Manufacturing Logistics and Packaging Management Using RFID

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1. Introduction

The chapter is centred on the analysis of internal flow traceability of goods (products and/or packaging) along the supply chain by an Indoor Positioning System (IPS) based on Radio Frequency IDentification (RFID) technology.

A typical supply chain is an end-to-end process with the main purpose of production, transportation, and distribution of products. It is relative to the products' movements from the supplier to the manufacturer, distributor, retailer and finally to the end consumer. Moreover, a supply chain is a complex amalgam of parties that require coordination, collaboration, and information exchange among them to increase productivity and efficiency [1, 2]. A supply chain is made up of people, activities, and resources involved in moving products from suppliers to customers and information from customers to suppliers. For this reason, the traceability of logistics flows (physical and information) is a very important issue for the definition and design of manufacturing processes, improvement of layout and increase of security in work areas.

European Parliament (Regulation (EC) No. 178/2002) [3] makes it compulsory to trace goods and record all steps, used materials, manufacturing processes, etc. during the entire life cycle of a product [4]. According to the European Parliament, companies recognize the need and importance of tracing materials in indoor environments.

Traditionally, the traceability system is performed through the asynchronous fulfilment of checkpoints (i.e. doorways) by materials. In such cases, the tracking is manual, executed by operators. Often companies are not aware of the inefficiencies due to these systems of traceability such as low precision and accuracy in measurements (i.e. no information between doorways), more time spent by operators and costs (due to the full-effort of operators who have to trace target positions and movements). According to [5] every day millions of transport units (cases, boxes, pallets, and containers) are managed worldwide with limited or even with lack of knowledge regarding their status in real-time. In order to overcome the lack of data due to traceability, automatic identification procedures (Auto-ID) could be a solution. They have become very popular in many service industries, purchasing and distribution logistics, manufacturing companies and material flow systems. Automatic identification procedures provide information about people, vehicles, goods, and products in transit within the company [6]. It is possible to note several advantages using an automatic identification system such as the reduction of theft, increase of security during the transport and distribution of assets, and increase of knowledge of objects' position in real-time.

Automatic identification procedures can also be applied to packaging products, instead of to each item contained in the package. Packaging is becoming the cornerstone of processing activities [7]. Sometimes products are very expensive and packages contain important and critical goods (for example dangerous or explosive materials) and the tracking of goods – and packaging in particular – is a critical function. The main advantage of automatic system application to packages is the possibility to map the path of all items contained into the packages and to find out their real-time position. The installation of automatic systems in packages allows costs and time to be reduced (by installing, for example, the tag directly on the package instead of on each product contained inside the package).

The purpose of the chapter is to provide an innovative automatic solution for the traceability of *everything that moves* within a company, in order to simplify and improve the process of logistics flow traceability and logistics optimization. The chapter deals with experimental research that consists of several tests, static and dynamic, tracing the position (static) and movements (dynamic) of targets (e.g. people, vehicles, objects) in indoor environments. In order to identify the best system to use in the real-time traceability of products, the authors have chosen Real Time Location Systems (RTLSs) and, in particular, the Indoor Positioning Systems (IPSs) based on Radio Frequency IDentification (RFID) technology. The authors discuss the RFID based system using UWB technology, both in terms of design of the system and real applications.

The chapter is organized as follows: Section 2 briefly describes IPS systems, looking in more depth at RFID technology. After that the experimental research with the relative results and discussion are described in Section 3. Section 4 presents an analysis of RFID traceability systems applied to packaging. Conclusions and further research are discussed in Section 5.

2. Background of Indoor Positioning System (IPS)

This section presents a general description of IPSs. First, the authors describe logistics flows (physical and informative). After that, the section moves on to describing IPSs (methods for determining the position of a target, criteria to evaluate IPSs, classification of IPSs), underlining the advantages of using automatic identification procedures for tracing objects. Final-

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ly, the section provides a brief description of RFID and in particular RFID-UWB technology (Radio Frequency IDentification-Ultra Wide Band).

2.1. Logistics flows

Generally, companies provide goods and/or services to customers, purchasing raw materials from suppliers. In order to increase productivity and efficiency within the supply chain, the parties (suppliers, manufacturers, and customers) have to exchange materials and information among themselves.

In a typical supply chain, logistics flows can be classified into *physical* and *informative*. Physical flows include operative activities (e.g. transport, storage of raw materials, semi-finished and finished products, etc.). A great purpose of the optimization of these flows is the reduction of transport and storage costs. Information flows concern the information on the demand, logistics, and production planning. Figure 1 shows a graphical representation of a supply chain, underlining physical and informative flows.

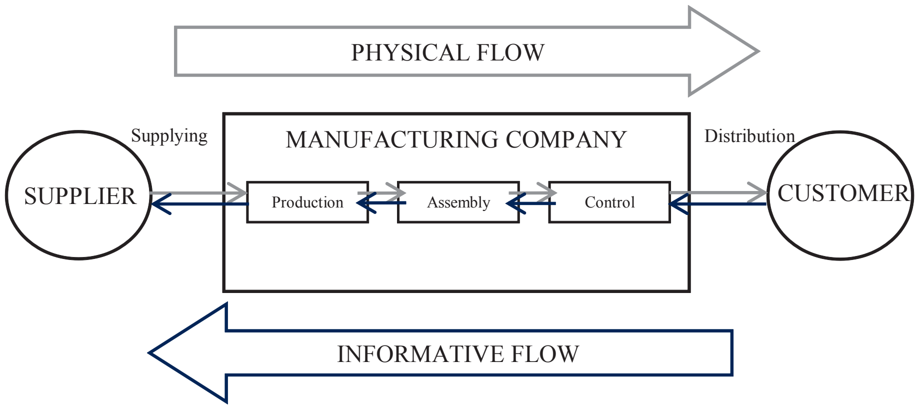

Figure 1. General scheme of a supply chain, underlining materials and information flows

Within the supply chain, it may be essential to know both the position and the movements of operators, pallets, tools, and packages. The traceability of flows within a company is a crucial aspect that has to be optimized.

Traditionally, the process of traceability of goods is performed through the asynchronous and automatic fulfilment of doorways by materials (e.g. bar code reading process) or totally manual by an operator who identifies and measures all movements between work centres, assembly and control workstations, and warehouses (Spaghetti Chart and From-To Chart are two technologies in which the presence of an operator to identify the position and map the movements of goods is necessary). This system implies approximate measurements, full-time effort and wasted time by the operator, and the possibility of human errors. In order to improve performances in the traceability process and to reduce costs optimizing the internal flows, companies are beginning to use automatic identification procedures (Auto-ID). The main advantage of this method is the time reduction in measuring the position and mapping the movements of an object. Real Time Locating System (RTLS) is an automatic system for identifying the real-time position of objects and IPS is the RTLS technology chosen by the authors for developing the experimental research.

2.2. Indoor Positioning System (IPS)

In recent years, indoor location sensing systems have become very popular [8] for locating the position and mapping the movements of goods and people. An Indoor Positioning System (IPS) is a process that continuously determines in real-time the position of something or someone in a physical space (e.g. the location detection of products stored in a warehouse, medical equipment in a hospital, luggage in an airport) [9]. According to [10], an IPS can provide different kinds of data for location-based applications. Any positioning system has at its core the measurement of a number of observable parameters (e.g. angles, velocity, ranges, and range differences) [11]. From the definition by Hightower [9], an IPS works all the time unless the user turns off the system, offers updated position information on the object, estimates position within a maximum time delay, and covers the expected area in which users need to use IPS [10].

In general, a real-time location system is a combination of hardware and software, continuously used to determine and provide the real-time position of assets and resources equipped with devices designed to operate with the system. A location may be described through relative position data with indication of distances, or absolute position data, with some accuracy in any defined grid of coordinates. Generally, location and ranging are reported visually, mostly referring to a map of land, a plan of a building, or in a graph. Alternatively, a change of location may be indicated with sound signals. In particular, a real-time location system uses sensors to determine the real-time coordinates of a tag, everywhere within the area of interest [11]. Curran et al. [11] describe the main industrial applications of indoor location determination systems for companies, in particular the real-time identification of the position of materials, the path control of material flows and warehousing.

Another important industrial application of location positioning system is the *traceability of packages*. Many companies need to track packages, first without the product and after with the products inside, to know the real path (and cost) of their material flows, allowing control of the Work in Progress (WIP) and finally to reduce costs of the system.

2.2.1. Positioning algorithms using IPSs

According to [11], there are several methods for locating and determining the position and movements of an object. A positioning location system can use only one method or combine a number of techniques to achieve better performance. The most commonly used methods are [8]:

- *Triangulation*: this uses the geometric properties of triangles to estimate the target location. It has two derivations: *lateration* and *angulation*.
  - *Lateration* estimates the position of an object by measuring its distance from multiple reference points (it is also called the range measurement technique). According to [8]

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this method implies the measurement of the *Time Of Arrival* (TOA, that is the travel time of the distance that divides the receiver and the transmitter, knowing the speed of signal propagation) or the *Time Difference Of the signal's Arrival* (TDOA, that is the distance of the difference between the arrival time of signals sent by the transmitter). The distance is derived by computing the attenuation of the emitted signal strength or by multiplying the radio signal velocity and the travel time;

  - *Angulation* (called also *Angle of Arrival* – AOA) is a method that locates the object to be measured through the intersection of several pairs of angle direction lines, each formed by the circular radius from a base station to the mobile target [8]. The main advantages are that a position estimate may be determined with as few as three measuring units for 2D positioning, and that no time synchronization between measuring units is required. The disadvantages include relatively large and complex hardware requirements and location estimate degradation as the mobile target moves away from the measuring units [8];

- *Scene analysis:* this refers to the type of algorithms that first collect the features (*fingerprints*) of a scene and then estimate the location of an object by matching online measurements with the closest *a priori* location fingerprints [8]. Location fingerprints refer to techniques that match the fingerprint of some characteristics of a signal that is location dependent. The location fingerprint is based on two moments: the offline phase, in which an analysis of the measuring environment is conducted, collecting a large number of coordinates, and the online phase, in which target data is compared with that collected before and the location is identified with the point with the most similar values [8]. This technique is subjected to signal interferences, because of obstacles presented in the environment;

- *Proximity* is the simplest method of positioning, but it can only provide an approximate location of the target, and not an absolute position. Proximity algorithms provide symbolic relative location information. Usually, this relies on a dense grid of antennas, each having a well-known position. When a mobile target is detected by a single antenna, it is considered to be located with it. When more than one antenna detects the mobile target, it is considered to be located at the one that receives the strongest signal. This technique can be implemented over different types of physical media. In particular, systems using RFID are often based on this method [8].

