IIoT-based Inventory Management

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Abstract—**The Industrial sector plays a very important role in the worldwide economy, however, the lack of offers of industrial management tools, namely inventory management tools, at competitive prices, with intuitive interfaces and off easy access, de-balances the growth of opportunities for companies in general, having a special impact in smaller to medium size (SMEs) companies and with less purchasing power. In order to solve this problem, IoT technology plays a fundamental role, facilitating the creation of technological standards that drive the development of inventory management systems that are cheaper, smaller, more efficient, with higher scalability and more intelligent. In this context, this Master's Thesis had two objectives: the first being the creation of a wide spectrum Inventory Management questionnaire to be applied to a Mozambican SME and the second to develop of a minimum viable product (MVP) which requirements came from the questionnaire findings as well as the IoT standards and the basilar characteristics of efficient inventory management systems.**

Keywords—Internet of Things, Industry 4.0, Inventory Management, Bluetooth Low Energy, Industrial Weighing scales, Trilateration, SMEs, Mozambique

I. INTRODUCTION

For centuries companies have struggled with the employment of efficient Inventory Management Systems. If at the beginning, inventory management systems were extremely basic and entirely manual, today the reality is much different. Supporting that, industry giants, namely a big portion of the Asian and German manufacturing sector and some companies of the American market, have cleared the path for companies of all sizes to start including Cyber Physical Systems to digitalize every person, process, and asset involved in the supply chain. As such, in what regards the industrial sector, IoT is propelling the materialization of what is being referred to as the next industrial revolution, i.e., the Industrial Internet of Things (IIoT). From this movement small to medium size enterprises (SMEs), which represent 98,8% of all businesses, that employ more than 2/3 of all workers and contribute with more than 1/2 of their regions gross value added (GVA), are expected to derive the most benefits from this virtualization [1]. Yet, specifically in what regards the adoption of advanced management systems and collaborative tools based on demand, production and delivery plans, SMEs can't compete with the big enterprises due to their restrictive resources and the impact of the ongoing economic crisis on their businesses [2]. From those, SMEs in developing countries, such it's the case of Africa, are an intuitive starting point to serve as a pilot for CPS development, as they become increasingly more dependable of IT inside and outside the business environment and the cost of hardware needed decreases at the same pace that the number of connected devices and meaningful data available grows. In Mozambique, specifically, tech-based projects in the lines of the "Scale-up your ambition" movement are particularly relevant. There's a growing interest in startups that promote the enhancement of business management quality and that contribute to the development of an entrepreneurial national unity focused on changing the country's industrial activity from a consumer-centred to a production-centred position [3]. In accordance, bridging the need of a sustainable economic growth of the industrial sector with the increasing availability of technologies as the IoT and professionals to make it a reality, makes it inevitable that the future of the Mozambican industrial sector will be centred in the inclusion of products that ease the control of Manufacturing companies' working capital. Adding the fact that inefficient inventory management is one of the four main causes of business failure among SMEs and that is a matter of smoothing the access to the proper technologies to close the gap of digital transformation, designing new and better inventory management systems for the industrial sector, is more than ever, of the outmost relevance [4]

A. *Objectives*

This thesis focus on studying the impact of efficient inventory management tools in the industrial sector and extol the enormous market opportunity for widespread adoption of IoT-based CPS. In summary, the objectives of this Thesis are:

- Overview the state-of-the-art concepts related to efficient inventory management systems;
- Review the IoT space, main drivers and technological standars;
- Develop a questionaire based off the concepts presented to be implemented for a Mozambican SME;
- Define the MVP requirements and specifications;
- Describe in detail the solution developed;
- Test the solution;
- Retrieve conclusions from the project.

B. *Minimum Viable Product*

The MVP presents as the first version of a new product that allows the aggregation of validated learning about costumers and their continuous development through testing of a minimum set of features. The MVP possess three key characteristics: It has enough value that costumers are willing to use it or buy it initially; demonstrates enough future benefit to retain early adopters; and pro- vides a feedback loop to guide future product tuning [5].

C. *Outline*

This first chapter made an initial introduction to the problem studied throughout this thesis, and the motivation behind the design of a IoT-based inventory management system for the industrial sector. An overview of the work methodology implemented to achieve the thesis goals is also provided. In Chapter 2 an overview of the basic themes related to Inventory Management and the connected supply chain is made. Besides that, the IoT space is defined, namely its key elements, enablers and drivers, underlining the importance of IoT technology in the future support in the design of efficient Inventory Management Systems for the industrial sector. Additionally, a market analysis is made by creating an application scenario developed based on the operation overview of a Mozambican pilot company, from which the MVP system's requirements are derived. Then, in Chapter 4, the actual inventory management solution is proposed in an architecture view, with all the system's components thoroughly described. Afterwards, in Chapter 5 the MVP's performance is assessed under relevant and meaningful conditions after being physically implemented as a proof-of-concept in an environment mimicking a manufacturing company. Finally, Chapter 6 sums up the main achievements of the work developed, and leaves some suggestions for future work on the MVP.

II. Industrial Inventory Management

Globalization and the market's harsh competition has demand that customers get the best products, in the right time, place and in the right conditions at the lowest costs, pushing organizations to no longer purely compete as autonomous entities, but rather as supply chains [6].

A supply chain (SC) consists of a complex network of entities involved in business ventures, that are connected by the flow of inventory, information and financial transactions, while dispersed over a large geography. The SC must always be perceived as a dynamic system that evolves over time due to changes in the network, e.g., changes in customers' demand, supplier capabilities and in system complexity [7]. Figure 1 illustrates an example of the links among the composing stages of a standard supply chain network.

