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Ultra Wide Band Indoor Positioning System: analysis and testing of an IPS technology

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Abstract: Due to their current operating context, all logistics processes, from the simplest to the most complex ones, are facing always more interesting challenges in terms of management of a huge variety of products and, at the same time, strict lead times. In such a framework, it turns out that logistics inevitably has to aim at avoiding or, at least, reducing, all the possible inefficiencies that could emerge during the execution of the various activities that are needed to deliver a required product to a customer. These inefficiencies could be, among others, delays in the searching of the needed product code within a warehouse, errors in the retrieval or in the picking of an item, waste of time for carts or for operators' travelling activity, lack of availability of warehouse facilities and devices due to failures and breakdowns. Of course, the overcome of the inefficiencies has to pass through the retrieval of the information that can be useful to increase the awareness of such existing lacks. For example, it would be important to have the data related to the movements of resources and to objects handling. In this paper, an innovative indoor positioning system is presented. Based on a real-time indoor location technology using Ultra Wide Band, it can be used for having an effective overview of a logistic system. After an introduction of the possible technologies for indoor positioning and tracking, the configuration of the system is showed, together with a description of a simple test and of an industrial application. The reported examples highlight some preliminary insights about the system accuracy and its applicability.

***Keywords**: indoor positioning, Ultra Wide Band, system test*

1. INTRODUCTION

In the last few years, the need to study and develop Indoor Positioning Systems (IPSs) are becoming always more important, for several applications. For example, such a technology has been successfully implemented in home-care and healthcare contexts. Other implementations have been developed in museums (Tesoriero et al., 2008) and supermarkets, in order to allow the user to view their location in real time on a device and, then, to discover the fastest path to reach a certain point of interest. The application of indoor location services in a commercial area, such as a supermarket, can bring benefit both to retailers and consumers. The consumers would be able to navigate through vast hypermarkets and, thanks to the device, to locate the product effortless, receiving real-time information based both on their personal preferences and current position. On the other side, the retailers would benefit from knowing the exact position of the consumers. From this information they could allocate the workforce accordingly, manage shelf replenishments more efficiently, and avoid out-of-stocks. Moreover, marketing suppliers can create personalized promotions, analyze statistics on route patterns and consumer behavior (Giaglis et al., 2002).

The potential of Indoor Positioning Systems is broad and may concern many fields, including the industrial one. According to Curran et al. (2011), for example, there are several techniques of real-time identification of the material's location and flow within a warehouse. This aspect becomes even more crucial when considering that most of the logistics processes, both the simplest and the most complex ones, are facing several challenges in terms of management of a huge variety of products and, at the same time, strict lead times. Within this context, it turns out that logistics inevitably has to aim at avoiding or, at least, reducing, all the possible inefficiencies that could emerge during the execution of the various activities that are needed to deliver a required product to a customer. These inefficiencies could be, among others, delays in the searching of the needed product code within a warehouse, errors in the retrieval or in the picking of an item, waste of time for travelling of carts or operators, lack of availability of warehouse facilities and devices due to failures and breakdowns.

From the above observations, it can be seen that there can be multiple uses of an indoor positioning system. Since each situation could require different performance, there is not a single best solution that is suitable for each scenario. Therefore, it is necessary to find a right compromise among various performance parameters like, for example, accuracy, scalability and cost.

The aim of this paper is to present a different application of a Ultra Wide Band (UWB) system with a good performance in terms of accuracy and reliability. According to the items on which the targets are put on, this system can be used, for instance, for the tracking of forklifts in a receiving and shipping area, for the estimation of the movements of a pallet or of a carton inside a warehouse, or for the measurement of the distances travelled by a picking operator. Once that these very useful (and usually difficult to get) data are available, and,

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therefore, once that the related probable inefficiencies emerge, it is then possible to propose some improving actions or adjustments for the analyzed process, that can also lead to a more aware logistics management. Moreover, this could be also the perfect basis, for instance, for the so-called *predictive analytics*, according to which a correct use of such kind of data can help a company to run more efficiently and cost-effectively, reacting in advance to some frequent emerging issues.

The remainder of the paper is structured as follows. In the next Section, a brief overview of various Indoor Positioning systems is presented. Then, Section 3 shows the description of the new IPS. Then, in the two subsections 3.2 and 3.3 a preliminary test and an industrial application of the system are reported. Finally, in the last section, the conclusions and some suggestions for future research are explained.