2.2.2. Evaluation criteria for IPS systems

In order to evaluate the performance of an IPS, various system performance and deployment criteria are proposed:

- *Accuracy* (or location error) is the most important requirement of a positioning system [8]. Usually, mean distance error is adopted as the performance metric, which is the average Euclidean distance between the estimated and true location. The higher the accuracy, the better the system. Accuracy alone, however, is not sufficient to completely define the performance of a positioning system and, as such, a trade-off between "suitable" accuracy and other characteristics is needed;

- *Precision* is the success probability of position estimation with respect to predefined accuracy [10] and considers how consistently the system works. Precision is a measure of the robustness of the positioning technique as it reveals the variation in its performance over many trials. In order to measure the precision of a system, the cumulative probability functions of the distance error is used;
- *Complexity* of a positioning system can be attributed to hardware, software, and operational factors. In particular, the software complexity is the computing complexity of positioning algorithms. Elements that influence the complexity are human efforts during the initialization and maintenance phases, and the computing time requested of the tag by the operator to determine the target position [8];
- *Robustness* is the ability of an IPS to keep operating even in serious cases, such as when some devices in the system are malfunctioning or damaged, or some mobile devices run out of battery power [10];
- *Scalability* is the ability to function normally when the positioning scope is large. Usually, the positioning performance degrades when the distance between the transmitter and the receiver increases. A location system may need to scale on two axes: geography (the covered area or volume) and density (the number of units located per unit geographic area/space per time) [8];
- *Cost* of a positioning system may depend on many factors, such as money, time, space, weight, and energy. The time factor relates to installation and maintenance. The space factor is linked to the space and weight constraints of system units. Energy is an important cost factor of a system: some mobile units are completely energy passive and only respond to external fields, therefore could have an unlimited lifetime. Other mobile units have a lifetime of several hours after which they have to be recharged or the battery needs replacing [8].

2.2.3. IPSs classification

According to [10], there are several criteria for classifying an IPS. One criterion is based on whether an IPS uses an existing wireless network infrastructure to measure the position of an object. IPSs can be grouped as *network-based* and *non-network-based* approaches. The network-based approach takes advantages of the existing network infrastructure, where no additional hardware infrastructures are needed. For cost reasons this approach is preferred. However, the non-network-based approach uses dedicated infrastructures for positioning and has freedom of physical specifications by the designers, which may offer higher accuracy.

More generally, IPSs are classified according to the method used to determine the target position. Figure 2 ([12] version modified by [8]) shows the technologies used to determine the target position according to *resolution* (the performance of IPSs) and *scalability* (the environment in which each technology is best suited).

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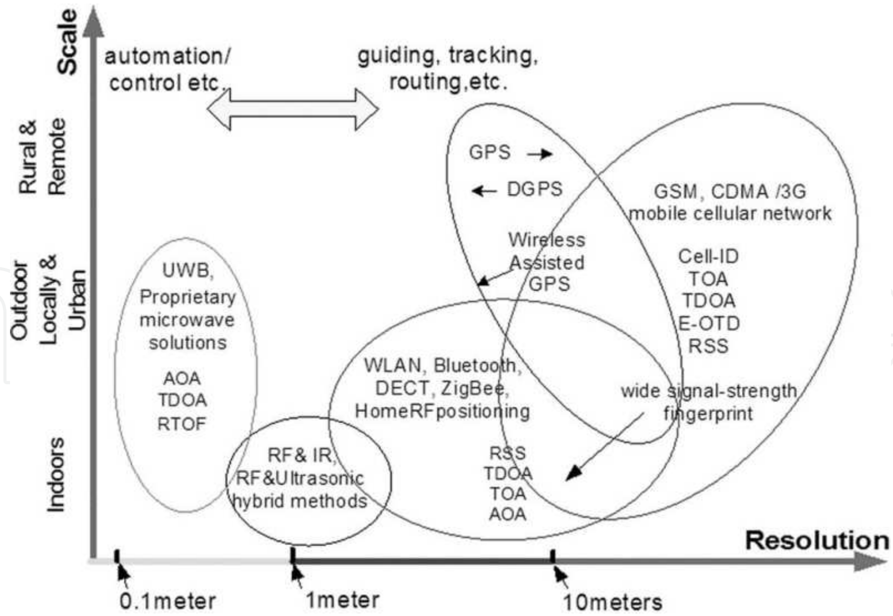

Figure 2. IPSs classification by *resolution* and *scalability* ([12] version modified by [8])

According to resolution and scalability, IPSs can be classified into several groups of automatic positioning systems. The most important are as follows:

- *Infra-Red (IR) based systems* are the most common positioning systems, since IR technology is available on board various wired and wireless devices, such as TVs, printers, mobile phones, etc. [13, 14]. They have several advantages such as wide availability, great positioning accuracy, simple system architecture and light and small tags. In addition, since the whole infrastructure is very simple, it does not need costly installation and maintenance [15]. The line-of-sight requirement and short-range signal transmission are two major limitations that suggest it is less effective in practice for indoor locations [16]. IR systems require the absence of interference and obstacles between the target and the sensor. For these reasons, they cannot be applied to some kinds of indoor scenarios in which the environment is complex;

- *Ultra-sound positioning systems* use diffusion, refraction, and diffraction phenomena, defined by the parameters of frequency, wavelength, speed of propagation and attenuation. Ultra-sound positioning systems are cheap solutions and their accuracy is high, but their precision is low when compared to IR-based systems, because of the reflection influence [15];

- *Radio Frequency (RF) based systems* are technologies used in IPSs, that can uniquely identify people or objects tracked in the system. They provide some advantages as follows. Radio waves can easily travel through walls and human bodies, thus the positioning system has a larger coverage area and needs less hardware compared to other systems. RF-based positioning systems can reuse existing RF technology systems [17]. They can cover large distances, since they use electromagnetic transmissions and are able to penetrate opaque objects such as people and walls. WLAN (Wireless Local Area Network), Bluetooth, Wireless sensor networks and RFID-UWB (Radio Frequency IDentification-Ultra Wide Band) are based on this technology [15], briefly described below.

- *WLAN* technology is very popular and has been implemented in public areas such as hospitals, train stations and universities. WLAN based positioning systems reuse existing WLAN infrastructures in indoor environments, which lower the cost of indoor positioning. The accuracy of location estimations based on the signal strength of WLAN signals is affected by various elements in indoor environments such as the movement and orientation of human bodies, nearby tracked mobile devices, walls, doors. RADAR system, Ekahau positioning system and COMPAS are the main techniques based on the WLAN positioning technology [18];

- *Bluetooth* is a technical and industrial method for transmitting data in a WPAN (Wireless Personal Area Network). It enables a range of 100 m communication to replace the IR ports mounted on mobile devices [19];

- *Wireless sensor networks* are devices exposed to physical or environmental conditions including sound, pressure, temperature and light, and they generate proportional outputs [20];

- *RFID-UWB* is a method for storing and retrieving data through electromagnetic transmission to an RF compatible integrated circuit [16]. RFID-UWB technology will be explained in detail in the next paragraph.

2.3. Radio Frequency IDentification (RFID)

In recent years, the application of RFID has attracted considerable interest among scientists as well as managers faced with the problem of optimizing production processes in several industries [6]. RFID has enormous economic potential, which many manufacturers (e.g. Wal-Mart, Tesco, Marks & Spencer and other retailers [21-23]) have already recognized and started to use successfully [24].

The main use of RFID systems in industrial applications deals with asynchronous identification. The traditional barcode labels that triggered a revolution in identification systems are inadequate in an increasing number of cases. Barcodes may be extremely cheap, but their limitations are their low storage capacity and the fact they cannot be reprogrammed [6]. A barcode is an optical machine-readable representation of data, which shows data about the object to which it is attached. Unlike an RFID, a barcode represents data by varying the widths and spaces of parallel lines, and may refer to a linear or one-dimension (1D).

Radio frequency identification is a method for storing and retrieving data through electromagnetic transmission to an RF compatible integrated circuit [16]. RFID positioning systems are commonly used in complex indoor environments and their function is to identify an object through radio frequency transmission. The main purpose of this technology is to assume information about animals, objects, or people identified by small tools in radio frequency associated to them. According to [25] some of the more transparent advantages of RFID are as follows:

- RFID does not require line-of-sight to capture data, hence saving time and labour by eliminating the need for unloading a pallet and identifying the load;
- RFID is able to read the contents of an entire pallet load or SKU (Stock Keeping Unit) in seconds and saves time and labour;
- RFID sensors can read data from tags from several meters away;
- Each RFID tag has a unique code;
- RFID can be a read/write system so data can be updated through the supply chain, providing insight into possible trouble spots in distribution, such as theft and damage.

On the other hand, RFID method is an expensive solution, but this limitation could be overcome with better performances of RFID systems.

By describing RFID components and their functions, it is possible to understand the technology and issues that influence the application of an RFID system. A typical RFID consists of three components:

- *RFID tag* (transponder) is the data-carrying device located on the object to be identified. RFID tags are categorized as either passive or active.
    - *Passive RFID* tags operate without a battery. They are mainly used to replace traditional barcode technology and are much lighter, smaller in volume, and less expensive than active tags. They reflect the RF signal transmitted by a reader, and add information by modulating the reflected signal [8];
    - *Active RFID* tags are small transceivers, which can actively transmit data in response to an interrogation. The frequency ranges used are similar to the passive RFID case except for the low and high frequency ranges. The advantages of an active RFID tag are the smaller antenna and the much longer range than passive tags (which can be 10 m). Active tags are ideally suited for the identification of high-unit-value products moving through a harsh assembly process [8];
- *RFID reader* (interrogator) has the overall function of reading and translating data emitted by RFID tags. Readers can be quite sophisticated, all depending on the type of tags that are supported and functions they need to perform. As a result, the capabilities and sizes of readers depend on the application [25]. A reader typically contains a radio frequency module (transmitter and receiver), a control unit, and a coupling element to the transponder. In addition, many readers are fitted with an additional interface to enable them to forward the data received to another system (PC, robot control system, etc.);
- *Host computer* communicates with the reader and information management system.

The RFID components and their connections are shown in Figure 3 ([6] version modified by [25]).

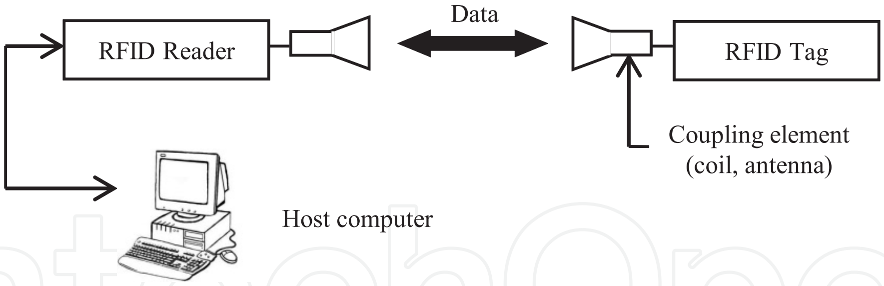

Figure 3. Components of an RFID system ([6] version modified by [25])

2.3.1. RFID – Ultra Wide Band (UWB)

Amongst RFID technologies, Ultra Wide Band (UWB) is the most accurate and fault tolerant system. It can have a widespread usage in indoor localizations.

RFID-UWB is an emerging radio technology marked by accuracy in the estimation of the position, and the precision with which it is possible to obtain that accuracy.