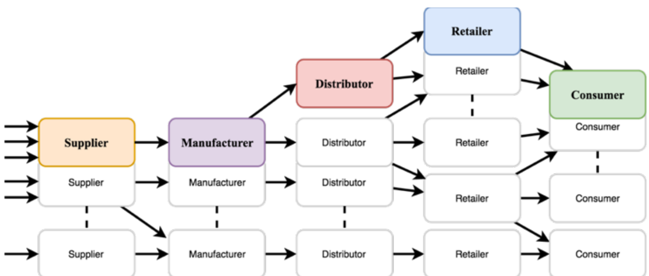


Fig. 1. The composing stages of a standard supply chain network.

Traditionally, to study and describe the SC's flow a cycle view is utilized, where processes are divided into a series of cycles, each performed at the interface between two successive stages of a supply chain. Each cycle is decoupled from the others by an inventory interface enabling their independent functioning and eliminating exposition to other cycles constrains [8]. Concordantly and in a general manner, the four primary cycles of a supply chain are, as shown in Figure 2, described as: the costumer order cycle, the replenishment cycle, the manufacturing cycle and the procurement cycle.

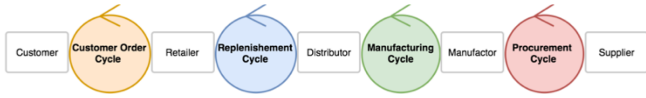


Fig. 2. The four primary cycles of a supply chain.

Concordantly, Supply Chain Management presents has the integration of key business processes that manage products, capital, people, and information within and across the supply chain with the aim off adding value to customers and minimizing the costs generated by flow between links. As a result, key requirements to efficiently manage the supply chain are connected to planning and controlling the flow of inventory [9].

A. *Inventory Management*

To well define the scope of Inventory Management (IM), it's first necessary to express the differences between stock and inventory: Stock consists of all the goods and materials that have economic value and which are held by an organization to facilitate their future consumption, sale or additional processing; inventory is a list of the items held in stock [10]. There are several metrics to classify different types of stock, the most common being that which categorizes it into raw materials, products in progress (also known as WIP) and finished products, with each type is distinguished from the others by their position in the value chain. Figure 4 illustrates the different stock classes within a factory floor.

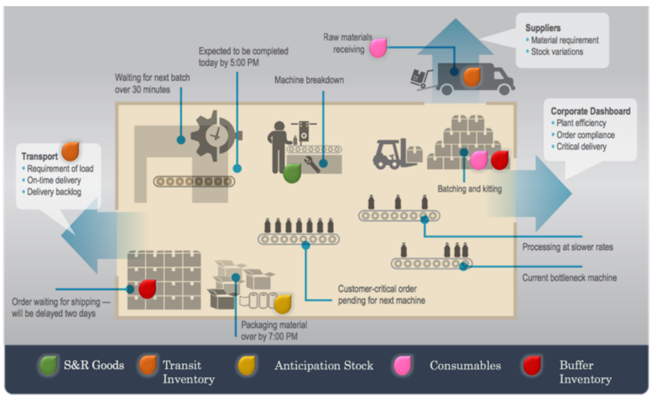


Fig. 3. The stock classes in the manufacturing sector.

Inventory management presents as the group of processes and operations employed by an organization that aims the maintenance of an optimum size of inventory with the minimum possible investment. Thus, inventory management aims to respond three basilar questions: How much inventory must a company hold to maintain optimum size of inventory? When should a company order inventory to ensure minimum investment? and Where should inventory be placed among a company and/or supply chain to maximize profitability?[11].

B. *Inventory Management in Manufacturing SMEs*

For many manufacturing companies, inventory is the largest part in their assets category. As result, manufacturing SMEs, recognized efficient inventory management policies as a vital tool to enhance competitive ability and market share, as well as being a key enabler in building successful SMEs. However, the positive impact of inventory management on manufacturing SMEs in developing countries is not as effective as in developed countries due to different industry conditions and reversal objectives [12][13]. In more developed countries, good business infrastructures and communication channels are already an integral part enterprise management, thus SMEs work towards having the most competitive prices by lowering total inventory costs to stay competitive. Yet, in developing countries, as the general industrialization policies are built in protectionist strategies and the capabilities of the local industries are small, manufacturing SMEs live by a regime of monopoly. Consequently, companies operate with no fear of losing market share, or major concerns in meeting delivery dates and reducing production and inventory costs. Still, as those companies need to rely heavily on imported materials and political and bureaucratic policies make the foreign exchange a slow and difficult process, ensuring regular supply of raw materials isn't easy [12][13][14]. In concordance, researches show that the primary inventory management challenges faced by SMEs in developing countries in descending order of occurrence are as follows:

- Poor inventory records;
- Delays in the delivery of materials: Specially from suppliers to manufacturers but also within the production line;
- Underproduction [15][16].

As poor inventory management presents as a worldwide problematic, studying the characteristics of efficient inventory management systems is of outmost importance.

C. *Efficient Inventory Management Systems*

Studying today's well-performing inventory management systems, one concludes that they're typically designed to fulfill three specific requirements: efficient product identification, order management and asset tracking [17].

1) *Product Identification Systems*

Product Identification Systems (PIS) represent the part of inventory management systems responsible for the input of all stock data held by a company in its system. Nowadays, the majority of PIS require identifiers on both product and physical locations to create an infrastructure that can track products as they move. Frequently, those products are perceived as stock keeping units (SKUs), i.e., distinct numbers assigned to inventory items which intrinsic attributes, such as the manufacturer, material, size, color and packaging, distinguish them from all other inventory items [11].

2) *Order Management Systems*

Order Management Systems (OMS) are the integral part of efficient inventory management systems responsible for the management of stock quantity. Hence, OMS aim to prevent companies from falling below a specific threshold of stock quantity by collecting knowledge of a company's following singularities:

- Reorder point: The number of units that should trigger a replenishment order;
- Order quantity: The number of units that should be reordered, based on the reorder point, stock on hand and stock on order;
- The lead demand: The number of units that will be sold during the lead time;
- The company's stock cover, i.e., the number of days left before a stock out if no reorder is made; and the company's system accuracy, regarding forecasting models and reports.