2. TECHNOLOGY OVERVIEW

This section analyses the criteria used to evaluate the performance of an IPS. After that, the section presents a view of most relevant technologies of IPS, also proposing a possible classification.

2.1 Criteria to evaluate an IPS

Some of the possible parameters that can be considered to evaluate an IPS are:

1) *Accuracy.* As defined in the Joint Committee for Guides in Metrology (JCGM) it is *the closeness of agreement between a measured quantity value and a true quantity value of a measure* (Mautz, R., 2012). Usually, a mean distance error is adopted as performance metric, which is the average Euclidean distance between the estimated position and the true location (Regattieri and Santarelli, 2013). Accuracy depends on the system considered and that is still a very challenging area of research (Al Nuaimi and Kamel, 2011).

2) *Coverage Area:* It is the surface extension that the system can achieve by ensuring a correct positioning result. Each IPS is characterized by its own range. According to Mautz (2012) there are three categories of coverage depending on the extension that can enclose the system: local coverage refers to a limited area like a single room, scalable coverage concerns the possibility to increase the area by adding a sensor. Or a worldwide coverage, where, the system is able to cover a worldwide area like GPS (Alarifi et al., 2016)

3) *Robustness.* Ability to be reliable even in case of device-related malfunctions. In fact, it could happen that signal is not available, and the positioning techniques have to use incomplete information to compute the location (Liu et al., 2007).

4) *Scalability.* Usually, the more the area to cover is vast, the more positioning performance is damaged. Scalability is the ability to operate at full capacity even in large space encodings. A location system may need to scale on two axes: geography and density. Geographic scale means that the area or volume is covered. Density means the number of units located per unit geographic area/space per time period (Liu et al., 2007).

5) *Cost.* This parameter can be measured in terms of money, time, space, weight and energy. For instance, installation and maintenance have an impact on the time and, then on the cost, since phase to configure the system is required. Energy is a cost important factor as there are some devices completely energy passive, so they have an unlimited lifetime, others, have to be recharged or the battery needs replacing (Regattieri and Santarelli, 2013).

6) *Complexity.* The human efforts or intervention can be considered an aspect of complexity of IPSs. It is more important that an indoor positioning system owns a simple set-up procedure as it allows the user to configure the system swiftly and almost without systematic errors. Another issue could be due to the time required by the user to determine his/her position, or target position (Liu et al., 2007).

2.2 Classification of IPSs

There are several types of systems that have been classified according to different criteria over time. They can be network-based and non-network-based technologies (Deak et al., 2012), or according to Liang et al. (2013) they can be subdivided into two classes, depending on hardware requirements: those requiring a special hardware in the environment and the self-contained ones.

The most important technologies that can be used for indoor positioning are the following:

- *Infra-Red (IR).* This is one of the most common wireless technologies used; however, it presents some critical limitations. The more crucial is related to the environment of use of this system, as it requires the absence of interferences and obstacles. Moreover, it has a limit due to the short-range signal transmission between devices. On the other hand, IR can provide several advantages, such as the possibility of limiting the signals inside a specific room, since the IR beam is not able to penetrate the walls (Mainetti et al, 2014).
- *Ultrasound.* The name originates from ultrasonic wave used to measure the position of a mobile target form a fixed-point receiver. Since this system is able to cover from 2 to 10 meters, it is considered a short-range technology.
- *Radio Frequency Identification (RFID)*. The localization of targets are transmitted through radio waves. This system is appreciated as it is able to cover large distances and easy travels through walls and human bodies (Gu et al., 2009). The RFID technology is widely spread as it is cheap and a flexible identification system. Moreover, it can also be linked to barcodes to facilitate the monitoring of objects to which it is identified.
- *Wi-Fi.* Within this kind of network it is possible to monitor the movements of a mobile device and, since Wi-Fi is widely spread inside buildings, this system is frequently used for indoor localization. Consequently, the low cost and the possibility to localize the position without using extra software are the main advantages of this technology. The accuracy is between 20 m to 40 m, and it is influenced by the number of access point. However, by adding wireless router,

or alongside it with newer technologies, the accuracy can be improved (Chen et al., 2014).

