Internet of Drones towards Logistics 4.0

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Abstract - Logistics main focus is to ensure the material's efficient flow. Warehouses are the places where products are consolidated in the supply chain and thus constitute a pivotal point in the material's effective flow. Recently there is a desire for warehouse digitalization driven by reduction costs, need to improve service level and safety. Two of such technologies, driving the costs' reduction in warehouses, are IoT and UAVs or drones.

Thus, in this dissertation, we present the design and evaluation through a business case of a prototype of a UAV RFID based system solution aimed to perform inventory management. The proposed design can be summarized as follow: an UHF RFID Reader is carried by a DJI Ryze Tello EDU drone that reads ALN-9662 item tags. The RFID reader is connected through a Wireless USB Adapter to a Raspberry Pi Zero. For safety concerns, the prototype was unable to be tested in a real warehouse environment. The alternative to simulate a real warehouse was to adapt a room so that it looked like a storage area with three corridors and four single deep pallet racking shelfs. The experiments and tests were conducted by exposing the drone to different scenarios within the room. In the experiments the total time that the system takes to perform the cycle counting was, on average 248,15 seconds. The autonomous system is capable of scanning the tags with 100% accuracy, identified misplaced items and update the warehouse database in near real time. The system has a great economic potential.

Keywords: UAV/Drone; IoT; RFID; Inventory Management; Cycle Count; Business Case

1.Introduction

1.1 – Problem background and motivation

Logistics concerns the management of material and information flows in business [1]. More specifically it encompasses the efficient planning and implementation of all kinds of products, services, and information flow in the supply chain from the starting point to the end point to meet customers' needs. While logistics operations remain crucial for transporting goods, they are not a revenue stream for companies and thus these operations are continuously receiving pressure to increase their efficiency. The apparent trade-off (High Customer Service Level and Low Cost) has been a point of conversation among scholars and practitioners. At the center of conversation sits a pivotal piece of the logistics operations: the warehouse. As never seen before and in an incredibly high speed, recent technological innovations are challenging the notion that these 3 trade-offs are mutually exclusive conditions. Two of such technologies, driving the costs' reduction in warehouses, are Internet of Things (IoT) and Unmanned Aerial Vehicles (UAVs) or drones, which equipped with visual based navigation and sensors [2] can help to achieve near real-time warehouse inventory.

1.2 – Objectives

A warehouse operation involves a wide variety of tasks that require interoperability and high level of cooperation between entities. Hence the radical application of technology in this context can be catastrophic. The main objective of the dissertation is to create a framework that grants companies with the opportunity to identify the benefits and costs that the implementation of drones in their warehouse operations can bring. This framework encompasses a creation and evaluation through a business case of a prototype of a UAV RFID based system solution aimed to perform inventory management and inventory traceability. Hopefully this dissertation contributes to accelerate the adoption of internet of drones towards Logistics 4.0.

2.Logistics 4.0 technologies' implications in Warehouse

This chapter aims to contextualize the reader, about the term Logistics 4.0, its main components, its main enabling technologies, and features. Furthermore, based on the literature review some of the key challenges that will need to be overcome in order to meet the requirements of Logistics 4.0 and Warehouse 4.0 are presented.

2.1 – Logistics and Warehouse

The current challenges in the area of logistics include managing inventory more efficiently, delivering more frequently and smaller orders, have a high depth of Stock Keeping Units (SKUs) and increasing the value-added services available to the customer. These challenges are related in certain part to digital technologies that have led to a customer-oriented and individualized supply chain and logistics [3]. Logistics performance is affected by two factors: structure and control issues [4]. The structure of logistics is related to the design part of the operations. It details how supply chain actors should be designed. As for control issues, these describe the day-to-day operations and how to execute them. Warehouses have three basic functions: movement, storage and information. These functions are sustained by several basic operations, that are carried out from the receipt of the finished product to its dispatch to customers. These operations can be grouped into receiving, storage, order picking and shipping [5]. Figure 1 show how performance is related to overall structure/design and operations/control issues.

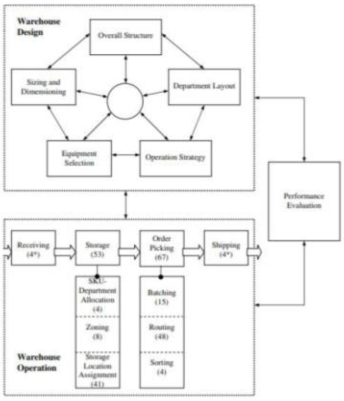

Figure 1. Framework for warehouse design and operation problems [5]

2.2 – Industry 4.0 concept

The term of Industry 4.0 was first used in 2011 at Hannover Messe, in Germany as a basic concept for the fourth industrial revolution [6]. The fourth industrial revolution, builds on the third combining the virtual and physical world of production, machines, systems and sensors to communicate with each other, share information and to control each other independently.

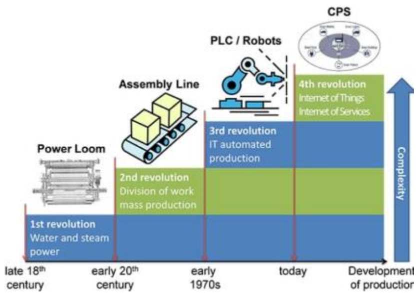

Figure 2. Four Industrial Revolutions [8]

2.3 – Industry 4.0 components

One can argue that the defining feature associated to Industry 4.0 is the intelligent networks based on cyber-physical systems [9]. In addition to CPS, Hermann et al. [10] identified more two components of Industry 4.0: Smart factory and The Internet of Things (IoT). Figure 3 shows a third generation of CPS. They can store and analyzed data and are equipped with multiple sensors and actuators with a full compatible network.