Nowadays, the best metrics of OMS include the trigger of alert mechanisms that help of company's managers to reorder products, avoiding running out of goods or tying up too much capital in inventory [10].

3) *Asset Tracking Systems*

Asset Tracking Systems (ATS) represent the part of inventory management systems responsible for the tracking of inventory movement within a company's facility and/or supply chain. The most common ATS are the Memory, Fixed, Random or Combination.

Memory systems are solely dependent on human recall, thus, being extremely simple, free of data entry and with added maximum utilization of all available space. On the other hand, Fixed location systems, assert a specific home to every item in the stock list and nothing else is allowed to placed there. This type of system normally requires large available spaces and may deal with honeycombing. Dissimilar from the previous, Random locator systems, are characterized by no item having a specific place to be in while knowing where everything is. Lastly, Combination systems are characterized by not being purely fixed nor purely random. Hence, these systems assign specific locations to items requiring special consideration, while the bulk of the product mix is randomly located [11].

Narrowing the focus of how product should be positioned within a business's warehouse, ATS may also predict the best physically arrangements of items to reduce cost of internal logistics, of holding stocks and lead times.

D. *Inventory Management Systems' evolution*

Inventory management is not a new concept. The earliest evidence of inventory management dates back to approximately 40,000 years and discloses how humans counted animals with ancient tally sticks. With the ascend of the second Industrial Revolution businesses grew to a point were inventory management became a mean to truly develop the market place. So, at the end of 1880s, Herman Hollerith, developed an electromechanical punch card tabulator that allowed companies to manage the financial and inventory recording aspects of their commercial transactions and develop the first ordering system. Nevertheless, it was shortly after the beginning of 1940s that the punch card adoption decayed due to the process being too expensive and slow to remain widely used and to keep up with the business demand. Following that, the first version of barcode technology was deployed to the market and so inventory tracking by hand was replaced by barcode scanners while inputting that information into computers was still handmade, which lead to poor efficiency and errors. To ease of the tracking systems and to diminish the existing problems, technology advancements in the 1980s and 1990s pushed larger companies to implement computerized systems to manage inventory. Then roughly from 1997 to 2001, the dot-com companies where created and a period of extreme growth in the usage and adaptation of the Internet emerged leading to the boom of Application Service Providers (ASP), who made the first efforts on creating inventory management applications available online. At that time ASP were extremely slow, inefficient and thus failed to scale, which opened the market for Radio Frequency Identification (RFID) systems, which ensured vendors to know for the first time which products they had and which were properly available having constant access to real-time sales data, since businesses no longer need to input data by hand and the classical barcode readers could instantly update databases. There's no doubt that Inventory Management has been a growing priority for businesses and supply chains. Thus, since the beginning of 2010 and with the entrance in the era of e-commerce, technologies like the Internet of Things (IoT) have been leading the peak of inflated expectations of inventory management systems for the manufacturing sector [6][18][19][20][21]. Figure 6 illustrates the timeline of inventory management systems until 2020.

Fig. 4. The evolution of the IMS.

E. The Internet of Things

The Internet of Things presents as the space of uniquely addressable virtual and physical objects, equipped with data capture and communication capabilities, interconnected through channels that enhance the analysis of huge amounts of data continuously generated from interaction with the surrounding environment. In that view, objects are computing devices ranging from computers, machines, people and physical goods that can sense, communicate, aggregate, analyze, act and react to people and machines around them for a clear human, business or social purpose [22].

These systems make use of connectivity, data, communication and intelligence capabilities to grant:

- Real time monitoring and data logging;
- Remote monitoring;
- Data analytics;
- Simplicity to access [23].

F. IoT key drivers

Every enabling technology in the Internet of things space is driven by a number of technical and market opportunities. These drivers are defined as the key catalysts of IoT CPSs, greatly influencing their future development and usage. Therefore, the main drivers of today' CPS are:

- The increasing availability of cheaper, smaller and smarter sensors;
- Higher power efficiency;
- Bigger identification spaces;
- Lower Internet transit prices;
- Bigger data rates;
- Growth of real-time data processing & analysis tools [24][25][26][28].

G. The IIoT: Architecture and standards

As the IoT space has the potential to influence everything from new product opportunities to business scalability, it's total impact may be yet unmeasurable. However, in what regards the industrial sector, IoT conducts the fourth industrial revolution movement, presenting as the interconnection of products to people, processes and infrastructures to Industrial applications, including, but not limited to, manufacturing [29]. This concept is nowadays described as the IIoT, i.e., the Industrial Internet of Things and aims to ease the access of companies to more automated, intelligent and streamlined processes. As the IoT space is fairly vast and in an attempt to narrow the focus this technology, Figure 5 illustrates the IoT's protocol landscape [30].

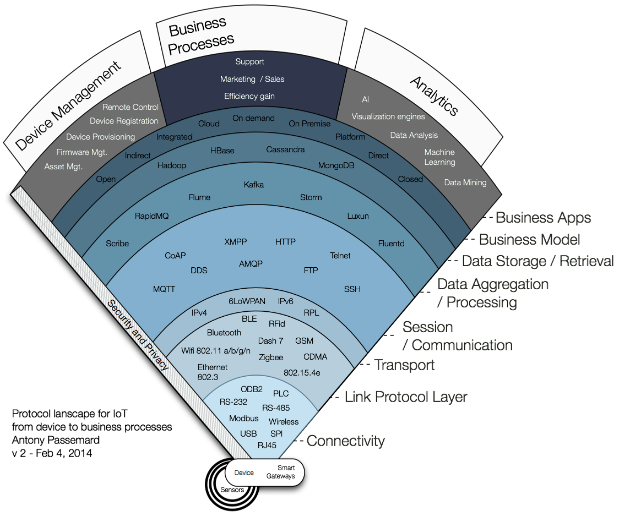


Fig. 5. The IoT architecture and the technological standars [31].

Analysing the previous, the IoT architecture can be divided in four layers: the device layer; the network layer; the service layer; and the content layer.