According to the most influential and widespread definition, provided by the *Federal Communications Commission Regulation* [26], an RFID-UWB system is defined as any intentional radiator having a fractional bandwidth greater than 20% or an absolute bandwidth greater than 500 MHz. These requirements mean that a band-limited signal, with lower frequency f_L and upper frequency f_H, must satisfy at least one of the following conditions (Equation 1, 2):

$$\frac{2(f_L - f_H)}{(f_L + f_H)} > 20\% \tag{1}$$

$$f_L - f_H > 500\ MHz \tag{2}$$

According to [27], the main characteristics of an RFID-UWB are the transmission of a signal over multiple frequency bands simultaneously and the brief duration of that transmission. RFID-UWB requires a very low level of power and can be used in close proximity to other RF signals without causing or suffering interferences. At the same time, the signal passes easily through walls, equipment and clothing [27-29] and more than one position can be tracked simultaneously. Moreover, RFID-UWB systems overcome limitations due to reflection, refraction, and diffraction phenomena, using pulses for the broadband transmission. The use of RFID-UWB offers other advantages, such as no line-of-sight requirements, high accuracy and resolution, lighter weight (the weight for each tag is less than 12 g) and the possibility to trace multiple resources at the same time, real-time and three-dimensionally. Furthermore, RFID-UWB sensors are cheaper, which make the RFID-UWB positioning system a cost-effective solution.

An RFID-UWB system comprises a computer and a hub (including a graphical interface), RFID-UWB sensors to record signals in real-time, RFID-UWB tags at low and high power and shielded CAT-5 cables. A set of sensors is positioned around the perimeter of the measured area. They receive pulses emitted by tags that include a set of data and are subsequently processed by the central hub.

The next section will describe in detail some experimental equipments developed by the authors based on the RFID-UWB system used in on-going research focused on real-time material flow traceability systems.

3. Experimental study

In this section, the experimental study about the traceability of material flows through IPS system based on RFID-UWB technology and its results are presented.

3.1. Components of the RFID-UWB system

The authors chose the RFID-UWB system, among IPS technologies since it is able to ensure the highest accuracy and precision in the measurements thanks to the combined use of AOA and TDOA techniques. The system comprises sensors, tags, and the software location platform, described below.

- *Sensors:* RFID-UWB sensors receive pulses from tags. Each sensor can determine the azimuth point and the arrival angulation thanks to the AOA technique. In this case, if only one sensor receives the signal, the system can determine the 2D location of the tag. Instead, if the signal is captured by more than one sensor, connected each other, it is also possible to find out the TDOA and obtain 3D location of tags. The configuration used reduces the infrastructure requisites, and consequently the costs, and guarantees high reliability and robustness of the system. The main characteristics of the sensors are:
    - *Reactivity in real-time*: each sensor maintains a constant frequency of 160 Hz, which means the tag can be seen every 6.25 ms by each sensor;
    - *Flexible installations*: this kind of infrastructure can be used for both small and large installations. Several sensors can be integrated in a unique system to monitor a big area and manage a large number of tags simultaneously;
    - *Synchronism:* in order to guarantee synchronism, the sensors are cabled with CAT-5 cables. A cell made up of several sensors is able to cover 10,000 m^2 of environment. In order to extend the covered area, the cells can be connected to each other;
    - *Bidirectional communication:* the sensors support bidirectional communication at 2.45 GHz. This allows the system to dynamically manage tags in an optimal way;
    - *Connectionsof sensors:* the sensors can be connected with standard Ethernet cables or through wireless adaptors, using pre-existing infrastructures like access point, switch Ethernet and CAT-5 wiring for communication between the sensors and the server;

- *Ease of maintenance:* the sensors are managed in a remote way through TCP/IP protocols and standard Ethernet for communication and configuration.

Figure 4 shows the sensors used in the experimental application.

Figure 4. Sensors used in the experimental application (courtesy of Ubisense Group plc)

- *Tags:* these are small and robust devices worn by a person or attached to an object to be accurately located within an indoor environment. Tags transmit brief RFID-UWB pulses that are received by sensors and are used to determine their position. The use of RFID-UWB pulses ensures both high precision (approximately 15 cm) and great reliability in complex indoor environments, characterized by noises like reflection from walls or the presence of metallic objects in indoor environments. Each tag is made up of movement detectors for instantaneous activation, LEDs for identification and buttons for executing particular operations. The main characteristics of tags are:
  - *Precise localization*: the tag transmits RFID-UWB radio pulses, used by the localization system for defining the tag position within 15 cm. The precision of the system is also maintained in complex indoor environments thanks to RFID-UWB technology. In this way it is possible to obtain accurate information on 3D positions even when the tag is detected by only two sensors;
  - *Bidirectional communication*: tags use a dual-radio system in addition to the mono-directional RFID-UWB radio communication, used for the spatial detection. The capacity of bidirectional communication allows the system to dynamically manage the update rate of tags, control of LEDs and battery status;
  - *Flexible update rate*: the software platform allows the update rate of tags to be varied. If a tag moves quickly, it can have high upgrading for more precise localization; instead, if it moves slowly the update rate could be reduced in order to save the battery. When the tag is at rest, it is put into energy saving mode thanks to a built-in motion sensor that allows restart in case of movement;
  - *Interactivebuttons*: slim tags have two buttons (while compact tags have only one button) to allow context-sensitive inputs in systems requiring interactivity. The applica-

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tions can use tag localization to work according to the events. The application can send feedback to the user through LEDs or acoustic signals;

- *Resistant and suitable*: tags are resistant in critical industrial environments, since they can withstand dust and water. They can also be installed in mechanical and electronic instrumentation safely;
- *Battery life:* the techniques of low-consumption and power management affect the duration of the battery. In a typical application, in which a tag is used to identify an operator every 3 sec, the battery has an average duration of four years.

Figure 5 shows an example of compact tags (on the left) and slim tags (on the right).

Figure 5. Compact tags (on the left) and slim tags (on the right), used in the experimental application (courtesy of Ubisense Group plc)

- *Software Location Platform* is used to control and calibrate the system, to manage the locations of data generated by tags and received by sensors and to analyse, communicate and inform users on the data system. The software platform is made up of the *Location Engine Calibration* and *Location Platform*.
- *Location Platform* is a software that collects and processes data from sensors and tags, viewable thanks to a graphical interface. In this way, it is possible to obtain 2D and 3D maps of the environment and detected assets. The collected data can be sent to other systems for further analysis and stored within the platform to act as a database.
- *Location EngineCalibration* (*LEC*) allows the sensors to be set, calibrated, and configured in cells using a graphical user interface. It is designed to allow the simple coordination of data from sensors and tags in order to be integrated in other applications. The Location Engine is the base component of the software platform since it allows the creation and loading of maps, single cell creation and setup of tags and sensors (deciding master and slave sensors), and the calibration of the system sensitivity (fixing the "noise threshold").
- The Location Engine supports several algorithms to determine tag position through sensor measurements. Each algorithm has a set of parameters that regulate tags behaviour. These parameters are called *filters* and can be applied to a single tag or a group of tags. The Location Engine presents one algorithm without a filter and another four filtered algorithms:

- *No filtering algorithm*: in this configuration, no filters are applied. This means that the position is evaluated only by measuring AOA and TDOA at a specific moment. In this way, any previous data is not processed and the path and speed of movements are not considered. Not using filters does not allow optimal measurements to be obtained.
- Filtered algorithms try to interpret tag movements to predict their positions during further measurements. Information coming from AOA and TDOA techniques is analysed and compared with the expected position that will be used in further measurement. The filter can eliminate measurements that can be deteriorated by reflections or disturbed by external noises. In order to do so, it is necessary to identify a movement pattern for the filter that defines the limitations to which the measured object has to be subjected. The higher the number of applied limitations, the better the robustness of the measurement. The filtered algorithms are presented below:
- *Information filter*: the tag can move along three directions but, if it is not seen for a period, the movement pattern assumes that it is continuing to move according to the last speed value and along the last detected direction. This algorithm is used for assets that move with predictable speed and without direction limitations;
- *Fixed height information filter*: the tag is free to move horizontally, but the vertical movements have to remain close to a predetermined threshold height. In this case, if contact with the tag is lost, it is assumed that it continues to move with equal speed along the horizontal direction, remaining close to the vertical predetermined height. Like the previous algorithm, the level of uncertainty of the location increases with the time. This algorithm is mainly used for vehicles moving at high speed and in two directions;
- *Static information filter*: the tag is free to move in three directions. If the tag is not detected, its position is identified with the last one and the level of uncertainty of localization increases with the time. This algorithm is used for assets that do not normally move or move in an unpredictable way, such as operators. The algorithm does not have any spatial limitations, allowing the detection of 3D movements (for example the movement of people climbing the stairs);
- *Static fixed height information filter:* the tag is free to move horizontally, but it is limited to the vertical direction. If the tag is not seen, it is assumed that its position is the last one detected and the height is close to the prefixed limit. This algorithm is used for targets that do not normally move or move in unpredictable way. Because of its vertical limitation, it is used for vehicles, tools, and people that move in two dimensions.

The parameters that can be regulated by the filtered algorithms are:

- *Handover stickiness*: indicates the tag's adherence to the cell in which it is located. It is measured indicating the maximum number of failed measurements of the tag's position before considering it out of the cell;
- *Handover minimum sensor count*: describes the minimum number of sensors belonging to the cell;

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- *Low support reset count*: defines the time in which the tag can be seen with low support modality (the situation in which the measurements rejected by the filter are more than the valid ones) before the reset of the filter;
- *Min reset measurements*: indicates the minimum number of support measurements before the reset of the filter;
- *Tag power class*: the filter can validate the tag's position based on the level of signal power received by each sensor. The filter has to recognize the type of tag that sends the signal, so as to interpret the received power correctly. The value 0 disables the function, value 1 indicates a compact standard tag and value 2 indicates a tag with amplified signal power;
- *Static distance*: describes the minimum distance travelled by a tag compared with the last one;
- *Static alpha*: defines the fraction (0.0 – 0.1) of the current measurement used by the filter when the tag is considered stable. The tag position is computed as follows:
- (alpha * current position) + (1.0 – alpha) * (last position)
- If alpha is close to 0.0, the movement of the tag will be significantly damped;
- *Max position variance*: describes the maximum variation in estimating the position;
- *Max valid position variance*: identifies the maximum variance in estimating the position. This value has to be less than or equal to the "max position variance". The difference between these two parameters is that if the uncertainty is higher than the max position variance, the forecast of the next localization does not change; while if the variance is higher than the max valid position variance, the filter will continue to track the position, but this measurement is not considered valid.

No-static algorithms can regulate other parameters such as:

- *Max velocity*: identifies the maximum velocity at which the object can move;
- *Horizontal velocity standard deviation*: the filter operates with a model of movement in which the tag velocity is considered constant. This parameter indicates the rate of velocity increase in X and Y as the time varies;
- *Vertical velocity standard deviation*: similar to the horizontal velocity standard deviation, but for the vertical velocity;
- *Vertical position standard deviation* (only for the filter with prefixed height): although the height is fixed, this parameter allows the tag to be varied along the vertical movement. If the value of this parameter is 0, the tag will only be detected in two dimensions;
- *Tag height above cell floor* (only for filter with prefixed height): fixes the value of height Z where the tag should always be.