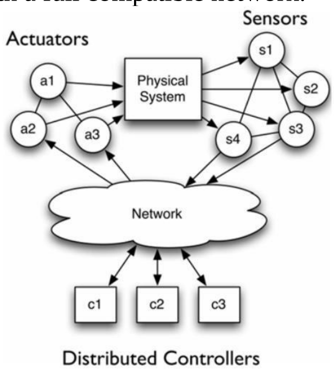

Figure 3. General architecture of cyber physical systems [9]

There is a wide range of technologies associated with Industry 4.0.

The big difference is that these technologies can transform extensive real-time data into highly efficient decision-making, changing how humans and machines interact with each other. Technologies revolutions have been called revolutions in part because of the features they offer to industries. Industry 4.0 offers mainly four features: interconnection, information transparency, decentralized decisions, and technical assistance [10]. The interconnection or interoperability is enabled by IoT that allow "things" and 'objects', such as RFID, sensors, actuators, mobile phones, to interact with each other and cooperate with their neighboring 'smart' components. The features of the Industry 4.0 are expected to cause a disruptive change in the era of information technology.

2.4 – Logistics 4.0 & Warehouse 4.0

The term "Logistics 4.0" is essentially the combination of using logistics with the technologies of "Industry 4.0" like CPS and IoT with everything they add. In this sense we consider that the analogy to define "Smart Factory", "Smart Products" and "Smart Services" can be used to define "Smart Logistics". Everything considered "Smart" in this context, whether it is factories, products or services, emphasizes the capacity to perform tasks that otherwise were performed by humans. These tasks normally are repetitive and dull. Logistics 4.0 give opportunities to companies to transform logistics from simply a cost center into something that enables firms to compete on speed, reliability and cost, in other words, enable firms to leverage Industry 4.0 technologies to create a weapon of creation of economic and competitive value by transforming traditional Logistics into Logistics 4.0.

It is expected that a modern warehouse must be able to leverage Industry 4.0 technologies in their facilities. Hence the emergence of Warehouse 4.0 is an emergent challenge, encompassing a smart warehouse developed with technologies that have flexibility at their core. Recent advances on Industry 4.0 technologies makes us believe that inventory counting can be reduced to hours instead of months, 100% inventory accuracy in near real-time is possible and overall safety of operations can be dramatically improved. Although scientific research just started recently, the technologies that seem to have the greatest potential inside the warehouse are AI solutions, to increase automation; IoT solutions, to boost communication and cooperation with 'smart' components; digital twins to ensure information transparency; UAVs or drones that in combination with IoT can carry different sensors to record data for monitoring operations. These technologies can finally bring the "smartness" to the heart of warehouse operations.

3.Drone/UAV Technology as part of Warehouse 4.0

The aim of this chapter is to define what are UAVs and drones. The different types of drones and associated technologies are surveyed and a suitability analysis of the different types of drones for a warehouse environment is performed.

3.1 – Drone/UAV: concept and types

Drones essentially are flying robots which include unmanned air vehicles (UAVs) [12]. Unmanned Aerial Vehicles or UAVs are drones but they need to have autonomous flight capabilities, whereas drones do not. Therefore, all UAVs are drones but not vice versa. Drones often are classified based on different parameters including the size, flight endurance and capabilities of the vehicle and the field of application.

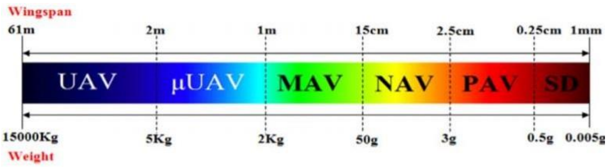

Figure 4 Spectrum of drones from UAV to SD [12]

The main interest of the dissertation is to study unmanned aircrafts and no other applications outside aviation; so, for the rest of the project dissertation when the author refers to drones or UAVs, he is referring to all spectrum of Fig. 4. If necessary, the terms µUAV, MAV, NAV, PAV and SD, will be used to discriminate the wingspan and weight of the drone**.** There are four majors' types of UAVs (Table 1.): Multi-rotor drones, fixed-wing drones, single-rotor drones, and fixed-wing hybrids. Multi-rotor drones can also be classified based on how many motors they have. The Quadcopter is the most frequently used model being power efficient and having a great handling. This UAV has four electric motors that can adjust the speed at which motor spin. Tricopters are drones that can fly with less than four motors but have been proven to be very instable. Hexacopters have six rotors and provide a bit more power and ability to carry objects than the Quadcopters. Finally, we have Octacopters with eight rotors included. These eight rotors give this drone high raw power.