H. *Market Analysis*

A market analysis, based in presential interviews, is conducted in the Mozambican Industrial sector, featuring enterprises of all sizes and fields of operation based in Maputo, including but not limited to both service-base and manufacturing-based type enterprises. A broad-spectrum questionnaire is created to be applied to companies anywhere in the world to aid the easy identification of strengths and weaknesses of their inventory management policies and therefore ease the characterization of the fundamental requirements to be developed in a minimally viable product that fights the gaps found and that exalts the already existing virtues of those companies' inventory management tools.

1) *The Mozambican Industrial Sector*

Mozambique's Industrial sector is still in its infancy, and remains marginalized from global value chains. Nevertheless, its geographical position, specially its close proximity to South Africa, the existent low labor cost and the transport infrastructure as well as port access, create favorable conditions for the sector's expansion. At present, the share of manufacturing is limited to 10% of the total country's GDP, including the manufacturing of wheat flour, food beverages, aluminum, petroleum products, textiles, cement, glass, and tobacco. [31]. Geographically, the majority of these companies are in the main urban areas of Maputo, Beira, and Nampula [32].

Regarding inventory management, today the majority of Mozambican companies heavily rely on memory locations systems and inventory documentation based on excel sheets. A small minority of these employ software based tools fed by .csv files, provided by one of the two most well-established IT Portuguese companies: Primavera and Adicional Logistics.

Despite that, the current state of Mozambique's business environment is depicted by the economic indicators illustrated in Figure 6.

Business	Last	Reference	Previous	Range	Frequency
Business Confidence (Index Points)	98.5	Feb/19	99.7	86.6 : 109	Monthly
Industrial Production (%)	8.5	Dec/18	7.9	-12.7 : 38.2	Monthly
Industrial Production Mom (%)	-11.1	Dec/18	-1.8	-32.5 : 20.9	Monthly
Internet Speed (KBps)	2364	Mar/17	2690	236 : 2690	Quarterly
IP Addresses (IP)	60570	Mar/17	57816	6811 : 99773	Quarterly
Changes In Inventories (MZN Million)	55713	Dec/17	122677	-643 : 122677	Yearly
Competitiveness Index (Points)	39.75	Dec/18	41.9	3.01 : 41.9	Yearly
Competitiveness Rank	133	Dec/18	125	119 : 138	Yearly
Composite Pmi	50.4	Mar/19	50	50 : 51	Monthly
Corruption Index (Points)	23	Dec/18	25	22 : 35	Yearly
Corruption Rank	158	Dec/18	153	56 : 158	Yearly
Ease of Doing Business	135	Dec/18	138	128 : 142	Yearly
Leading Economic Index (%)	-12.8	Jan/19	-6.8	-15.8 : 15.8	Monthly
Mining Production (%)	14.5	Dec/18	5.3	-34.8 : 204	Monthly

Fig. 6. Mozambique's economic indicators.

2) *Appication Scenario: AFRITUBO*

Through the course of the interviewing process, there was a vast obstruction of information by the companies' side due to the lack of confidence and knowledge on how their sensitive information would be handled. Therefore, to not compromise this thesis final objectives, the company which provided more information and general openness throughout the interviewing process would be chosen as a pilot company for a real application scenario. As a rule of conduct, only managers would participate in the interviewing process and a minimum one-year experience was required. With the previous in mind, AFRITUBO is chosen as the pilot for this thesis project.

AFRITUBO is Mozambique's largest thermoplastic pipe manufacturing company and a quality certificate factory. Today, for the purpose of managing inventory, AFRITUBO uses an Enterprise Resource Planning (ERP) system, in Dbase 3, specifically developed for the group. The system deals with 3 different managing programs: A billing dedicated software (Clipper), a production management data base that feeds from the clipper software data and a costs management database. Furthermore, the system comprehends 60 different references of final products and 18 different references of raw material solely for AFRITUBO operation. From those, there's two types of special care materials to be managed: final products that can degrade when exposed to UV rays and corrosive raw materials.

Regarding reorder point, order quantity and lead demand policies, the company employs protectionism measures to deal with market pull, not setting a zero-tolerance inventory target, i.e., a maximum amount of inventory that can be order and purchased. Thus, material orders are placed without any efficient inventory management strategy, being today the company's policy to buy enough raw material to ensure the factory is able to continuously operate for two full moths, if necessary. As a result, AFRITUBO intensely struggles with available storage space for the held overseas materials, causing the factory to have extremely high lead times while in operation. Additionally, regarding stock cover, i.e., the company's system accuracy, forecasting models and reports, there's no system employed.

As far as material handling is concerned, AFRITUBO combines a first in, first out (FIFO) work methodology with a horizontal consumption method which presents as a good solution for the available stock space. Moreover, the company utilizes a family grouping placement method, positioning items with similar characteristics together in specified location spaces, which eases the storage and retrieval processes of products. Additionally, the factory operates with a Combination method, with a mixture of characteristics from memory, and fixed location systems. Contiguous to the storage room, the factory also allocates a maximum of 2 to 6 % of obsolete and damage stock, which is totally re-utilized further in the supply chain with pulverizing and mill systems already in place.

In what regards inventory tracking features, the company's ERP system doesn't encompass any. That combined with poor identification features, both on products and on site, make inventory reconciliation very challenging and heavily reliant on worker's memory, responsibility and professionalism.

Relative to billing orders, as it's the case of the majority of companies worldwide, there's today no system in place that can predict how many days are necessary to fulfill a specific order, which diminishes the quality of customer service and pushes managers to make decisions based only on experience and not on factorial data.

For managing internal and external logistics AFRITUBO is now using WhatsApp. Additionally, the factory owns 200 m^2 of usable space and employs an average of 15 employees distributed through work shifts of 4 hours.

3) The MVP requirements: Questionnaire Findings

To fulfill the objectives of the market analysis, a questionnaire is developed to further explore the MVP requirements. The questionnaire is built in such a way that allows the complete characterization of a company's inventory management operation in and out of the supply chain, identifying current problems and solutions, alike an audit trail. As such the questionnaire is orderly divided into the following three parts: "Accessing current inventory management policies", "Accessing recurrent inventory management challenges" and "Accessing company's needs".