Static algorithms can also regulate another parameter:

- *Horizontal position standard deviation*: the filter operates according to the movement pattern in which the tag's position is considered constant. The uncertainty of the tag's position increases with the time although the tag's forecasting continues to be in the last position. This parameter identifies the increasing rate of standard deviation of position in X and Y as the time varies.

It is possible to underline the difference between static and dynamic filtering algorithms. In the case of dynamic filter, there are long straight lines that identify the moments in which the sensors lose track of the tag and find it again few moments later. Consequently, the measurement's accuracy is low, mainly in the computing of distances travelled, which may be compromised. In the case of static filter, the traced path is very close to the real one, without straight lines, since the tag is always under control. Figure 6 shows an example of tracking of the same path using a dynamic filtering algorithm (on the left) and a static filtering algorithm (on the right).

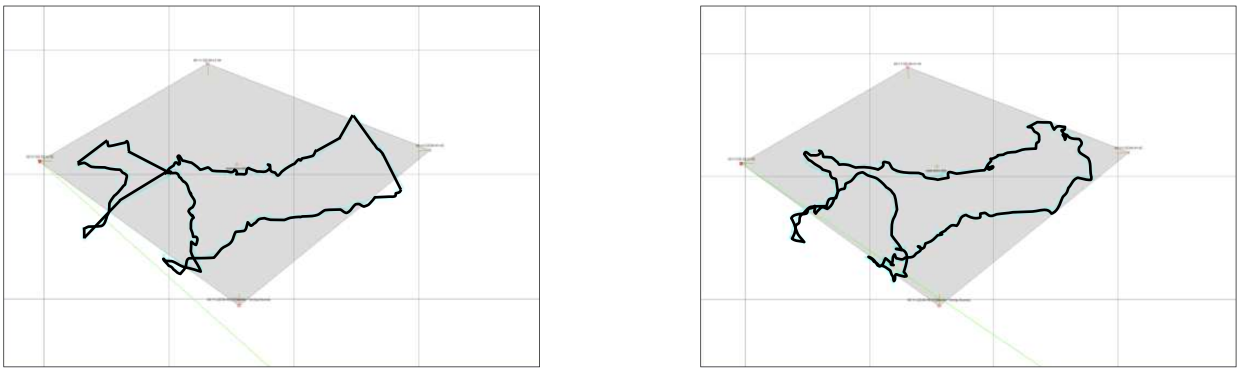


Figure 6. Path traced with dynamic filtering algorithm (on the left) and static filtering algorithm (on the right)

3.2. Installation and calibration of the system

The authors decided to install an IPS experimental system based on RFID-UWB technology in the Laboratory of Manufacturing System of Bologna University that, thanks to the presence of walls, machinery and metal objects, could be representative of a real industrial application.

Figure 7 shows the 2D map (on the left) and the 3D map (on the right) (obtained by LEC platform) of the laboratory, where the white squares indicate the position of the sensors. The optimal configuration needs sensors to be installed in the four corners of the building, but in actual fact, because of the presence of obstacles in the corners of the laboratory, the sensors are installed according to a rhombus distribution, able to guarantee total coverage of the area.

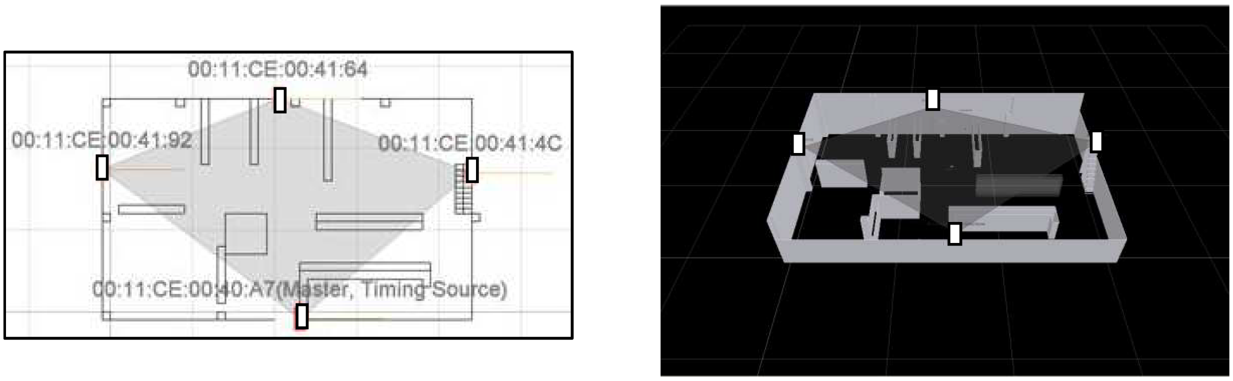


Figure 7. Map (on the left) and map (on the right) of the indoor environment considered in the application

The coordinates of sensors are presented in Table 1:

Sensors name	X [m]	Y [m]	Z [m]
00:11:CE:00:40:A7 (master)	15.618	-0.582	4.336
00:11:CE:00:41:4C (slave)	30.868	11.945	4.545
00:11:CE:00:41:64 (slave)	13.085	18.898	4.336
00:11:CE:00:41:92 (slave)	-0.308	11.039	4.651
STA (reference point)	15.409	10.833	2.100

Table 1. Coordinates of sensors

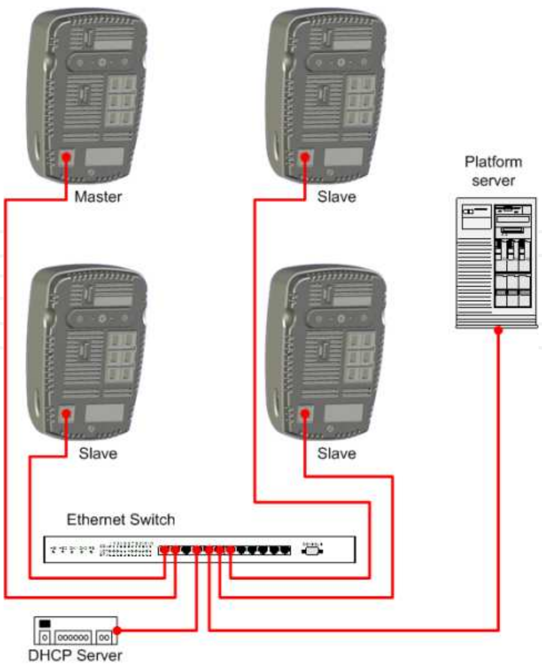


Figure 8. Connection of sensors with the system

The sensors have to be located as close as possible to the ceiling of the building to guarantee maximum coverage of the space and their angulation has to be directed towards the centre of the building. The sensors are grouped into rectangular cells, where they are connected to the switch POE that guarantees the power that is in turn linked with the PC (Figure 8). Each cell is characterized by a main sensor (master) that coordinates the activities of the other sensors (slave) and communicates with the tags. The master sensor has to be connected with the slaves by CAT-5 cables (Figure 9), in order to ensure the time synchronization. When the connection is made, the Location Engine Configurator is set to “Running” mode and the system is ready to work.

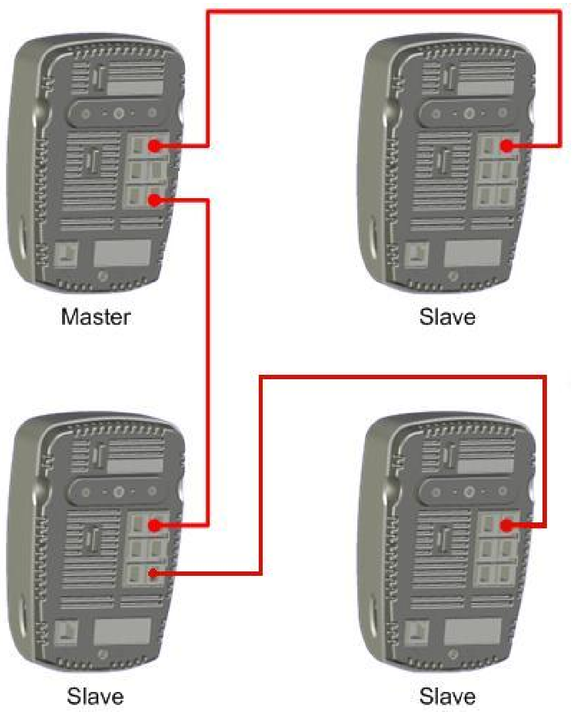


Figure 9. Connection between master and slave sensors

The threshold level of the “background noise” has to be decided, so to allow the system to distinguish valid signals from environmental noises. In order to calibrate the sensors, the power level detected by them is measured, verifying that the “background noise” remains below the threshold level. After that, it is possible to calibrate the sensor orientation. The sensors are oriented to a known tag, taken as reference. Figure 10 shows the sensor calibration through AOA. The green lines connect each sensor to the detected position of the tag.

In order to activate the localization through TDOA, it is necessary to calibrate cables that synchronize all the slave sensors with the master. When the cable calibration is completed, blue strips are added to the green lines, one for each pair of sensors. In absence of obstacles, assets, and reflection phenomena, the blue lines are straight; in actual fact, they are curved lines, with increased bending as interferences and noises increase (Figure 11).

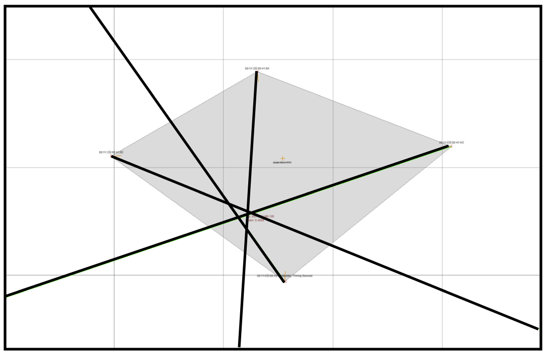


Figure 10. Calibration of sensors

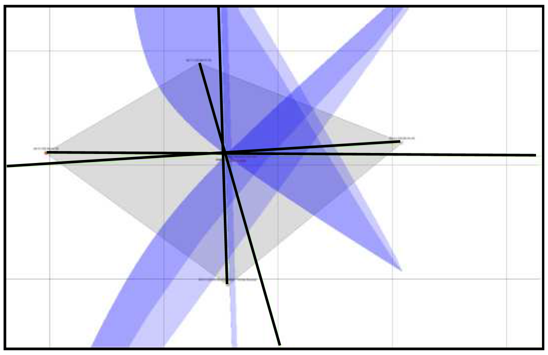


Figure 11. Calibration of cables

The system has to be connected with the layout of the environment to be monitored. A map of the laboratory has to be created, according to the external and internal walls, the columns and any other architecture present in the laboratory (Figure 12).