- *Vision.* Thanks to the use of video data it is possible to evaluate phases of movements. This approach can use two different camera systems: fixed or mobile. In the first case, the position of mobile devices is estimated based on the camera's fixed position inside the captured image. In the latter case, the camera is attached to the target, so that it moves with it. In this case, the movements can be estimated through the monitoring of the position and of the orientation of the mobile camera.
- *Ultra Wide Band (UWB).* This approach is characterized by ultrashort pulses (typically <1 ns) and, unlike the RFID technology, which uses a single portion of the frequency spectrum, the UWB uses multiple bands of frequencies simultaneously to transmit its own signal. The peculiarities that have made this technology so appreciated and used are attributed to the high accuracy offered, the absence of multi path distortion and no line-of-sight requirement. Furthermore, it is important to emphasize that UWB is a scalable system, thanks to the large coverage range of sensors and quite cheap, making this approach more widespread (Gu et al., 2009). Among others, Bortolini et al. (2015) propose a system with 4 readers, 15 tags and 15 asset tags. This has been tested also in an industrial environment, in particular to validate the applicability of UWB technology to trace inbound material flows. The tests were carried out both from a static and a dynamic point of view. The resulting accuracy of the experiments is 0.03 m in the case of static tests, while for the dynamic ones the accuracy is about 1 m.

3. THE SELECTED TECHNOLOGY FOR INDOOR POSITIONING

The studied Indoor Positioning System is a kind of Ultra Wave Band device, characterized by high resolution, good accuracy and the ability to show a 3D location of objects indoor. In the light of the advantages first expressed, in particular with reference to the high degree of accuracy, it was decided to use this system because the objective of the experiment was to trace the movement of an object within a space closed. Therefore, it was necessary that the difference between the position recorded and the real one was minimal to ensure a result closer to reality, especially in a context of limited internal environment where the position difference of 2-3 meters is more pronounced. Therefore, it can be easily used to monitor small objects moving in real time. To obtain a good balance between static and dynamic accuracy, a UWB has been selected. Moreover, the simplicity of installation and setting, combined with a low cost, has meant that this was the most suitable technology.

3.1 System operation

The system is composed of three principal devices: nodes, targets and a server (Figure 1). The nodes are fixed objects placed inside the building with the aim of tracking and measuring the movements of the objects being considered. All nodes are connected to the central server through Ethernet or Wireless LAN. Ethernet is preferred when higher reliability is required. The system operates using a single UWB frequency (about 6.5 GHz), having a 6.81 Mbps transmission data rate.

The targets are small devices that can be easily installed on the objects that need to be tracked. The nodes have to be properly placed, in order to delimit the area in which the targets are moving. Usually, at least four nodes are needed to have accurate measures in an area of about 625 square meters, but the network and the operating space can be easily expanded, by adding more nodes. The first, and more important, operation that the user have always to do is the set-up of the nodes. During this phase, it is necessary to precisely measure the position of their antenna and then insert the x, y, and z coordinates in relation to the selected source point. This operation allows to identify each antenna in a precise space. As soon as all nodes are placed inside the building and synchronized each other (and with the server), the system is ready to start. Regarding the targets, they are attached to objects that need to be traced. The program recognizes the presence of active targets and, through nodes distributed within the space, it is possible to uniquely identify the position of each target and recording the routes. The number of targets that can be tracked simultaneously is very high, and already reached 100 units in some applications. The targets are also equipped with a stand-by function to save their battery life. This function is activated after that the nodes have not captured any variation in the movements for 12 seconds. Any change in their cruising speed make them wake up, starting again to generate records in the system.

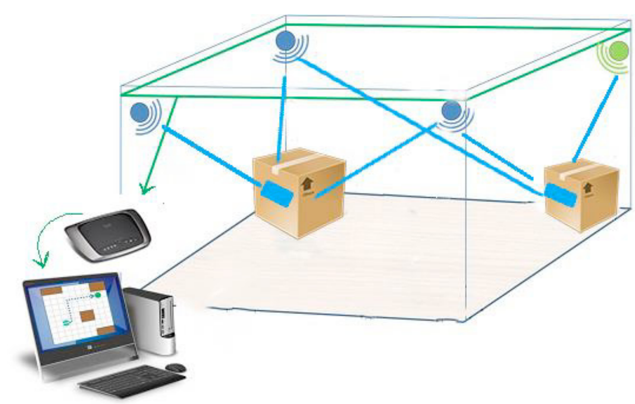

Fig. 1. Scheme of the Indoor Positioning System under study.