After analyzing the AFRITUBO's responses (displayed in the third part of the questionnaire), two pie graphs are made to illustrate what the future direction of the MVP's development should be and its general features, as it's shown in Figures 7 and 8.

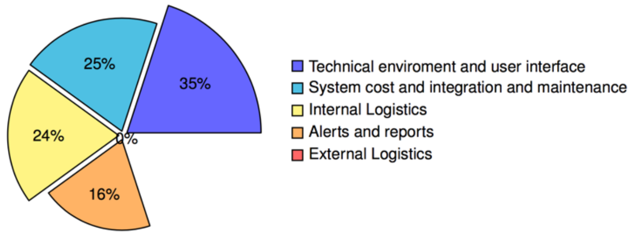


Fig. 7. Distribution of the MVP's specifications

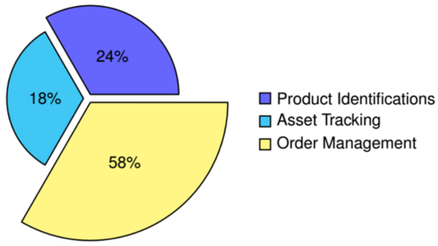


Fig. 8. Distribution of the MVP's inventory management focus.

By analysing the questionnaire findings, the following set of features are defined as the MVP requirements:

- Real time reports of stock quantity, positioning and count;
- Daily reports of stock positioning and quantity;
- User interface and functionality similar to Whatsapp;
- Low cost;
- Low integration time.

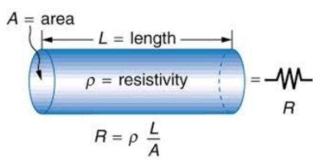
III. The Minimum Viable Product

A. The MVP specifications

The MVP is divided into three subsystems: a weighing system, an indoor positioning system and a messaging application bot.

1) Weighing system

The MVP weighing system makes use os four load cell, one at each corner of the pallet, linked in a Wheaston bridge configuration. The system makes use of the piezorresistive effect to retrieve the load weigth as illustrated in Figure 9.



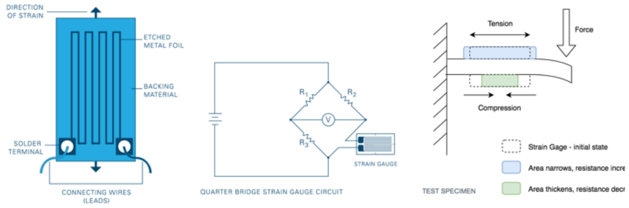


Fig. 9. The piezoresistive effect in the load cells operation [33][34][35].

As the output voltage of the brigde is fairly low (in the order of the mV) an amplifier and an ADC is used between the processing unit and the bridge. Adding to that, this system is powered by four AAA batteries, making use of a voltage regulator to make constant the desired circuit voltage of 3.3 V.

2) *Indoor Positioning System*

Considering that the MVP is to be developed for an indoor positioning system, the indoor path loss model must be considered. This model is based on the premise that RSSI follows a log-normal distribution over distance when it is applied inside a building or densely populated areas [36][37]. Hence, this path loss model is expressed in therm of RSSI as,

$$RSSI = RSSI_0 - 10 \cdot n \cdot \log_{10}(\frac{d}{d_0}) - X_g(dB)$$

For the purpose of simulating the MVP's accuracy, classroom 1.64 of the Taguspark campus serves as the simulation room that models the AFRITUBO's enviroment. For that reason, the path loss exponent n is considered to be 2 and the standard deviation X_g will be defined empirically through some measurements in the indoor scenario. Finally, distance can be obtained from,

$$d = d_0 \cdot 10^{\frac{RSSI_0 - RSSI - X_g}{10 \cdot n}}$$

Materializing the previous, a trilateration algorithm is used. The trilateration method measures distances from a point to at least three references points, forming circles that ideally intersect each other. That intersection will give the exact location of the object, as illustrated in Figure 10 as "B".

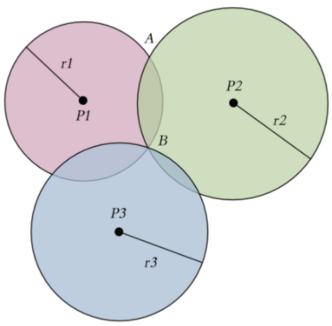


Fig. 10. The trilateration method (2D) [37].

There are several mathematical methods to resolve the Trilateration equations. The following equations are used to solve the trilateration problem.

$$(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2 = r_i{}^2$$

$$Ax = b$$

$$A = \begin{pmatrix} x_2 - x_1 & y_2 - y_1 & z_2 - z_1 \\ x_3 - x_1 & y_3 - y_1 & z_3 - z_1 \\ \vdots & \vdots & \vdots \\ x_n - x_1 & y_n - y_1 & z_n - z_1 \end{pmatrix} \quad x = \begin{pmatrix} x - x_1 \\ y - y_1 \\ z - z_1 \end{pmatrix} \quad b = \begin{pmatrix} b_{21} \\ b_{31} \\ \vdots \\ b_{n1} \end{pmatrix}$$

Due to factors such as multipath fading and reflection phenomenon, the circles in the Trilateration method may not always only intersect at a common point or even intersect at all, in the worst case scenario. In these cases the Trilateration method must not be approached as a geometrical problem but as an optimization problem. As such, in that point of view, the goal is to find the point (x, y, z) that minimizes a certain error funtion [38].