Table 1. Types of Drones: Pros and Cons [14]

	Pros	**Cons**
Multi Rotor	Accessibility; Ease of use; VTOL and hover flight; Good camera control; Can operate in a confined area	Short Flight times; Small payload capacity
Fixed-Wing	Long endurance; Large area coverage; Fast flight speed	Launch and recovery needs a lot of space; No VTOL/hover; Harder to fly; Expensive
Single rotor	VTOL and hover flight; Long endurance (with gas power); Heavier payload capability	More dangerous; Harder to fly; Expensive
Fixed-Wing Hybrid	VTOL and long-endurance	Not perfect at either hovering or forward flight; Still in development

3.2 – Drone/UAV Application on Warehouse 4.0 operations

The list of tasks that drones can performed in warehouse fall into three categories: Inventory Management, Intra-Logistics and Inspection & Surveillance. Intelligent networks based on cyber-physical systems are the defining feature of Industry 4.0. Drones can fit in the general architecture of CPS (Fig. 3) in two different ways. Drones can be used as mobile sensors in the warehouse, since they have the ability to hover and fly autonomously all over the warehouse facilities easily, thus acquiring and transmitting data about processes (physical systems). As sensors, drones serve better for Inventory Management or Inspection & Surveillance [15]. In addition, drones can be used as actuators, performing various physical operations. As actuators, drones serve better for intra- logistics. Inventory Management applications appear to have the highest potential for use of Unmanned Aerial Vehicles (UAVs) or drones in warehousing operations. The field of intra-logistics does not offer the same potential use cases for drone applications as inventory management because of the lack of payload capacity. To keep product traceability and obtain the inventory of a warehouse the drone need to have a labelling and an identification technology, a local database, and an indoor navigation algorithm.

4.Methodology

This chapter aim to present the steps of the proposed methodology used during this dissertation. Usually, the development of the business case, for an adoption of a technology, implies a great knowledge of how the technology works and how it will change the operations of the company where the technology will be implemented. In the instance of this dissertation, the technology itself and the use case where the technology will be implemented, until this chapter, were unknown. A diagram including the 8 steps of the methodology used in this dissertation can be consulted in Figure 5. The end result of following the methodology should be a business case creation.

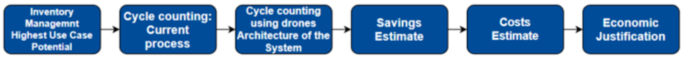

Figure 5. Methodology

4.1 – Inventory Management Highest Use Case Potential

One of the objectives of this dissertation is to design, implement and evaluate an UAV based system prototype. This prototype will be developed in joint venture between the author and another student from the MSc in Telecommunications and Informatics accordingly with some specifications. These specifications will vary a lot accordingly with the application chosen for the drone. Consequently, the complement technologies will also vary. Therefore, prior to study how a specific technology works, how it supports the current activities of the warehouse, it will be needed to discover the highest potential use case for inventory management activities inside a warehouse. To discover the highest potential use case for the use of drones in warehouses, several sources can be used to match drones' capabilities with warehouse's activities characteristics. To construct a business case around this "match", it is necessary to use the North Star Metric Framework. This framework help to define a metric or leading indicator, that defines the relationship between the customer problems and the long-term business results. The list of tasks that can be perform autonomously by drones in a warehouse, fell in three categories: Inventory Management, Intra-Logistics, and Inspection & Surveillance. The necessary knowledge to decide which is the promising area of indoor drone application was obtained through literature review. The finding and respective north star (state of Drone Technology) are presented in the first layer of the North Star Metric Framework (Figure 6). Despite the conclusion that Inventory Management applications seem to have the highest potential for the use of UAV in warehousing operations, drones can be used for numerous tasks. In order to enable the application of this methodology to particular cases, it is needed to construct a more robust argument using the North Star Metric Framework. The findings of this process constitute the second layer of Figure 6. By augmenting the existing technologies adopted by warehouses, UAVs help improve the RoI on existing infrastructure. The RoI is the North Star Metric in this decision-making process. Nevertheless, the North Star Metric is impacted by Input Metrics. In this case, these input metrics are divided into two categories: ease of drone automation adoption and crave for cost effective operations. The highest potential use case for the use of drones in warehouses, is the one that suits the two-input metrics the best. In other words, the task to be automated by drones, should be a manual-routine activity which is a highly time and resource consumption activity. The highest potential use case for the use of drones in warehouses, is the cycle counting use case since it is the one where all metrics apply at full potential. Nevertheless, the other use cases should not be discarded, mainly because they have synergies between them. A UAV based system with the aim to perform cycle counting can perform other tasks while doing it. This possibility should be evaluated.

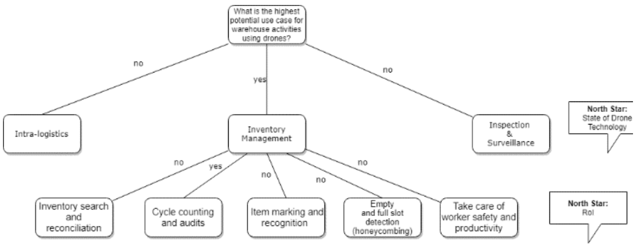

Figure 6. North Star Metric Framework

4.2 – Cycle counting: Current process

Cycle counts refers to the process of counting inventory items available in physical locations depending upon the nature of inventory, number of transactions and the value of items, cycle count can be carried on periodically or perpetually. There are numerous ways of doing cycle count. The inventory system throws up a count list with SKUs' number, description, and location number. The operator goes to the location, checks the SKU, counts the quantity available and updates the list, which is then fed into the system. The system reconciles the physical quantity with system quantity and throws up the discrepancy report, which is further worked upon to tally and adjust inventory. There are four reasons to implement cycle counting [16] as a regular part of business' processes, namely: Improved service levels through focus on improved flow; It is more costly to address inventory discrepancies after they have had a negative impact on the warehouse's operation; Eliminate the need for wall to wall physical inventories; Measure accuracy of the company's inventory records. There are five cycle count strategies, meaning, five different ways to choose the products to count on any given day [16]: Geographic counts, Ranked-based counts, Random counts, Low Balance counts and Exception Counts. A cycle counting program should be planned in order to know what to count and how to count products at any given day. The cycle counting procedure in a broader sense can be described by the following steps: 1. Complete data entry on all inventory transactions, so the inventory database is fully updated; 2. Print the report and assign it to the particular staff; 3. Location, quantities, and other details cited in the report will be compared with the items on the shelf; 4. Investigate if there are any differences; 5. Modify the process to alter the error if there are any; 6. Adjust the inventory record database to remove the error found by the cycle counter. The three main limitations of this process fall into three categories: very intensive-dangerous labor activity, time to perform the activity and lack of accuracy on discrepancies reports. The last is the result of tiredness of the labor force or related to the dull nature of the job.

