9.075463 | 22          | 61.4     |
| 10 | 31/05/2024 07:16 | 38.860297  | -9.075426 | 22          | 61.3     |
| 11 | 31/05/2024 07:31 | 38.860267  | -9.075487 | 22          | 61.2     |
| 12 | 02/06/2024 14:52 | 40.297044  | -7.375271 | 25.3        | 43.6     |
| 13 | 02/06/2024 15:04 | 40.297067  | -7.375275 | 25.6        | 43.1     |
| 14 | 02/06/2024 15:16 | 40.297032  | -7.375283 | 26.4        | 41.9     |
| 15 | 02/06/2024 15:27 | 40.297046  | -7.375296 | 26.5        | 41.2     |
| 16 | 02/06/2024 15:28 | 40.297047  | -7.375292 | 26.6        | 41.2     |
| 17 | 02/06/2024 17:21 | 40.296995  | -7.375333 | 25.4        | 42.8     |
| 18 | 02/06/2024 17:22 | 40.296996  | -7.375335 | 25.4        | 42.9     |

Fig. 4. Data export

As the application receives over time the environmental data form the sensing layer, it keeps a record of it in a database. As such, it is possibly to posteriorly retrieve the stored data in Comma-separated values (CSV) format. To do so, the user has at it's disposal in the application layer a form where the range of dates is inputted, retrieving the sensed data for the period selected by the user, and automatically download-it to the user computer. Figure 4 presents an example of the data by the functionality previously described.

## VII. CONCLUSION

With this work it was achieved a solution based on LoRa technology capable of reporting to users the key values that ensure the proper conditions of refrigerated goods, and recording such data for later use by extracting it from the application layer. As for future work, the efficiency of the proposed solution is to be measured in regarding the ability of monitoring the main parameters that ensure the integrity of

the cold chain logistics such as temperature and humidity, and it's ability to alert the key recipients in the event of deviations of the ideal parameters for the cargo being transported.

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