The Linear Least Squares (LLS) approximation, for example, consists in minimizing the sum of the square of the residual errors of the linear system. So, the function to be minimized is

$$S = (b - Ax)^T (b - Ax)$$

That leads to the following solution

$$x = A^T A^{-1} A^T b$$

3) *Messaging Application Bot*

The messaging application bot uses a Telegram API to create an interface between the MVP system and the user(s). Some of the most important specifications include but are not limited to:

- Real time messaging;
- Editable group chat;
- Share photos and videos;
- End-to-end encryption;
- Auto-destructing messages;
- Cloud synchronization between devices;
- Open source;
- Optimized transfer speed [39][40].

B. *MVP Architecture*

By carefully analyzing the MVP's specifications, presented in the previous section, the system architecture is derived. Figure 11 illustrates the high level architecture of the MVP.

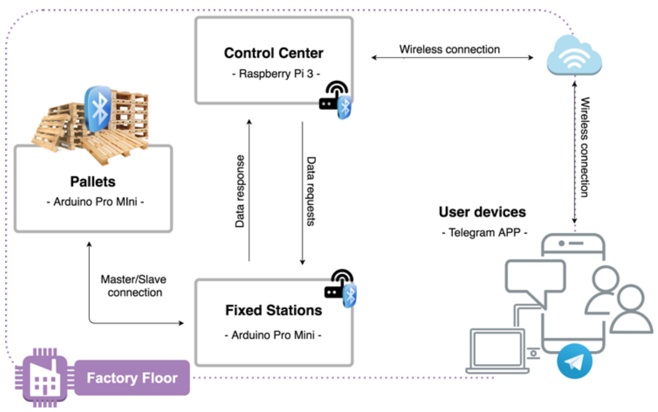


Fig. 11. High-level view of the MVP system architecture.

The MVP is composed of a weighing system, a indoor positioning system and a Telegram bot. Each MVP parts is composed by the following elements:

- The pallet unit: Senses and stores various types of data, e.g. the pallet's current weigh, battery status and RSSI values, and sends it to the fixed station units. Each pallet unit has a unique identifier (MAC address) and the reporting frequency and data types are established by the fixed station units. This unit is small enough to fit the pallets measurements while not interfering with the fork-lifters' operation. Each pallet unit is composed by the following modules:
    - Communication module – A Bluetooth Low Energy module, the HM-10, responsible for establishing communication with the nearest fixed station units;
    - Central Processing Unit (CPU) – The Arduino Pro Mini is in charge of the pallet unit control and information processing;
    - Power Supply - Due to the size available to fit the power supply and the movable nature off the pallets as well as the required input voltage of the other components of this unit, it utilizes the farnell's four AAA battery holder and the Alkaline Manganese AAA batteries to supply voltage to the system;
    - Voltage regulator – The XCG215B332NR, is responsible for automatically maintaining a constant voltage level of 3.3 V for all the weighing system's modules;
    - Analog-to-Digital Converter (ADC) – Primarily used for industrial control applications, the HX711 is responsible for conditioning the signal output of the sensors in the Wheatstone bridge. This module encompasses a 24-bit precision ADC and a on-chip active low noise PGA with selectable gain of 32, 64 or 128;
    - Four load sensors – The single compression load cells are responsible to measure the pressure forces applied on top of the pallets. They are connected in a wheastone bridge, to increase system linearity and diminish external factors dependence, as is the case of temper-ature.

Figure 12 illustrates the illustrates the electrical circuit developed for the pallet unit in a "breadboard view".

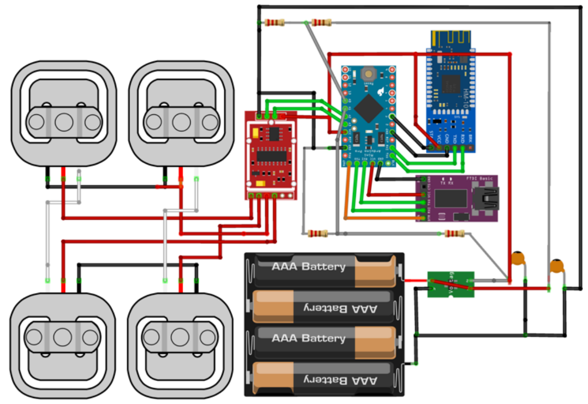


Fig. 12. The pallet unit – schematic breadboard view

- The fixed station unit: has the same parts as the pallet units except the load cells and the HX711; Figure 13 illustrates the corresponding schematic circuit.

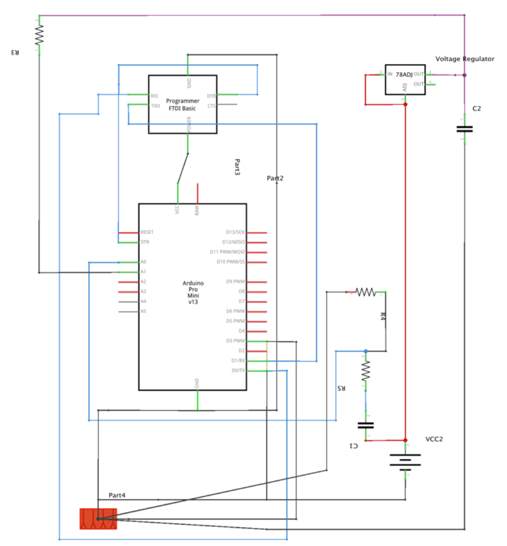


Fig. 13. Electronic circuit of the fixed station units.

- **The control center unit**: Collects and processes the information retrieved from the fixed station units as well as enables the bidirectional communication to the user via the Telegram APP. Uses a Raspberry Pi 3 module B.

The resulting pallet's PCB measures 26,73 x 101.96 mm and the fixed station PCB measures 27,40 x 80.30 mm. Figure 14 illustrates the modules developepd for the MVP .

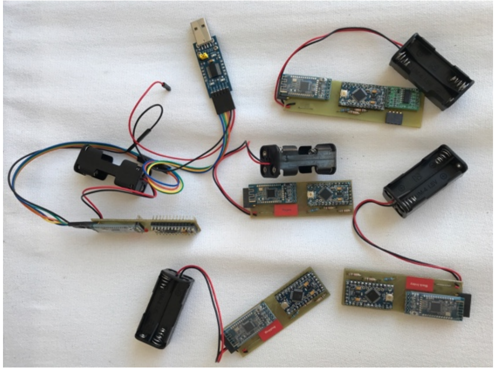


Fig. 14. The developed MVP modules.