4.3 – Cycle counting using drones | Architecture of the System

The prototype to be developed between the author and another student from METI (Guilherme Portela), is a proof of concept. The two dissertations have different scopes. The requirements stated above were built together in order to be possible to build the prototype. Although the software and hardware will be built by the student of METI, the collected information on 4.2.1 were important to define the structure of the proof of concept. The goal of this dissertation is to use the results of the prototype build by the student of METI and applied them to a business case. It is important to define the four components build the student of METI to better understand the implications in the business case. To perform cycle counting inside the warehouse, the UAV based system has to have four main components incorporate, namely: Inventorying component, navigation component, communications component, and a local database.

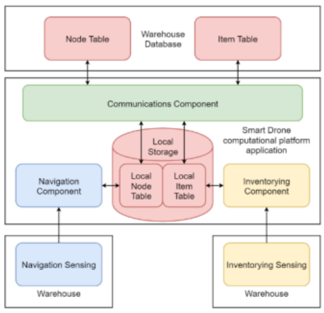

Figure 7. System components [17]

The UAV RFID based system prototype should meet the following requirements:

• The system must be able to scan the labelling technology attached to the item, a tag or a label. Mandatorily, the system need to collect the information associated from these tags, whether they are in line-of-sight or obstructed by either another item or farther inwards on the shelf.

• The labelling technology should be affordable in bulk and ideally reprogrammable, and it should be easy to put on the items.

• To issue discrepancies reports, the system should identify misplaced items in the shelfs.

• Ensure that drone hardware and software both have collision avoidance capabilities in order to work alongside operators doing other operations simultaneous.

• Don't be dependent on human labor. We want the system to be as autonomous as possible.

• The system needs to communicate with the WMS, in order to keep inventory levels updated in near-real time. Consequently, the connection between the drone and the computational platform should have the minimum amount of downtime possible.

The prototype to be developed between the author and another student from the MSc in Telecommunications and Informatics, is a proof of concept. Figure 4.5 portray the proposed communications architecture.

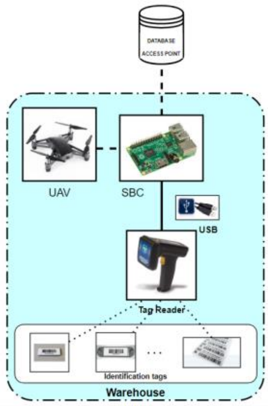

Figure 8. Proposed communications architecture

The main objective of the inventorying component is to process the information contained in the tags attached to the items to be inventoried. The tag reader to be installed in the drone is a RFID sensor system and the warehouse sensors to be used are the passive RFID tags. Preferably, the RFID sensor system should be EPC Class 1 Gen 2. The basic function of the navigation component is to allow the drone to fly autonomously throughout the warehouse according to a virtual map. It is intendent to use RFID tags (node tags) to compute the drone's position. The RFID tags are different from the ones used for the inventorying component, in the sense that they don't have information of items. They just serve the only propose of feeding coordinates to the navigation component. This component will create a virtual map that will guide the drone. The communications component communicates directly with the local storage and with the warehouse database. These communications aim to update the warehouse database based on the information stored in the local storage. These updates happen periodically and whenever a Wi-Fi connection is available, through a reliable transport layer protocol such as TCP. Furthermore, this component should be able to audit the information contained in the local storage, issuing discrepancies reports when the information of the local database and the warehouse database don't match.

The cycle counting using drones can be described as follow. First off, the item and node tags should be deployed throughout the warehouse. This system relies on both to do the cycle counting. Once the tags are deployed, the system can be launched through the application by an operator. The Navigation Component takes over the system. The system proceeds to hover and begins to move autonomously according to a pre-calculated route through the shelves. This route is optimized for the shortest path, in order to cover the storage area with the least amount of movement possible. The drone moves from node tag to node tag. These tags are deployed in strategic intermediate points in the aisles floor of the warehouse. The drone only moves to the next shelf level once the entire previous shelf level has been scanned using the RFID tag reader. The drone continues this process, using its navigation component, until all shelf levels have been scanned. During this movement, the inventorying component is processing the data from the RFID tag reader and storing in the Local Database. If a connection to the warehouse database endpoint is available, it will attempt (through its communication system) to update the warehouse database through Wi-Fi. In parallel, the information inside the node tags are being transmitted to the warehouse database as well. If the drone happens to stray from its original course, it corrects itself once it reaches a checkpoint in its path. If everything goes accordingly with the route calculated in the beginning, and the system scans every item, the drone returns to its starting position. In the meanwhile, the communication component is updating the warehouse database. If any of the item is flagged, with "1", it issues a discrepancy report because that item is misplaced. Nevertheless, when the drone returns to the starting point, the warehouse database should be fully updated with near real time information. The cycle counting procedure is finished. In Figure 9, a three-dimensional system overview is presented. In Figure 9, a three-dimensional system overview done by student of METI is presented. This 3-D representation aims to represent the UAV based system doing the cycle counting procedure inside a warehouse.