3.2 System testing

The system is mighty appreciated for the high level of accuracy. Its principle aim is the dynamic tracking of large scale, particularly in environments where there are thousands of small objects, like in a warehouse. In order to test the behaviour of this instrument and its accuracy, it has been applied in a practical test. The test has been carried out in an underground garage with a surface of 700 m^2, characterized by the presence of 4 concrete pillars in the center of the ground.

First of all, to delimit the space virtually, so that the system can record the boundaries within which the subsequent movements are recorded, it is necessary to fix a source, called O, whose coordinates are all equal to zero. Then, it is necessary to place the nodes, so that to delimit the area considered, and taking into account that each node has a coverage range of 20 m. In this text, six nodes were used. For each node, the x, y, z coordinates have to be inserted in reference to the previously set point O. In this way, the software can insert the nodes in the exact points of the virtual space and properly trace the target positions. Once the setting of the nodes has been completed, the targets can be switched on. The targets are recognized by the program through a unique serial code, and are user-protected. These appear on the virtual planner of the software with a specific colour and a name. In any moment, it is possible to know the coordinates of its position by simply selecting it.

The test carried out in the underground parking was aimed at verifying the accuracy of the measurements of the system. The closed path selected for the test was made up of six straight segments of different length. Each target that had to be tracked was given to a person, who had to hold it in hand trying to keep it close to the body, so as not to interfere with involuntary shocks due to his gait. Moreover, the operator was required to walk along the defined path at a constant speed of at least 1.5 m/s, considered as the average speed of one person while walking (Figure 2). Later, the same path was travelled at a higher speed to simulate a carriage inside a hypothetical warehouse, thus maintaining a speed of about 2 m/s (Figure 3). In the same Figure it is also possible to see that there are some points that are beyond the ordinary path. These refer to the simulation of an extra test, in which the person stopped for 2 minutes at a specific point, in order to observe the behavior of the system from a static point of view.

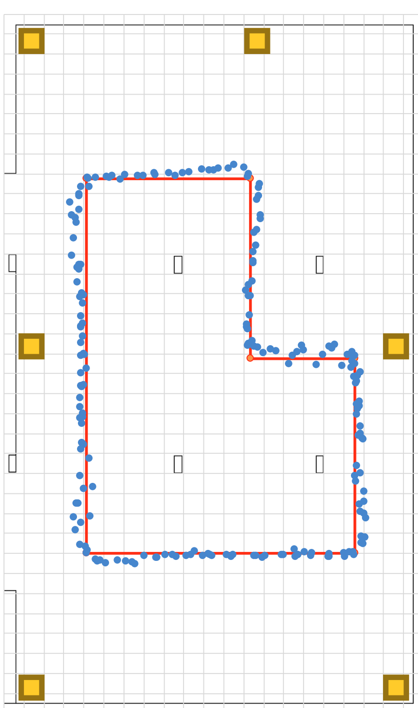

Fig. 2. Tracking of one target moving at an average speed of 1.5 m/s.

After having completed the experiment, the records were exported and analyzed, to detect the average error of all measurements. The number of records obtained for the two trials are 205 in the first case and 229 in the second one. For each registered position, the difference between the recorded and the established path position has been calculated, thus obtaining the error of each single measurement.

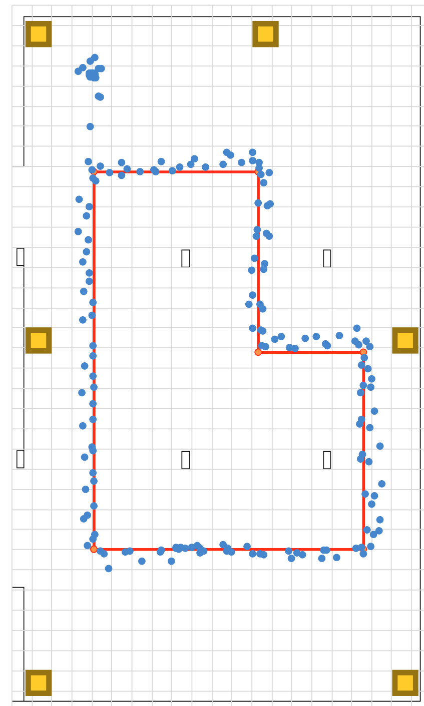

Fig. 3. Tracking of one target moving at an average speed of 2.0 m/s.