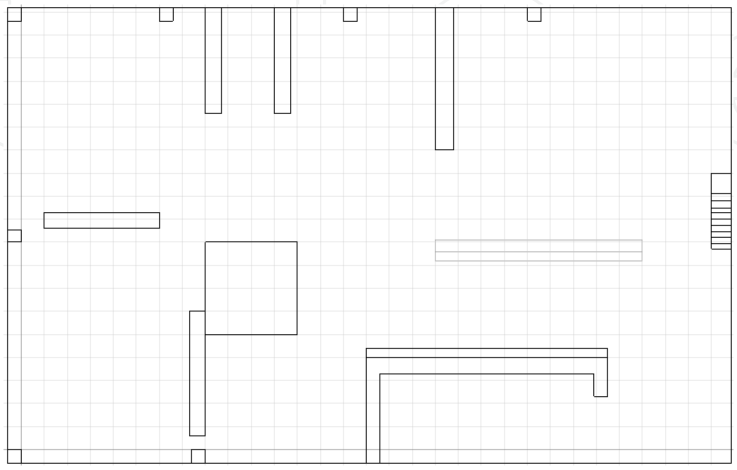


Figure 12. Map of the area controlled by the proposed system

When the map is loaded into the system, the coordinates of the sensors' position and some reference points within the area to be monitored have to be determined. A corner of the building is identified as the axis origin and is indicated by (0;0;0); the other corners will be identified with (X;0;0) and (0;Y;0) where X and Y are the length of the building sides. The level of floor is set as Z=0 so to use the 3D localization capacity of the system. In order to connect the position of the sensors with the laboratory's corner coordinates, the object localizations have to be calibrated, using known points as references. After that, the software will provide a 3D image of the area to be monitored.

In order to complete the calibration and verify the absence of errors, it is important to test the system, moving a tag within the area and ensuring that the sensors work correctly and that all necessary data is displayed.

3.3. Experimental evidence

The experimental research consists of several tests, static and dynamic.

The static tests consist of the identification of different points (to which tags are applied) within the area to be monitored. The sensors have to detect the coordinates of the tags to compare the estimated and detected coordinates of every point.

The dynamic tests consist of the application of a tag to an operator that goes around the monitored area. The operator follows prefixed paths, and the route and distance travelled by him are compared with the estimated values, measured in advance.

3.3.1. Static tests

In order to undertake the accuracy and precision of the proposed RFID-UWB system, the first test is the measurement of known point coordinates through a laser. 16 points within the monitored area, chosen according to the characteristics of visibility, proximity to metal objects and position, are identified.

The static tests are performed according to the variation of some tag parameters, such as:

- Filter used (*No-filter, Information Filter, Fixed Height Information Filter, Static Information Filter, Static Fixed Height Information Filter*);
- Update each four time slot;
- Frequency: 37 Hz;
- All tests are performed by putting the asset on a support 0.5 m high, except point 13, which is placed 2 m high.

Figure 13 shows the considered 16 points represented in the map of the laboratory.

For each point, four tests are performed in order to understand the average error between the estimated and detected coordinates.

Test 1

- Filter: *Static Fixed Height Information Filter;*
- Update each four time slot;
- Frequency: 37 Hz.

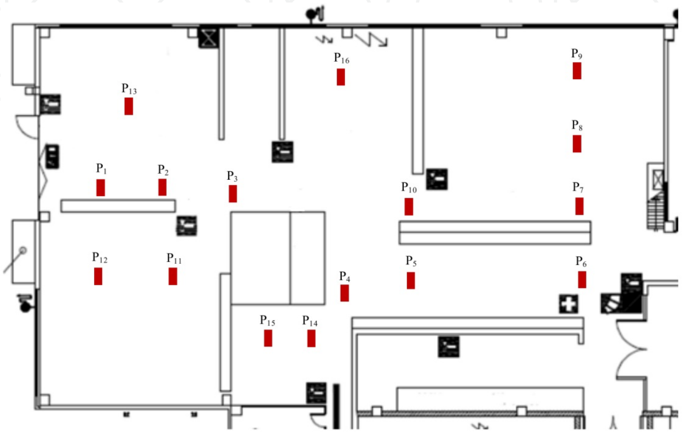


Figure 13. Reference points for static tests

Table 2 presents the estimated and detected coordinates of the 16 points, specifying the error between them.

Point	X [m]	Y [m]	X detected [m]	Y detected [m]	Error [m]
1	5.826	11.113	6.1007	11.0112	0.2930
2	7.976	10.991	7.6250	10.7717	0.4138
3	11.389	11.207	11.5024	11.0014	0.2347
4	15.693	7.138	15.9791	7.2085	0.2946
5	18.627	7.138	18.6374	7.1973	0.0602
6	26.39	7.138	26.1077	7.4651	0.4320
7	26.39	11.204	26.5720	10.8224	0.4227
8	26.39	14.028	26.2713	13.4417	0.5980
9	26.39	16.6	29.1303	18.6123	3.3998
10	19.347	11.207	19.5315	10.5318	0.6999
11	8.17	7.113	7.8618	7.2394	0.3330
12	3.415	7.05	3.7401	8.0534	1.0548
13	3.399	15.739	3.3871	14.3100	1.4289
14	16.397	2.748	14.9795	3.2646	1.5085
15	11.367	2.748	11.7532	4.3628	1.6602
16	15.637	15.187	15.8656	14.9317	0.3426

Table 2. Analysis of static *Test 1*

The average error of *Test 1* is 0.8236 m.

The points situated in the best positions (excluding points 9, 12, 13, 14 and 15) are located with high accuracy and present an average error of 37 cm. The worst result of point 9 is due to the presence of numerous obstacles around the considered area that make the tag visible to only one sensor. The same causes also influence the detection of points 12, 13, 14 and 15, although with lower impact.

Test 2

- Filter: any filter applied;
- Update each four time slot;
- Frequency: 37 Hz.

Table 3 presents the estimated and detected coordinates of the 16 points, specifying the error between them.

Point	X [m]	Y [m]	X detected [m]	Y detected [m]	Error [m]
1	5.826	11.113	5.8597	10.9974	0.1203
2	7.976	10.991	7.9914	11.1263	0.1362
3	11.389	11.207	11.4886	11.1252	0.1289
4	15.693	7.138	15.8387	7.2311	0.1729
5	18.627	7.138	18.4915	7.0736	0.1499
6	26.39	7.138	21.3617	3.6867	6.0987
7	26.39	11.204	28.4824	11.4226	2.1038
8	26.39	14.028	25.6281	13.6126	0.8676
9	26.39	16.6	28.6270	9.2454	7.6872
10	19.347	11.207	19.4776	10.3303	0.8863
11	8.17	7.113	7.7177	7.6014	0.6656
12	3.415	7.05	6.5425	5.6330	3.4335
13	3.399	15.739	3.5185	14.9626	0.7855
14	16.397	2.748	14.7514	2.9406	1.6567
15	11.367	2.748	10.9230	4.2645	1.5800
16	15.637	15.187	15.7053	15.1101	0.1028

Table 3. Analysis of static *Test 2*

The average error of *Test 2* is 1.661 m.

The absence of filters means that the oscillations of the tag positions are not damped. This leads to the worst result of all the tests. It is possible to note that the easily reachable and visible points present low error values, while for the most critical points the system performance is worse, even reaching high error values (in the order of metres).

Test 3

- Filter: *Static Information Filter*;
- Update each four time slot;
- Frequency: 37 Hz.

Table 4 presents the estimated and detected coordinates of the 16 points, specifying the error between them.

Point	X [m]	Y [m]	X detected [m]	Y detected [m]	Error [m]
1	5.826	11.113	6.0484	10.8824	0.3203
2	7.976	10.991	7.4876	11.0006	0.4884
3	11.389	11.207	11.3885	10.9646	0.2423
4	15.693	7.138	15.9165	6.9975	0.2640
5	18.627	7.138	18.6268	7.0524	0.0855
6	26.39	7.138	21.5961	4.4598	5.4912
7	26.39	11.204	26.5539	10.9868	0.2720
8	26.39	14.028	25.7937	13.2303	0.9959
9	26.39	16.6	22.0670	9.2817	8.4996
10	19.347	11.207	20.3456	10.0280	1.5450
11	8.17	7.113	7.1760	7.0652	0.9950
12	3.415	7.05	3.4986	7.7185	0.6737
13	3.399	15.739	3.1959	14.0444	1.7067
14	16.397	2.7481	14.9009	2.8403	1.4989
15	11.367	2.7481	12.5534	3.8802	1.6399
16	15.637	15.187	15.8690	14.8410	0.4165

Table 4. Analysis of static *Test 3*

The average error of *Test 3* is 1.5709 m.

Like the other two tests, points 6 and 9 present largely incorrect values, because of the condition of the area in which they are located. The other values are in line with the estimated measurements.

Test 4

- Filter: *Information Filter*;
- Update each four time slot;
- Frequency: 37 Hz.

Table 5 presents the estimated and detected coordinates of the 16 points, specifying the error between them.

Point	X [m]	Y [m]	X detected [m]	Y detected [m]	Error [m]
1	5.826	11.113	6.1134	10.8474	0.3913
2	7.976	10.991	7.4098	11.1165	0.5798
3	11.389	11.207	11.4637	11.0003	0.2197
4	15.693	7.138	15.7641	7.0616	0.1043
5	18.627	7.138	18.7090	7.1121	0.0860
6	26.39	7.138	20.3066	4.3934	6.6738
7	26.39	11.204	26.5290	10.9065	0.3283
8	26.39	14.028	22.7547	9.2591	5.9963
9	26.39	16.6	27.3837	17.1635	1.1424
10	19.347	11.207	19.5325	10.7986	0.4484
11	8.17	7.113	5.5139	7.2697	2.6607
12	3.415	7.05	4.0360	7.3234	0.6786
13	3.399	15.739	3.4861	14.5849	1.1573
14	16.397	2.7481	14.9694	3.0857	1.4668
15	11.367	2.7481	11.8527	3.4522	0.8554
16	15.637	15.187	15.7347	15.1152	0.1212

Table 5. Analysis of static *Test 4*

The average error of *Test 4* is 1.4319 m.

In this case, the results are better than *Test 2* and *Test 3*, but the problems regarding the presence of obstacles in the area to be monitored, noted during the other tests, remain.

From a comparison between the four static tests (Table 6), it is possible to note that the best algorithm in terms of the lowest average error between estimated and detected tag position is *Test 1* that uses a *Static Fixed Height Information Filter*.

Filter used	Average error [m]
Static Fixed Height Information Filter	0.8236
Any filter applied	1.661
Static Information Filter	1.5709
Information Filter	1.4319

Table 6. Comparison between the average errors of static tests

3.3.2. Dynamic tests

Dynamic tests are performed by applying a tag to an operator that goes around the laboratory following prefixed paths. The length of these paths, measured in advance, is compared with the real distance travelled by the operator. In this way, it is possible to see the precision of each known point and test the capacity of the system to reconstruct the trajectory.

The first part of the paragraph presents the results obtained by dynamic tests, using a static filter (*Static Information Filter*), while the second part shows the same results using a dynamic filter (*Information Filter*), underlining the differences between them.