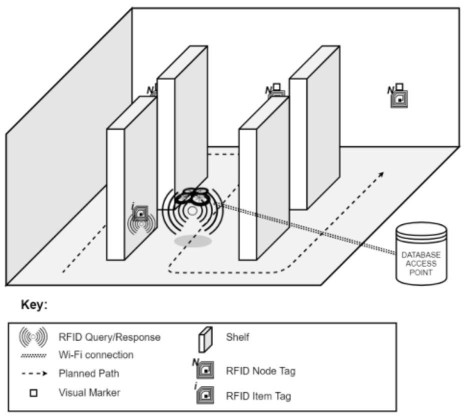

Figure 9. Three-dimensional system overview. Cycle counting using drones

4.4 – Opportunities for improvement

All the theoretical benefits that can be presumed the implementation of drones will bring are on Figure 10. Each benefit is explained, in order to allow the readers of this work to reproduce the methodology and analyse which benefits coincide with its case. These benefits have been adapted from business cases on the implementation of a warehouse management system [18] and have been divided into five categories represented in Figure 10.

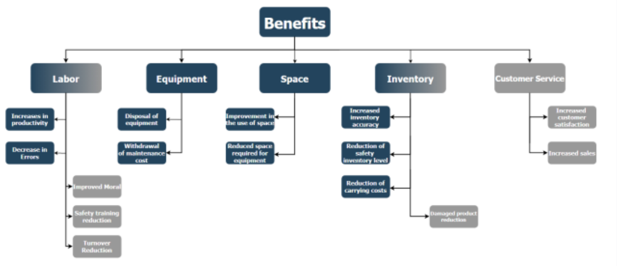

Figure 10. Expected Benefits

The above benefits are divided into qualitative and quantitative benefits (or savings). The qualitative benefits are identified with gray tint and the quantitative benefits are identified with the blue tint. The last should be evaluate in magnitude. This can be done by looking at the metrics used to assess the performance of the cycle counting and comparing that with the opportunity for improvement. It is necessary to establish the changes that drones will bring to cycle counting and what values are expected that these performance metrics will have. After knowing the current and expected value of the performance metrics, it is then possible to give a magnitude to the expected savings. This distinction will influence the way each benefit is included in the business case. The qualitative benefits being included in the narrative form and quantitative benefits being included together with the costs constituting the economic justification of the project [18].

5.Resuts Analysis

5.1 – Implement Architecture | Tests and experiments

Figure.11 portray the actual implemented communications architecture by the student of METI. A brief definition of each component implemented by the student of METI is given to give context to the reader. In order to perform the cycle counting, an RFID Reader (WRD-130-U1 UHF RFID card reader) is carried by a DJI Ryze Tello EDU drone. Regarding the used RFID tags, they are ALN-9662, Higgs-3," Short" Inlay type tags, that can be read with the RFID card reader. The RFID card reader is connected through an USB Wi-Fi Adapter (TP-Link TL-WN321G 54 Mbps Wireless USB Adapter) to the SBC (Raspberry Pi Zero). The item tag information contained in the ALN-9662, Higgs-3," Short" Inlay type tag, is first storage in the local storage of the SBC and then sent through Wi-Fi to the warehouse database, which, for the experiments performed in this dissertation, was run in the laptop of the MSc student in Telecommunications and Informatics.

The results used to build the business case are presented. The prototype build by the student of METI performed some Unit and Functional Tests. Along the section some comments regarding these tests are given and the impact off them in the business case. The DJI Ryze Tello EDU drone performed some unit testing in order to understand its practical limitations. The drone's battery has an effective flight time of 8 minutes to perform the cycle count, and the drone remains airborne for 10 minutes and 14 seconds. The battery percentage and the time have a direct proportionality.

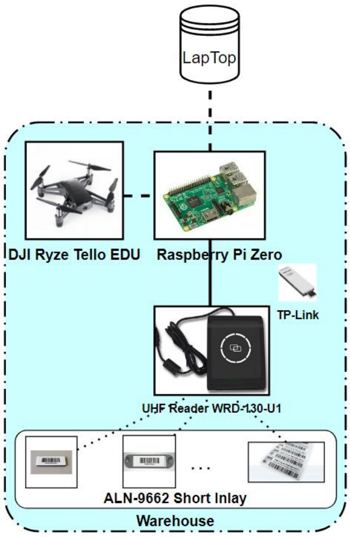

Figure 11. Implemented communications architecture

The drone takes approximately one hour to fully recharge its battery. This limit the amount of flights per day of work to less than ten. The drone to SBC connection SNR remains constant throughout the test. In the first minutes of use, the internal temperature of the drone increases dramatically as expected but then this internal temperature stabilizes at 72°C and 74°C. While testing its main camera and video streaming functionalities, the drone was found to overheat and shut down approximately in one and half minutes. The critical temperature of the drone is 75°C. The functional tests showed that the VPS of the drone presented major difficulties. To obtain good results, the drone was kept a consistent altitude throughout 80% of tests. This made it impossible to test the scanning in different shelf levels. Furthermore, the functional tests allowed to realize that the drone does not compensate for its speed when stopping after a "move" command whatever its speed. Two weeks after the testing phase began, the drone developed a problem with its rear-right motor. The most direct impact of this problem was a horizontal spinning motion that caused the drone to slowly rotate clockwise at a rate of approximately 0.21°/s. The RFID Reader is carried by hand along with the SBC because, the drone cannot carry the RFID system. In future work a different drone should be chosen.