C. MVP Operation

To better understand how the MVP system works, let us divided it in three parts, representing the three sides of the communication system: a 'At the pallet' system, a 'At the fixed station' system and a 'At the control center' system.

1) At the control center

At the control center, the python code chabot.py runs indefinitely whenever the Raspberry Pi 3 module B is powered on. The board is connected to the Wi-Fi network, being accessed by the DDNS, whenever and wherever a user wants to connect to the board and is connected to the Internet. In the case where the user connects to the board via the Telegram app, there are a number of features a user can request, namely:

- Stock levels: Returns a visual representation of the inventory;
- Stock tracking: Returns a visual representation of the spacial location of the pallets within the factory at current time;
- Prevision: Returns the nearest available day to complete an order;
- Reports: Returns stock levels, stock count and stock tracking reports in .csv format;
- Make operation manager decisions with the following commands:
    - New slave: to enter a new fixed slave device into the ble mesh;
    - Upload stock: upload a .csv file with current invetory available in the factory;
    - Upload item: update the inventory database one item at a time;
    - Upload production plan: upload a .csv file of the production plan;
    - Upload time: upload a .csv file of the time interval associated with the production plan of every sku vs machine in the factory;
    - Alerts: choose a time of the day to receive the daily reports;
- Exit command: Live the current request in the middle of the action;

Adding to these, the user can chat with the bot about trivial things, and receive autonomous daily alerts from the bot. These features are enabled by a state machine, that changes the state of the program to fulfill the user needs, otherwise bidirectional speech would not be accomplished. Concerning BLE communication, the ’At the control center’ system always roles as a master, i.e., can have multiple link layer connections to peripherals (slaves) and simultaneously scan for another devices. Thus, whenever the stock tracking state is activated, the BLE module will scan for BLE devices near him and by comparing those entries with the database of known BLE devices, the Raspberry pi can grant these connections and retrieve or talk to those BLEs. Note that, for the connection to be successful the devices MAC address, as well as, the universally unique identifier (UUID) must be known. In a general manner, the Raspberry pi is always ”listening”, retrieving the weighing system loads and RSSI value measured. As a fisrt approach the program will try to locate the pallets via the trilateration method, however, whenever that is not possible the LLS aproximation is used. After that these data is added to in the database and used in the graphical representations to be sent to the user or stored for future reports. Figure 15 illustrates the different states in which the BLE modules can operate.

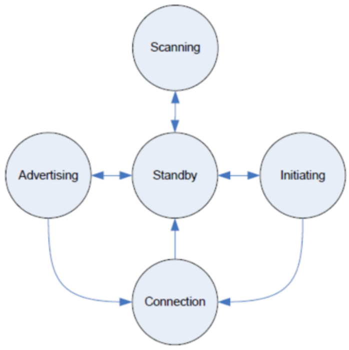


Fig. 15. BLE’s link layer state machine.

2) At the pallet

At the pallet, the code bleslave.ino enables the serial communication to allow BLE communication to the environment. Adding to that, the HX711 is calibrated: data is read though a 24 clock pulse, the gain factor is set to the maximum and a replicate of the most significant bit to pad out a 32-bit signed integer is made. Thereafter a 32-bit signed integer is constructed and the Arduino returns a valid reading from the HX711. Function for low power mode are also created.

3) At the fixed station

At the fixed station, the bleslave.ino code is reduced to only encompass the low power mode as well as the serial communication. It is important to note that to retrieve the RSSI value from the pallets' unit, the fixed stations must be initiate a series of AT commands in aggregation with the pallet's unit, so that the master/slave connection can occur.

IV. RESULTS

The results of the experiments carried out during the MVP development are here presented. The assessment of the solution performance as well as a summary off its advantages and limitations is given.

A. *Weighing system*

For the purpose of simulating the MVP performance, an almost exact 1:4 replica of the Europallet dimensions presented in previous chapters is constructed. Figure 16 illustrates the final result of the simulation pallet.

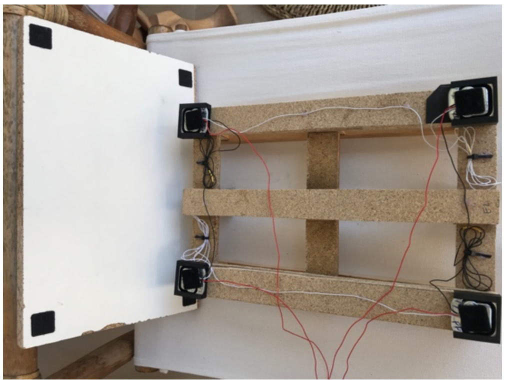


Fig. 16. Pallet construted (1:4 scale)

In order to correctly measure the load cells' strain, a supporting box is developed and placed at the corners of the pallet. A Velcro tape was used to secure more firmly the base plate of the weighing system to the pallet to retrieve more accurate measurements. Similarly, to the load cell's supporting box, a PLA cover is also designed to enclose the battery holder and the PCB of both the weighing system and the units for the fixed stations. The 3D printing technique was chosen to make the MVP boxes because it is a fast and cheap way to prototype a mockup.

After the MVP subsystems were assembled, the load cells' calibration was performed. The resistive divider that connects to the weighing system registered a supply voltage of 3.308 V. Thereafter, a linear regression of the weights measured is performed, resulting in Figure 17.