3.3.2.1. Dynamic tests using Static Information Filter

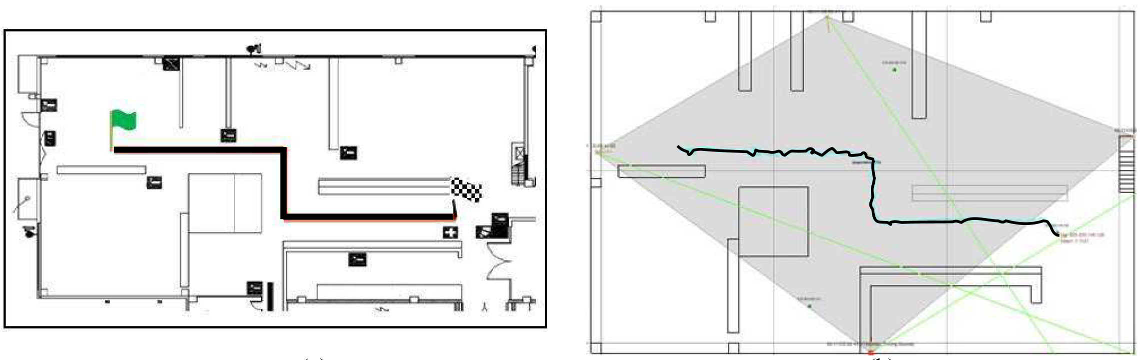
Four tests are performed, according to the following parameters:

- Filter: *Static Information Filter;*
- Update each four time slot;
- Frequency: 37 Hz;
- Threshold speed: 2 m/sec;
- Velocity of tag: 2 m/sec at a constant height of 1.5 m.

In order to cover the whole interested area, several proof paths are decided and measured in advance.

Test 1

The path is 28.8 m long: the first part is made up of an area with good coverage by sensors without obstacles, while in the second part the operator has to cross an area with numerous obstacles and metallic materials. Figure 14 shows the estimated path (Figure 14a) and the detected path travelled by the operator, obtained using LEC software (Figure 14b).



(a) (b)

Figure 14. a. Estimated path of dynamic *Test 1* b. Detected path of dynamic *Test 1*

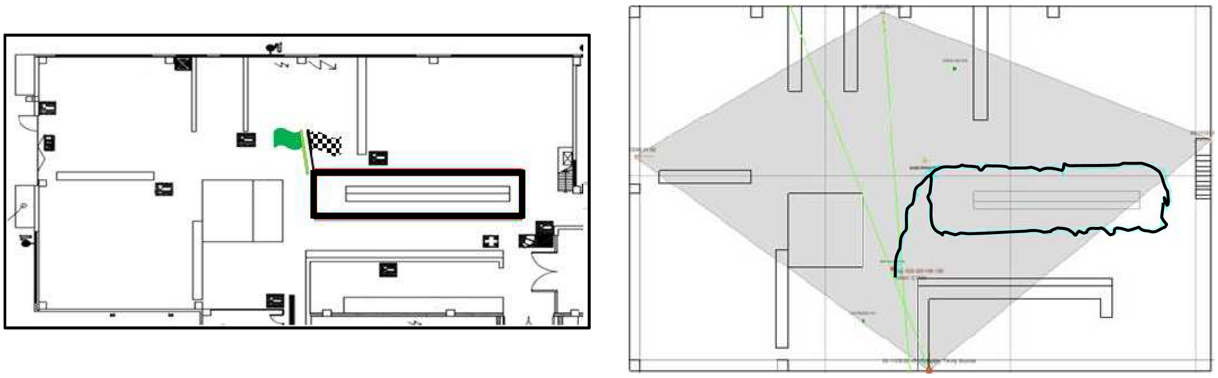
Table 7 shows the detected and measured distances and the difference between them.

Distance estimated [m]	Distance travelled [m]	Error [m]	Error [%]
28.8	31.22	2.421	8.408

Table 7. Synthesis of dynamic *Test 1*

Test 2

The path is 30 m long and it travels around a metallic shelf in the centre of the laboratory. Figure 15 shows the estimated path (Figure 15a) and the detected path travelled by the operator, obtained using LEC software (Figure 15b). As can be seen from Figure 15b, the blue-sky line representing the path, presents some noises, due to the momentary loss of the signal.



(a) (b)

Figure 15. a. Estimated path of dynamic *Test 2* b. Detected path of dynamic *Test 2*

Table 8 shows the detected and measured distances and the difference between them.

Distance estimated [m]	Distance travelled [m]	Error [m]	Error [%]
30	30.45	0.4594	1.5315

Table 8. Synthesis of dynamic *Test 2*

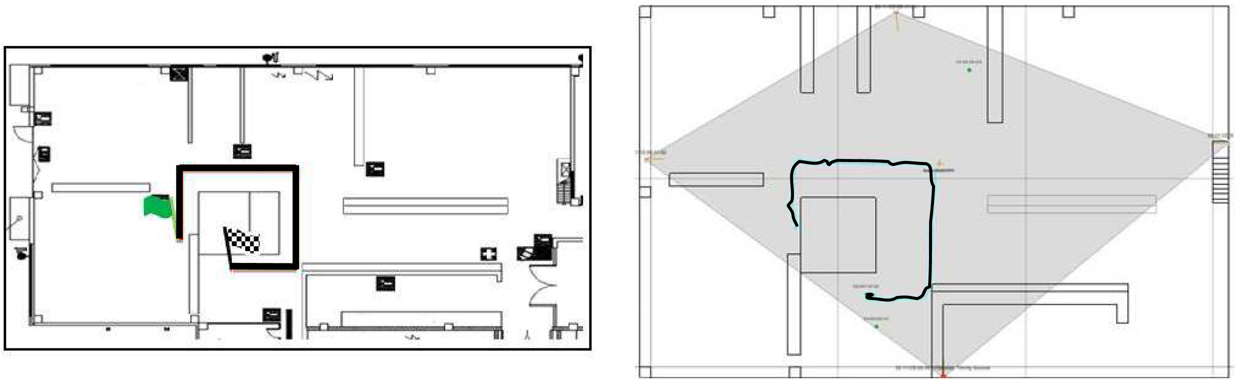
Test 3

The path is 23.5 m long: the first part is made up of an area with low coverage, because of the presence of walls, shelves and several metallic machines and objects. In the final part, the path is made up of an area surrounded by machineries and this makes the correct localization of the tag difficult. Figure 16 shows the estimated path (Figure 16a) and the detected path travelled by the operator, obtained using LEC software (Figure 16b).

Table 9 shows the detected and measured distances and the difference between them.

Distance estimated [m]	Distance travelled [m]	Error [m]	Error [%]
23.5	24.02	0.5199	2.2125

Table 9. Synthesis of dynamic *Test 3*

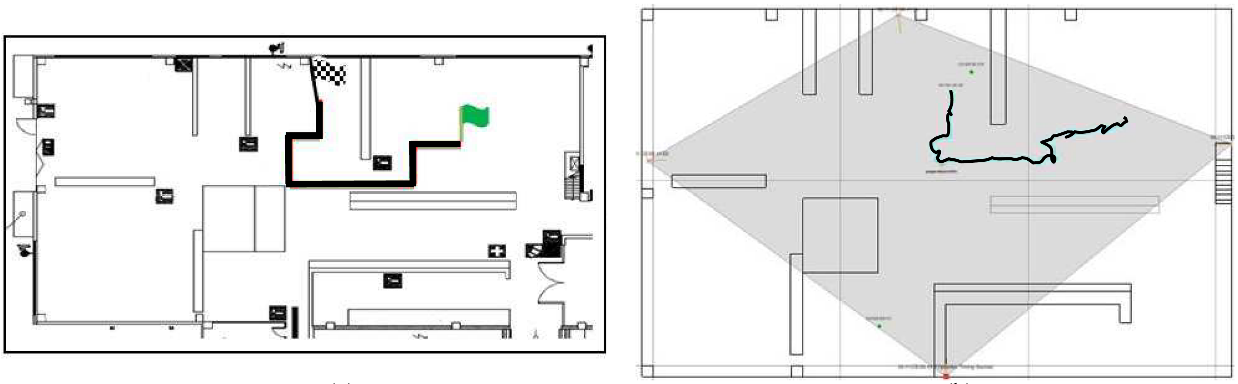


(a) (b)

Figure 16. a. Estimated path of dynamic *Test 3* b. Detected path of dynamic *Test 3*

Test 4

The path is 11.5 m long. It is situated in a complex environment, characterized by the presence of walls and several machines that strongly hinder correct signal reception by the sensors. Indeed, it is possible to observe the irregular trend that causes problems in the correct evaluation of the distance travelled. Figure 17 shows the estimated path (Figure 17a) and the detected path travelled by the operator, obtained using LEC software (Figure 17b).



(a) (b)

Figure 17. a. Estimated path of dynamic *Test 4* b. Detected path of dynamic *Test 4*

Table 10 shows the detected and measured distances and the difference between them.

Distance estimated [m]	Distance travelled [m]	Error [m]	Error [%]
11.5	14.42	2.9285	25.465

Table 10. Synthesis of dynamic *Test 4*

3.3.2.2. *Dynamic tests with Information Filter*

The authors decide to re-apply the same tests applying a dynamic filter, called *Information Filter*, to the algorithm, in order to compare the results with those obtained by using a static filter. If the sensors lose the signal, the static filter maintains the last detected position and updates it when a valid signal arrives. The dynamic filter, instead, stores the velocity and the direction of the tag moment all times and, in case of absence of valid signals, it assumes that the target continues to move in the same direction and at the same velocity as the last measurement. The use of a dynamic filter results in lower performance of operations for the reconstruction of trajectories, since the paths do not reflect the real tag movements.

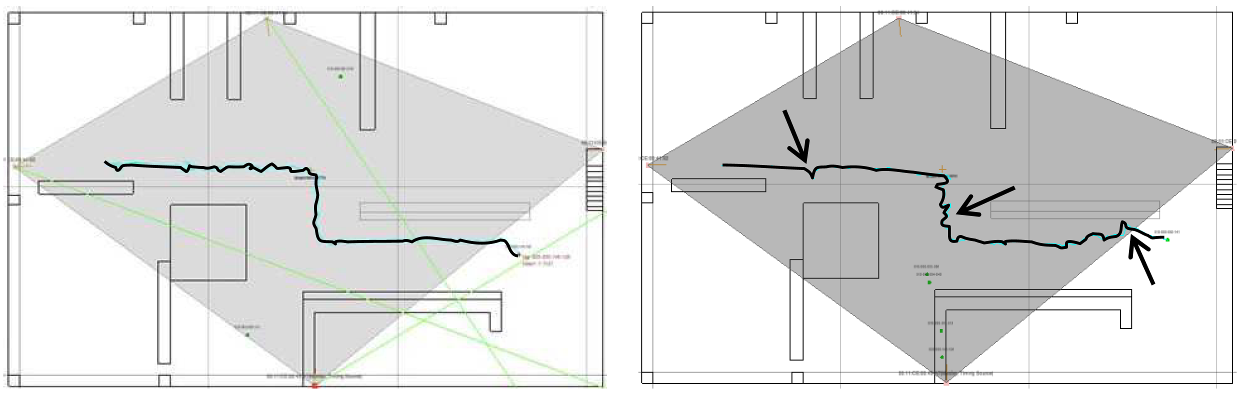
The tests are performed according to the same parameters as the dynamic tests with a static filter:

- Filter: *Information Filter*;
- Update each four time slot;
- Frequency: 37 Hz;
- Threshold speed: 2 m/sec;
- Velocity of tag: 2 m/sec at a constant height of 1.5m.