The RFID system also performed some unit testing in order to be programmed to maximize read range and signal quality. Two different experiments were performed. The first experiment helped verified the ideal SOAP for a tag, the choice of the best frequency to use for tags and the gain of the RFID Reader. The SOAP specifications were established: Size (7cm wide and 1,7cm tall); Orientation (tag placed on a vertical surface with its widest sides parallel to the ground); Angle (front-facing with the RFID); Placement (against a non-metal surface). The performance of the RFID reader was maximized when the RFID reader was configured to emit queries at the TW frequency setting (922 MHz to 928 MHz) and its gain was set to its maximum value (power setting 14 at approximately (25 dBm). The objective of the second test was to know the minimum distance between tags that the RFID could read with 100% accuracy. This experiment allowed to conclude that the drone can only travel at a maximum constant speed of 20 cm/s, the RFID should be placed 20 cm away from tags, and the tags should be set 15cm apart when placed at their tallest to maximize reading efficiency. In addition, this experiment show that in reality this RFID Reader is not able to read multiple tags at once through bulk reading explained by the collision phenomenon observed in the tag responses. In future work a different RFID should be chosen to performed bulk reading.

Afterwards, some flying tests were conducted to know how fast the system can perform the cycle counting and the success rate of its scanning while doing it. A "move" command delay was observed. Worst case scenario the "move" command causes a delay of 18s and best-case scenario the "move" command on the first attempt. In the flying tests, the time it takes the system to perform the cycle counting can be described by the following steps:

1. The drone was facing North, so it had to turn 180° to advance to node $O_{(0,2)}$. This movement command is called RTT. In the flying tests, this command took, on average, 2s to be performed. The "move" command was accepted on average on the second attempt. In total this command comprises, on average, a total of 8s (RTT movement (2s) + "move" command (2 attempts, 3s each)). In total, the drone makes this move five times: on node (0,3), (0,0), (1,0), (1,3) and (2,3)
2. After rotating, the drone can travel to node $O_{(0,2)}$. The movement from one node to another is called Forward Moving Vertical or FWD_Vertical. In forward moving vertical, the drone travels at a constant speed of 20 cm/s. The distance between nodes is 147cm. In the flying tests, this movement took, on average, 7,35s (147cm/(20cm/s)) to be performed. The "move" command was accepted on average on the second attempt as well. In total this command comprises, on average, a total of 13,35s. This movement is done three times in each corridor. In the first corridor this movement is from node (0,3) to (0,2), (0,2) to (0,1) and (0,1) to (0,0). In total, this forward moving takes 40,05s in one corridor.
3. After the system reaches the node (0,0) it has to adjust its trajectory. This command is done by the navigation component and it is called ADJ. In the flying tests, this command took, on average, 30s to be performed. The "move" command was accepted on average on the first attempt. In total this command comprises, on average, a total of 33s (ADJ movement (30s) + "move" command (1attemp, 3s each)). In total, the drone makes this course correction movement two times: on node (0,0) and (1,3). The course correction made on node (2,0) is not considered to be part of the cycle count activity.
4. After performing the course correction, the system travels to node (1,0), in order to scan the second corridor. The movement from one node to another horizontally is called Forward Moving Horizontal or FWD_Horizontal. In forward moving horizontal, the drones travels at a constant speed of 20 cm/s. The distance between horizontal nodes is 100cm or 1m. In the flying tests, this movement took, on average, 5s (100cm/(20cm/s)) to be performed. The "move" command was accepted on average on the second attempt as well. In total, this command comprises, on average, a total of 11s. In total the drone makes this move two times: (0,0) to (1,0) and (1,3) to (2,3).

Based on the description above, the time it takes the system to perform the cycle counting can be computed by as follow:

$$\boldsymbol{TimeCycleCount}\ (\boldsymbol{s}) = \big(\mathbf{3}\ \boldsymbol{FWD_{Vertical}}(\boldsymbol{s}) \times \boldsymbol{N^{o}\ Corridor}\ (\#)\big) + (\mathbf{5}\ \boldsymbol{RTT})\ (\boldsymbol{s}) + (\mathbf{2}\ \boldsymbol{ADJ})\ (\boldsymbol{s}) + (\mathbf{2}\ \boldsymbol{FWD_{horizontal}})(\boldsymbol{s}) \quad (1)$$

Based on the flying tests, the Total Time the system takes to perform the cycle counting was, on average:

$$\boldsymbol{TimeCycleCount}\ (\boldsymbol{s}) = (\mathbf{3} \times \mathbf{13,35} \times \mathbf{3}) + (\mathbf{5} \times \mathbf{8}) + (\mathbf{2} \times \mathbf{33}) + (\mathbf{2} \times \mathbf{11}) = \mathbf{248,15}\boldsymbol{s}$$

During the flying tests each component executed its tasks correctly with minimum time of execution. The computational time of each component to perform its tasks is very small, so we can conclude that the drone obtains the information in near real time. In case that some obstacles were placed in front of the tags, the RFID had no problem scanning the items' tag information, unless the obstacle is made of metal. Additionally, the local database was populated beforehand with record of 13 items. Between them, were misplaced products on purpose to see if the RFID system could locate misplaced items. The inventorying component correctly update the item tag information and issued a flag of 1, indicating that the item was misplaced. Despite all the shortcomings exposed by the tests, the UAV RFID based system build by the student of METI to perform the cycle counting, work as a valid proof of concept. This proof of concept is a realization that a UAV RFID based system has practical potential to perform cycle counting. The performance metrics should not be taken harshly because the system is flawed in some way and only work as a proof of concept. Nevertheless, this performance metrics obtained by the student of METI were the utilize to construct the business case.