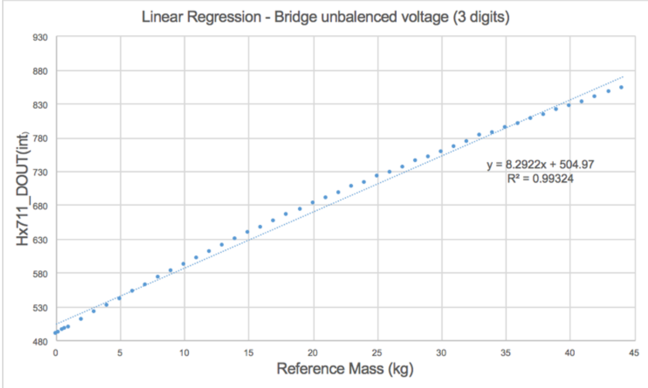


Fig. 17. Linearization of the weighing system.

By applying this linear regression to the Arduino program, an average error of 2 kg is encountered in the succeeding readings. This error is due to the lack of initial calibration of the scale. However, as this scale is intended to be used in a factory, such error is not particularly discouraging. It is also important to note that the weighing system performs as espected, with no significant variations in the results when the load is off centered and that the system performs very closely to the linearization, having a a coefficient of determination really close to one, has desired.

B. *Indoor positioning system*

As far as the fixed station units are concerned, very few results were obtained, due to not having used an official HM-10 BLE module. The module used for the BLE commutation was the AT-09 and although this module functions closely to 99% equal to the HM-10 module, the RSSI value could not be always obtained, which compromised the correct functioning of the indoor positioning system. Despite that, the AT-09 module has the exact same footprint as the HM-10 module, so a number of future development choices can be made, namely the flash of the official firmware into the AT-09 module or the purchase of official HM-10 modules. Although no real results could be retrieved from the indoor positioning system made for this first version of the MVP, a dummy database was created in the Raspberry Pi, to simulate the RSSI values that would be received from the fixed station units. Therefore, it was concluded that the system functioned as desired.

C. *Messaging Application bot and other considerations*

In accordance with the specifications of the messaging application bot, Figures 18 and 19, illustrate the different functions of the bot. For the purpose of this Thesis, the name John was attributed to the chatbot, due to being a very popular name in Mozambique and due to facilitate the humanization of the machine.

Fig. 18. Stock level reports and Telegram's interface.

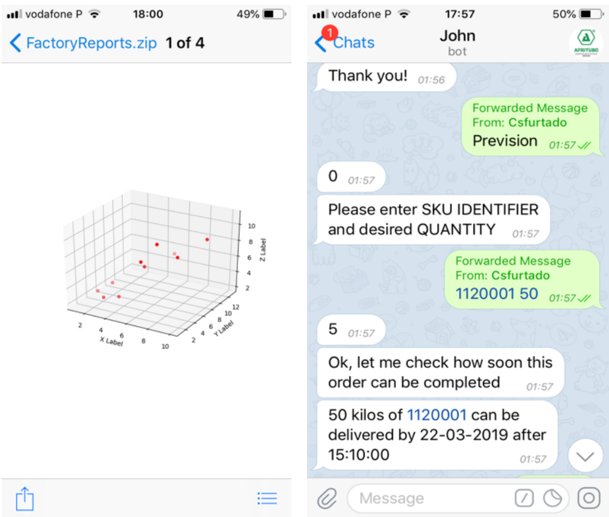


Fig. 19. Indoor positioning report and prevision report.

As it is seen, the Telegram bot works as desired. Regarding system cost, let's consider the individual cost of every module. Figure 21 illustrates the costs retrieved from the Mouser Electronics and the Gearbest web-sites. In the case of AFRITUBO, as disclosed previously, the factory is intended to always have 30 000 kg of material. As each pallet can not support more than 200 kg, the number of pallets in the factory is 150, representing the same number of pallet units. As such, the total cost of the pallets units is 5991,3 €. Recalling that Afritubo has a factory space of about 200 m^2 , the number of fixed stations should be around 6, with each station costing 24,26 €. Therefore, the total cost of the fixed units is 153,56 €. Adding the cost of 1 kg of fillament and one central station, the total cost of the MVP for the Afritubo company is 6144,86 €, which is a very low price for this type of management systems.

Module	Price
Arduino Pro Mini	3.61 €
HM-10	13.53 €
HX711	0.99 €
XC6215B332NR	5.90 €
Load cell	3.33 €
PLA filament	17.84 €
Battery Holder	1.22 €
Raspberry Pi 3 Module B	39.90 €
LR03 AAA battery	0.343 €

Fig. 20. MVP's parts cost.

V. Conclusions and Future Work

To develop the MVP, three autonomous and real-time based systems were created: a weighing system, a indoor positioning system and a messaging application bot. Various 3D printed parts were also developed to enclose the aforecited systems' modules as well as to serve as a base to the load cell's sensors that enable the measurement of the factory's pallets. The indoor positioning system update and the overall data communication of the MVP was done via BLE transceivers, following the log-distance path loss model and the Trilateration method. Adding to that, the user interface was developed via the Telegram API and a simple website was also created. The performance of the MVP solution was accessed resourcing a 1:4 replica of an Europallet, created for that purpose. The solution has shown that it provides very good results in the weighing system, however, due to having used a non-official HM-10 module, the RSSI value between devices could not be retrieved and only a dummy database served as proof of concept for the good results of the indoor positioning system. As far as the Telegram interface is concerned, all the system requirements were also achieved.Thus, the designed solution proves that it is possible to achieve the deployment of efficient inventory management tools for the Industrial sector, with high performance, real-time update and automatic detection of stock movements and quantities, using available IoT technology, that only will get less expensive, smaller and smarter as time goes by. Therefore, is safe to state that the Internet of Things will continue to impulse humanity to work smarter, not harder. there is still room to improve the overall performance and generalization capabili- ties of the proposed system. By doing so, and by continuously improving the MVP questionnaire to target the performance of each specification at a time may result in a better product to market fit and eventually start the integration of the system into the operation of the factories of SMEs all over the world. Such achievement would significantly improve the effectiveness of the industrial sector, thus helping to ensure the growth and sustainability of the SMEs for generations to come and the popularization of smart and low-cost IoT-based inventory management systems worldwide.

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