Figure 4 shows the cumulative curve of the errors counts related to the dynamic tests. The number of measurements belonging to a certain error range has been counted and plotted in this graph. As it can be seen, for the 70% of the measurements the gap between the tracked position and the real one is lower than 0.40 meters. This gap represents the accuracy of the system. As far as static test conditions are concerned, accuracy reaches 6 cm or even 3 cm.

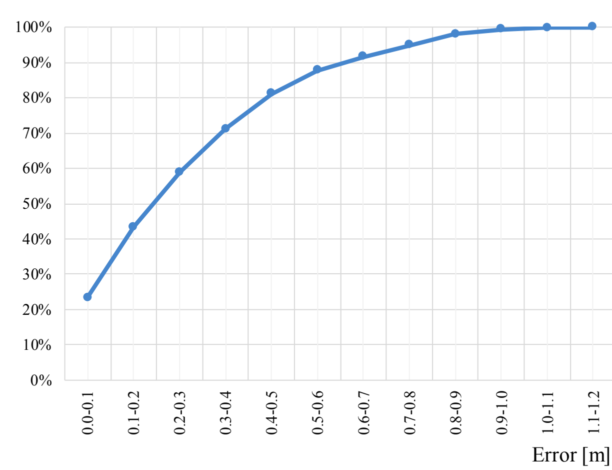

Fig. 4. Cumulative curve of errors counts.

3.3 System application

The system has been applied also in an industrial study. The aim was to track various forklifts in the receiving area of a warehouse. The test lasted 2 hours, during which the positions of the forklifts as a function of the time have been obtained. Therefore, it has been possible also to derive their speeds and all their stops. For example, the forklift reported in Figure 5 was dedicated to simple cycles, for the handling of the incoming Stock Keeping Units (SKUs) from the receiving area to the input of the automated warehouse. In this case, it has been easily calculated that for the 67% of the time the forklift was stopping, for uploading and downloading of the SKUs and for some idle time. The average speed (considering stops) was equal to 0.14 m/s, with a maximum value of 2.79 m/s.

In such a study, it has been possible to derive interesting insights about the movements of the forklifts, their activities and their paths. In particular, it has been useful to have evidence about the possible congestion points of the receiving area and on the use of the available resources, both forklifts and drivers.

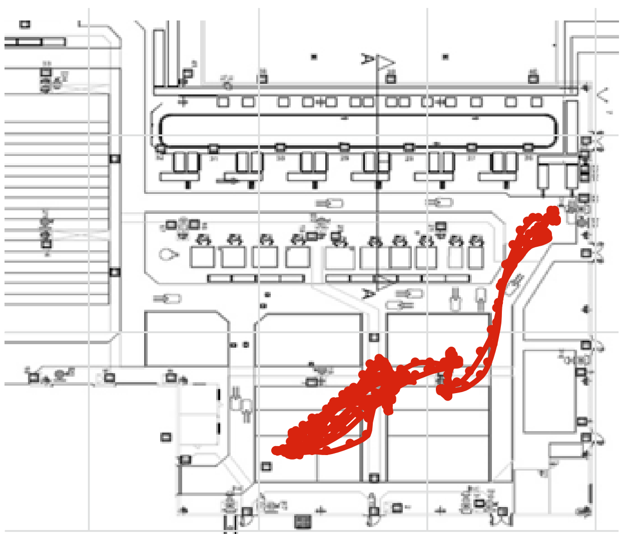

Figure 5. Path of one of the tracked forklifts.

4. CONCLUSIONS AND FUTURE RESEARCH

The paper presented a new system for indoor positioning. Based on a well-known technology like Ultra Waves, it easily allows to locate and track objects moving in a delimited area. The data that can be derived from the system are fundamental to get evidence on the movements of the tracked objects. Then, these can also be used for further considerations, according to the problem considered. In this paper, the introduced technology has been tested in a simple environment to measure its accuracy. Moreover, one of its possible applications has been reported, dealing with the tracking of the forklifts in the receiving area of a warehouse.

Considering that the potential of such a system is still under evaluation, future research is absolutely needed. Indeed, further tests are required, for understanding the stability of the system and its extensibility. Moreover, it is needed to provide more industrial applications, to derive the real strengths and weaknesses of such a system.

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