The paths are the same as the dynamic tests with static filter.

Test 1

The application of a dynamic filter does not heavily modify the results, except for the central stretch and the last part of the path, since it is made up of metallic materials. Figure 18 shows the comparison between the maps obtained using LEC software, in the case of static (Figure 18a) and dynamic filter (Figure 18b). The arrows show the main differences between the paths travelled using a static and a dynamic filter.



(a) (b)

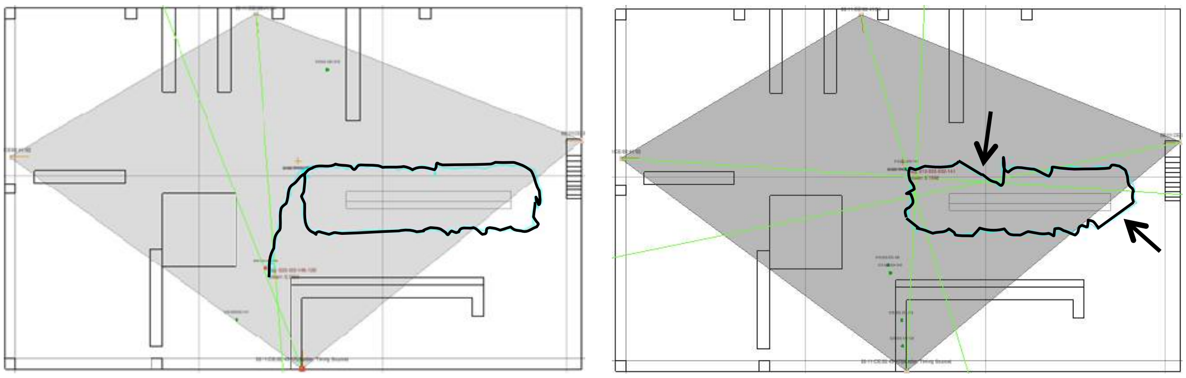
Figure 18. a. Path travelled using static filter b. Path travelled using dynamic filter

http://dx.doi.org/10.5772/53890

The path travelled by an operator in the laboratory using a dynamic filter, presents more noise than that travelled using a static filter. It is possible to note some peaks along the path, due to loss of signal. Indeed the *Information Filter* allows the target to move along the three dimensions, but, if it is not seen for a period, the system assumes that it is moving along the same direction and at the same velocity.

Test 2

In this case, the path is strongly modified at the point where the signal is lost. In particular, it is possible to observe the formation of straight lines that indicate that sensors were not able to detect the tag presence for some seconds. In this way, the last trajectory is maintained, but it does not reflect the real path travelled by the target. Figure 19 shows the comparison between the maps obtained using LEC software, in the case of static (Figure 19a) and dynamic filter (Figure 19b). The arrows show straight lines formed because of the loss of signal by the sensors, unlike the case of a static filter.



(a) (b)

Figure 19. a. Path travelled using static filter b. Path travelled using dynamic filter

Test 3

In this case, the errors in the traceability of the path are less evident than in the last case, but it is possible to note that the line appears more indented. This is an indication of more noises during localization. Moreover, in the final part, the trace overlaps with a wall, underlining the limits of the localization with the dynamic filter. Figure 20 shows the comparison between the maps obtained using LEC software, in the case of static (Figure 20a) and dynamic filter (Figure 20b). The arrows show the main differences between the paths travelled using a static and a dynamic filter.

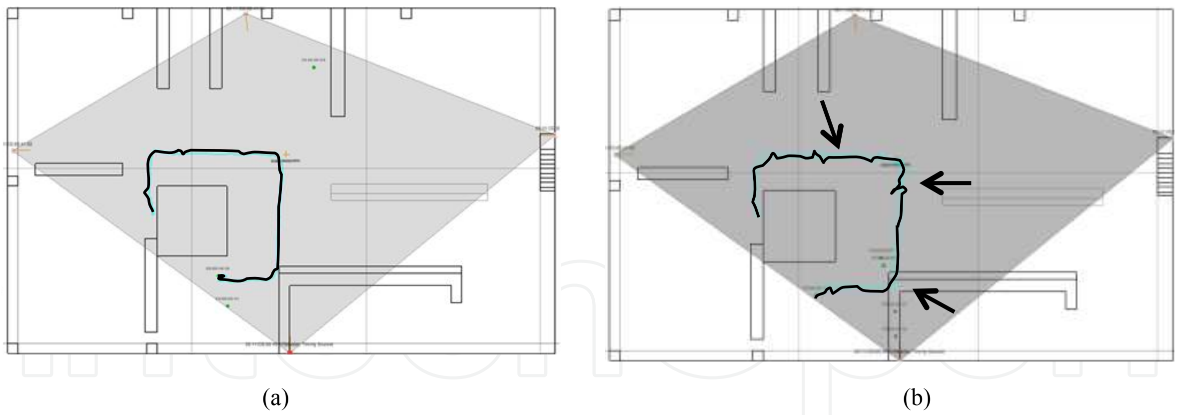


Figure 20. a. Path travelled using static filter b. Path travelled using dynamic filter

Test 4

In this case, the errors in the traceability of the path are evident, because of the critical environment in which the path is travelled. In the middle of the path the signal is lost and found again only in the proximity of the final part of the path. This leads to the creation of a straight line that does not reflect the real movement of the tag. Figure 21 shows the comparison between the maps obtained using LEC software, in the case of static (Figure 21a) and dynamic filter (Figure 21b). The arrows show the main differences between the paths travelled using a static and a dynamic filter.

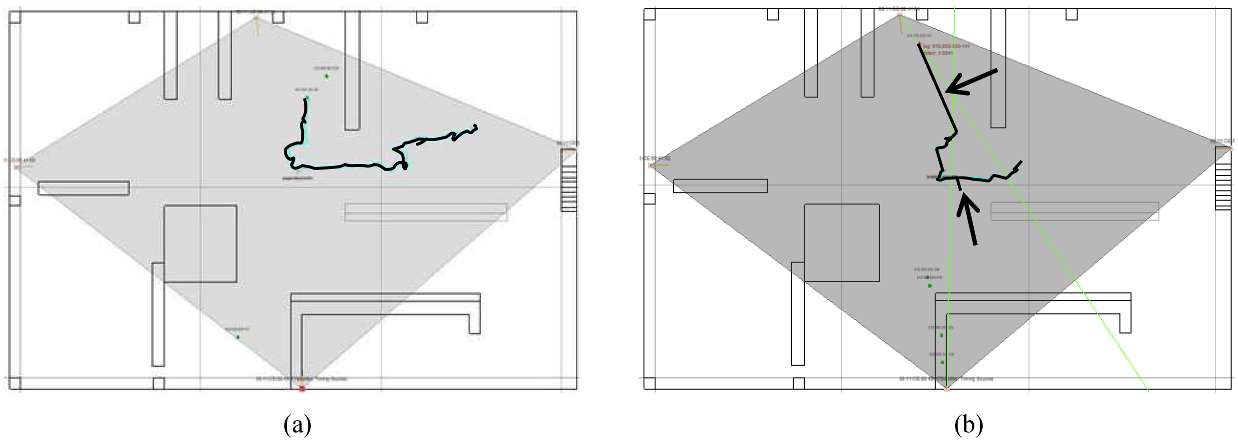


Figure 21. a. Path travelled using static filter b. Path travelled using dynamic filter

The algorithm using a static filter provides better results than that using the dynamic filter. A comparisons between the two algorithms show that if the sensors lose the tag signals for a period, the system assumes that the tags continue to move according to the last velocity value and along the last direction of movement. The greater the moment of no-detection of tag's position, the higher the inaccuracy of the system, causing a distortion of the path.

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3.4. RFID technology applied to packaging system

RFID technology is introduced in the packaging sector due to the logistics advantages regarding the utilization of automatic identification systems. This introduction mainly focuses on the secondary and tertiary packaging levels because the utilization in the item level (product identification) has been difficult to justify in economic terms [30]. Specifically, 250-300 millions of tags were used in 2006 in the tertiary level [31]. Furthermore, Thoroe et al. [32] have predicted that in 2016 there will be 450 times more RFID tags in use than today. Therefore, a rapid increase in RFID tag consumption is expected in the packaging sector.

Technological developments in recent years, along with a reduction in tag price and emerging standards have facilitated trials and rollouts of RFID technology in packaging. A study conducted by IDTechEx Limited [33] stated that the main benefits of RFID technology in packaging are better service and lower costs.

Packaging incorporating RFID technology is usually referred to as *smart packaging* (called also *active* or *intelligent packaging*) and it is commonly used to describe packaging with different types of value-adding technologies, for example placing in the package a smart label or tag. The term smart packaging was used by Yam [34] in 1999 to emphasize the role of packaging as an intelligent messenger or an information link. According to the Smart Packaging Journal [35], smart packaging is described as *packaging that employs features of high added value that enhances the functionality of the product* and its core is responsive features. These high-value features have a variety of characteristics, but are mainly made up of mechanical or electronic technology features such as mechanical medicines, dispenser of packaging tagged with electronic devices like RFID technology. Smart packaging is often used to refer to electronic responsive features where data is electronically sensed on the package from a distance, using an automatic identification system as the RFID technology. Schilthuizen [36] pointed out that identification and sensor technology enable intelligent functions in packaging.

Usually packages – and the products contained within them – are traced with systems obtained through asynchronous fulfilment of doorways by materials. In such cases, the tracking is totally manual, executed by operators. These manual activities could be eliminated or replaced by an automated identification activity, using an RFID system. The application of RFID to packaging allows more frequent and automated identification of packages (e.g. pallets, cases, and items) increasing the accuracy of the system, reducing the labour and time needed to perform the identification of packages and enabling near real-time visibility, which in turn facilities the coordination of activities within and between processes. The costs of RFID technology in packaging and potential benefits will vary, according to the packaging level that is tagged. Figure 22 (modified version of [25]) illustrates the influence that tagging different packaging levels has on the retail supply chain processes.