5.2 – Business Case

The proposed methodology developed for the creation of the business case begins with the identification of benefits. As previously said, not all opportunities for improvement, will be a reality for all companies that adopt the proposed prototype. Ideally, this prototype should have been applied a real case Being a proof a concept with a lot of functional issues, we were unable to apply the prototype to a real warehouse, for safety concerns. To simulate a real warehouse, we utilize an artificially lit room with an area 4m wide, 5,60m long and over 2m tall picture in Figure.12 The warehouse layout consists of a grid of three nodes (x-axis) by four nodes (y-axis). In other words, this mock-up represent a storage area with three corridors and four single deep pallet racking shelfs.

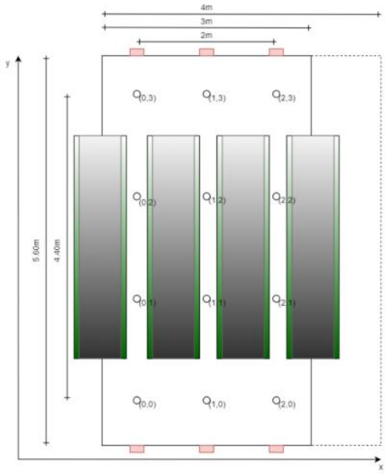

Figure 12. Warehouse Layout Mock-up

In the business case part, a breadth of the scenarios were thought to represent different corridors of a warehouse. In each corridor the "cycle counter" had to count 26 tags that correspond to 26 products. The corridor is 4,40m long. The first scenario aims to represent the section of a warehouse in where the products are fully stored in pallets (C and D products). In this scenario, the "cycle counter" takes 2,6 hours per corridor. The second, third and fourth scenarios aims to represent sections of a warehouse that are close from the outbound (A and B products). Picking zones or replenishment zones. For these sections, the "cycle counter" takes 0,07 hours per corridor. In contrast the UAV RFID system is agnostic to the storage type. It takes 0,023 hours to scan a corridor. For a corridor with Full Pallets, a company can replace 2,6 hours of work, get the information about inventory level 2,577 earlier and save in the process, 52€. For a corridor of 4,40m with 26 bin locations to be counted, a company can replace 0,07 hours of work, times six times per year, get the information about inventory level 0,047 hours earlier and save 1,4€, times six events per year. Regarding the disposal of equipment, the UAV RFID system offer the opportunity to replace completely a forklift. Previous to the introduction of the UAV RFID system, a company has to rent a forklift 6 times in a year in order to perform all the scenarios. The system saves at least 342€ to the company. As for the inventory accuracy, the results indicate that the proposed UAV system delivered a 100% inventory level accuracy in near real-time. Total Cost of the System was 340€. The drone is the DJI Ryze Tello EDU (160€). The RFID is an UHF RFID Reader (150€). Regarding the RFID tags, we choose the ALN-9662 tags. These tags came in packs and each pack cost 30€. We use a laptop to perform the tasks of the SBC. Additionally, all the software used is open source. Additionally, the unit tests performance, showed that the system is capable of scanning the tags with 100% accuracy, identified misplaced items and update the warehouse database in near real time. The system is autonomous, so the overall safety of operations will dramatically improve. The system is very cheap overall. The Unit Economics of the drone while performing the cycle count activity are very promising and the system has huge potential.

6.Conclusions

This dissertation had as main objective the creation and evaluation through a business case of a prototype of a UAV RFID based system solution aimed to perform inventory management and inventory traceability. This objective was established after the literature review allowed us to conclude that, although UAV have been a studied topic towards Warehouse 4.0, there is few detailed business cases constructed around the performance of UAVs for inventory management, especially with RFID technologies. For this reason, the first part of the methodology consisted of an analysis find the highest use case potential for the use of drones in warehouses. The North Star Metric Framework was used to conduct this analysis in two layers. In the first layer, to decide between Intra-logistics, Inventory Management, and Inspection Surveillance and the second layer to decide between a handful of activities related to inventory Management. The framework used helped to choose Inventory Management field as the most promising field and the cycle counting activity as the highest potential use case for the use of drones in warehouses. The second part of the methodology consisted of an extensive description of the processes that occur today in the cycle count, in order to identify the current limitations of these processes. With the information gathered in this step, we were able to present the proposed design of the UAV based system prototype aimed to perform cycle counting.

Finally, after the use case was identified and the prototype presented, it was possible to identify the various benefits (quantitative and qualitative) that were expected to arise with the investment on drones to do the cycle counting activity. The set of quantitative benefits include increases in productivity, disposal of equipment, improvement of the use of space and increased inventory accuracy, among others. The qualitative benefits identified were, among others, an improved moral, lower turnover rate of employees and increased customer satisfaction. In addition to the benefits, a set of costs for the construction of the proof of concept were identified. The economic justification strategy used was different from most cases where the NPV and Payback Period are the most common options. The main reason for using a different strategy, was the fact that the prototype developed between the author and another student from the MSc in Telecommunications and Informatics, be a proof of concept. The major realization of a certain proof of concept is to demonstrate its feasibility, not their economic viability so, the NPV or Payback Period do not suit the dissertation's business case. The strategy chosen was to do an economic justification related to a use case proof of concept. This approach removes the importance to established time horizons, because it assumes that there is too much uncertainty about the project to estimate good values of Cashflow along that years. Instead it looks for how much is gained each time the new system performs the work that otherwise was performed by the old system.