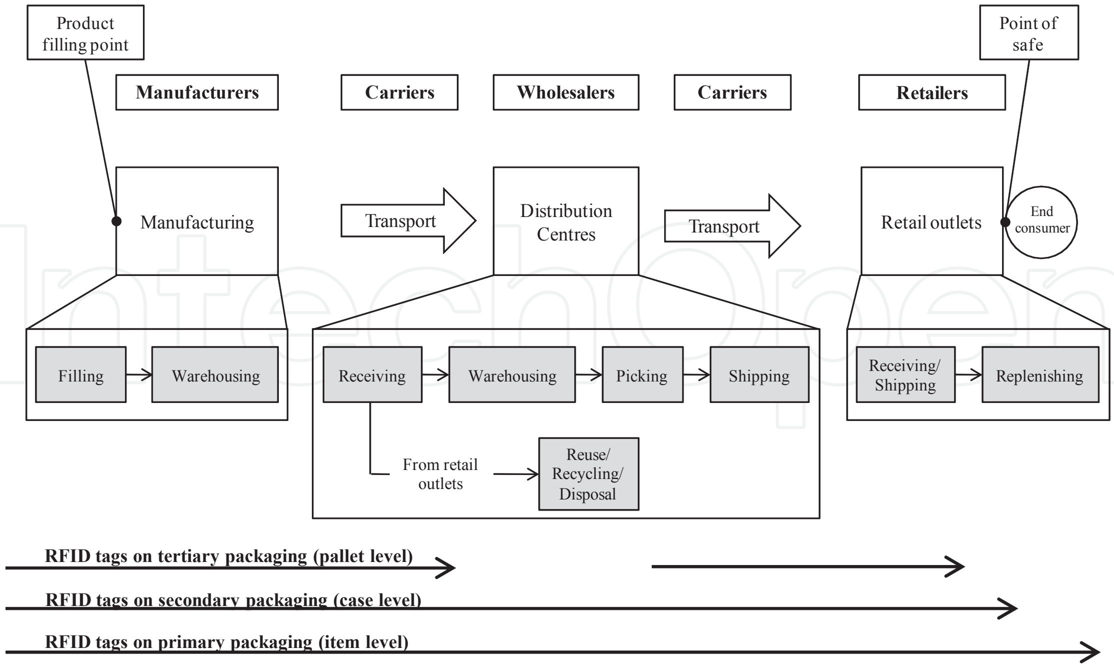

Figure 22. The influence of tagging different packaging levels along the supply chain (modified version of [25])

As can be noted in Figure 22, RFID tags on tertiary packaging may be used from the filling to the storing process. Furthermore, the tags on tertiary packaging may be used from the shipping process of the distribution centre to the receiving and shipping process of the retail outlet. RFID tags on secondary packaging could be used further downstream in the supply chain than tagged tertiary packaging, i.e. from the filling process and all the way to the replenishing process. Irrespective of the activities within the replenishment processes, tagging of primary packaging may be used in the whole supply chain, from the point of filling by the manufacturer to the point of sale in the retail outlet. Tagging of primary and secondary packaging could also provide opportunities beyond the point of sale in retail outlets e.g. recycling, reusing, and post-sales service and support. Although tagging on the primary packaging level will bring about the greatest level of benefits for the retail supply chain, tagging on secondary and tertiary packaging levels could provide valuable benefits for the supply chain. The model presented in Figure 22 indicates that a manufacturer who applies the tags to packaging can gain direct benefits from primary and secondary packaging tagging. According to [25], the average time to pick an order decreases by roughly 25% when RFID technology is used in secondary packaging. This means that the workforce conducting the picking activity, which is the core and the most labour-intensive activity in distribution centres could be reduced by approximately 25%. Hellström [25] also stated that the ability to automatically generate orders by capturing the inventory levels through tagging of primary packaging could reduce out-of-stock situations by approximately 50%.

Figure 23 shows the traceability of a primary package patterns within a manufacturing company (in particular in an assembly station) using the RFID-UWB system.

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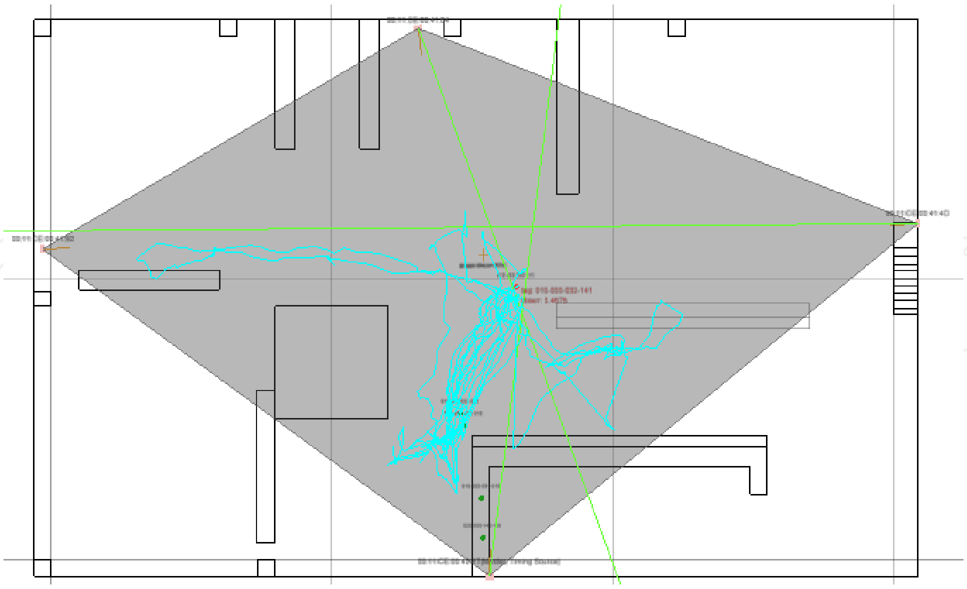

Figure 23. Traceability of a package with RFID-UWB system (Spaghetti Chart)

The traditional approach provides the well known *Spaghetti Chart* (manually realized). In addition, the data is approximate and does not provide precise values. In order to overcome the difficulty in analysing data from a traditional tracking method, Real Time Location System is perfect for the traceability of goods.

The framework on RFID and packaging shows the importance of tracing packages since several benefits can be achieved (e.g. reduction of costs and time, increase of efficiency and effectiveness, accuracy of the activities along the supply chain, security of the products, etc.). The RFID-UWB system presented in the chapter is perfectly aligned with the problem of package traceability.

3.5. Results and discussion

The results obtained during the static tests show that the average error between the estimated and the detected measurements is approximately 1 m. However, it is important to consider the non-optimal installation of the sensors. In fact, the most suitable arrangement to obtain the maximum coverage of the area is obtained by placing the sensors at the corners of the area to be monitored. Because of the presence of obstacles and metallic objects, the authors have had to opt for an alternative solution, placing each sensor in the middle of each wall. This causes the incomplete coverage of the monitored area.

Despite this limitation, the authors have chosen to include in the tests some points located outside the optimal coverage area. In these cases, the obtained accuracy is much lower than that obtained by points located where the coverage is maximum. For example, in some cases, there are errors of several meters, not compatible with the project needs and that affect the estimation of the average error that increases greatly. For this reason, these points are eliminated in the computing of the average error estimation, obtaining a considerable improvement in the accuracy, reaching an average error of 40 cm.

Regarding dynamic tests, the problems connected with the layout of the area are the same as the static ones. The authors have set the tests to simulate paths all around the area. Several critical points cannot be seen by the sensors. In particular, in some areas, the tag is seen only by one or two sensors, which results in inaccuracies in the traceability of the path travelled by the target.

Unlike the static tests, during the dynamic tests, it is necessary to control the typology of filters used. The results show that the best performance is obtained using a static (*Static Information Filter*), rather than a dynamic (*Information Filter*) filter, with an error of 5% between the estimated and the real distance travelled. If the sensors lose the signal and the filter is dynamic, the system continues to see the tag moving along the same direction and at the same velocity as the previous measurement. On the contrary, if the sensors do not see the signal and the filter is static, the system assumes that the position of tag is the same as the last measured. In conclusion, systems using dynamic filters provide less accurate results than systems using static filters.

In order to improve the performance of the system, several changes could be made:

- Install sensors according to the optimal layout, locating them in the corners of the monitored area, so to obtain greater coverage and eliminate points in which the intensity of the signal is low;
- Locate sensors as high as possible so that each point is in the line-of-sight of at least two sensors;
- Customize the filter configuration, finding a combination of parameters, better suited to the characteristics of the monitored area, and type of application (velocity of movement, static or dynamic detection, etc.) to be achieved.

4. Conclusion

In recent years, more and more companies are recognizing the importance of tracing logistics flows in indoor environments (e.g. factories, warehouses, production plants, etc.). One of the best ways to analyse internal flows of materials is the Real Time Location System (RTLS) and in particular the Indoor Positioning System (IPS). IPS is a process that continuously determines in real-time the position of something or someone in a physical space [9]. RFID-UWB (Radio Frequency IDentification-Ultra Wide Band) technology is the best method to use for tracing targets within a company, among others. The main advantages of RFID-UWB technology are that it requires a very low level of power and can be used in close proximity to other RF signals without causing or suffering interferences. At the same time, the signal passes easily through walls, equipment, and clothing [27-29] and more than one position can be tracked simultaneously. The use of RFID-UWB offers other advantages,

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such as no line-of-sight requirements, high accuracy and resolution and the possibility to trace multiple resources in real-time. Furthermore, RFID-UWB sensors are cheaper, and this makes the RFID-UWB positioning system a cost-effective solution.

In order to trace the position and to map the movements of targets (e.g. people, materials, products, vehicles, information), the authors have developed an experimental IPS system based on RFID-UWB technology in the Laboratory of Manufacturing System of Bologna University which, thanks to the presence of walls, machineries and metal objects, can represent a real industrial application. The system is made up of active tags – positioned on forklifts, packages, or operators –, sensors that receive the signal from tags, and a software platform that collects data in order to present, analyse and communicate information to the final customer. The tags, which must be positioned around the tested areas, transmit short pulses to the sensors, organized in rectangular cells. Each cell is characterized by a main sensor (*master*) that coordinates the activities of the other sensors (*slave*) and communicates to the tags the detected position within the cell. The software platform carries out the positioning calculations based on information by the sensors and then analyses the results.

The experimental research consists of several tests, static and dynamic. The results present useful conclusions in terms of system performance, accuracy, and measurement precision.

The static tests give good results in terms of average error (approximately 40 cm) between the estimated and detected position of all considered points. The dynamic tests are performed using filters that regulate the behaviour of tags. The filters can be static or dynamic. The tests performed by applying a static filter produce better results compared with dynamic filter. If the sensors lose the signal and the filter is dynamic, the system continues to see the tag moving along the same direction and at the same velocity as the last measurement. On the other hand, if the filter is static, the system assumes that the position of tag is the same as the last measured. In conclusion, systems using static filter provide more accurate results (with an average error between the estimated and detected real distance travelled of 5%) than systems using the dynamic filter.

RFID technology can be also applied to packaging. Although the use of RFID technology in packaging is still limited, more and more companies are recognizing the importance of tracing packaging products moving within indoor environments. During recent decades, the importance of packaging and its functions is been increasing. Packaging is considered an integral element of logistics systems and its main function is to protect and preserve products. More often companies have to transport and distribute particular goods (e.g. dangerous or explosive products) or expensive products, such as some kinds of medicines. Since companies need to reduce thefts, increase security, and reduce costs and time spent on the traceability of products, they are starting to use RFID in packaging.

Rapid advances in factory automation in general and packaging operations in particular have posed a challenge for engineering and technology programs for educating a qualified workforce to design, operate and maintain cutting edge techniques such as RFID systems [37]. The system proposed by the authors tries to play this challenge.

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