To explain the way in which the data used to build the business case were obtained, the implement prototype build the student of METI was presented. This system can be summarized as follow: an UHF RFID Reader (WRD-130-U1) is carried by a DJI Ryze Tello EDU drone. Regarding the used RFID tags, it was chosen the ALN-9662 tags. The RFID card reader is connected through a TP-Link Wireless USB Adapter to a Raspberry Pi Zero. The item tag information contained in the ALN-9662 tag, is first storage in the local storage of the Raspberry Pi Zero and then sent through Wi-Fi to the warehouse database, that is run in the laptop of the MSc student in Telecommunications and Informatics. The UAV RFID based system has to have four main components incorporate, namely: Inventorying component, navigation component, communications component, and a local database. Unfortunately, for safety concerns, the prototype was unable to be tested in a real warehouse environment. This made it very difficult to quantify the benefits. In future work, the system should be applied to a real warehouse environment. The alternative to simulate a real warehouse was to adapt a room (with an area 4m wide, 5,60m long and over 2m tall), so that it looked like a storage area with three corridors and four single deep pallet racking shelfs. These circumstances inhibited a deeper analysis of the possible benefits. Six of the nine quantitative benefits do not apply under the simulated warehouse.

Although the software and hardware will be built by the student of METI, the collected information on 4.2.1 were important to define the structure of the proof of concept. The goal of this dissertation was to use the results of the prototype build by the student of METI and applied them to a business case. The results of the prototype was acquired by running experiments and tests in order to quantify the benefits. The desired outcome of the tests perfomed by the student of METI was the hardware and software performance and its limitations.The prototype build by the student of METI performed some Unit and Functional Tests. The data used in this desertion

The DJI Ryze Tello EDU drone performed some unit testing in order to understand its practical limitations. The drone's battery has an effective flight time of 8 minutes to perform the cycle count, and the drone remains airborne for 10 minutes and 14 seconds. The battery percentage and the time have a direct proportionality. The drone takes approximately one hour to fully recharge its battery. This limit the amount of flights per day of work to less than ten. The drone to SBC connection SNR remains constant throughout the test. In the first minutes of use, the internal temperature of the drone increases dramatically as expected but then this internal temperature stabilizes at 72°C and 74°C. While testing its main camera and video streaming functionalities, the drone was found to overheat and shut down approximately in one and half minutes. The critical temperature of the drone is 75°C. The functional tests showed that the VPS of the drone presented major difficulties. Among others, the biggest difficulty was the change in altitude that triggered the Attitude mode. In Attitude mode the aircraft was not able to position itself. To obtain good results, the drone was kept a consistent altitude throughout 80% of tests. This made it impossible to test the scanning in different shelf levels. Furthermore, the functional tests allowed to realize that the drone does not compensate for its speed when stopping after a "move" command whatever its speed. Two weeks after the testing phase began, the drone developed a problem with its rear-right motor. The most direct impact of this problem was a horizontal spinning motion that caused the drone to slowly rotate clockwise at a rate of approximately 0.21°/s. A solution was developed but the problem persisted, so the only possible conclusion to be derived from this situation is that the rear-right motor is either faulty or more worn-out than the others. The RFID Reader is carried by hand along with the SBC because, the drone cannot carry the RFID system. In future work a different drone should be chosen.

The RFID system also performed some unit testing in order to be programmed to maximize read range and signal quality. Two different experiments were performed. The first experiment helped verified the ideal SOAP for a tag, the choice of the best frequency to use for tags and the gain of the RFID Reader. The SOAP specifications were established: Size (7cm wide and 1,7cm tall); Orientation (tag placed on a vertical surface with its widest sides parallel to the ground); Angle (front-facing with the RFID); Placement (against a non-metal surface). The performance of the RFID reader was maximized when the RFID reader was configured to emit queries at the TW frequency setting (922 MHz to 928 MHz) and its gain was set to its maximum value (power setting 14 at approximately (25 dBm). The objective of the second test was to know the minimum distance between tags that the RFID could read with 100% accuracy. This experiment allowed to conclude that the drone can only travel at a maximum constant speed of 20 cm/s, the RFID should be placed 20 cm away from tags, and the tags should be set 15cm apart when placed at their tallest to maximize reading efficiency. In addition, this experiment show that in reality this RFID Reader is not able to read multiple tags at once through bulk reading explained by the collision phenomenon observed in the tag responses. In future work a different RFID should be chosen to performed bulk reading.

Afterwards, some flying tests were conducted to know how fast the system can perform the cycle counting and the success rate of its scanning while doing it. A "move" command delay was observed. Worst case scenario the "move" command causes a delay of 18s and best-case scenario the "move" command on the first attempt. Based on the flying tests, the total time that the system takes to perform the cycle counting was, on average 248,15 seconds. During the flying tests each component executed its tasks correctly with minimum time of execution. The computational time of each component to perform its tasks is very small, so we can conclude that the drone obtains the information in near real time. However, the finals final results were greatly affected by the problem of the rear-right motor. At the end of the cycle counting, the drone was roughly 2m off-course with a 45° of incorrected yaw error. In case that some obstacles were placed in front of the tags, the RFID had no problem scanning the items' tag information, unless the obstacle is made of metal. Additionally, the local database was populated beforehand with record of 13 items. Between them, were misplaced products on purpose to see if the RFID system could locate misplaced items. The inventorying component correctly update the item tag information and issued a flag of 1, indicating that the item was misplaced. Despite all the shortcomings exposed by the tests, the UAV RFID based system build in order to perform the cycle counting, work as a valid proof of concept.

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As a final note, the present work is expected to be a useful tool to encourage future implementations of drones in the cycle counting activity.

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