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New RFID pick-to-light system: Operating characteristics and future potential

Alessandro Andriolo, Daria Battini, Martina Calzavara*, Mauro Gamberi, Umberto Peretti, Alessandro Persona, Francesco Pilati and Fabio Sgarbossa
Department of Management and Engineering, University of Padua, Vicenza, Italy

Abstract. The recent changes in customers' orders, which on one hand are becoming more frequent and on the other require smaller quantities of several products, inevitably impact the job of warehouse picking managers, who find themselves in the necessary position to satisfy a high pick volume in a short time window. Moreover, warehouse manual picking is traditionally characterized by a high human factor impact; which derives that improving such a system requires a reduction of both orders processing time and human possible errors. In this sense, a possible strategy can be the development and employment of technological systems able to support operators during their picking tours. The aim of this study is to present a new pick-to-light design solution capable of driving different operators through their activities, preventing or reducing errors by a new real-time control and alert system, based on the main potentialities of the RFID technology. After the description of the technical characteristics and of the operation of the new solution, a qualitative comparison with other existing paperless picking systems is also proposed.

Keywords: Warehouse manual picking, paperless picking, pick-to-light, RFID technology

1. Introduction

Order picking is the activity of collecting items in a warehouse for distribution, and represents the most critical warehouse operation (Tompkins et al., 2010; Battini et al., 2015b). Although, over the years, different automated solutions have been proposed and studied (Bozer and Cho, 2005; Lehrer et al., 2006; De Koster et al., 2007), the most widespread solutions are still based on manual picking, characterized by a high human factor impact. Such aspect becomes even more crucial considering the manufacturing and warehousing recent trends of high flexibility and efficiency in processing orders that are always smaller and needed in very short turnaround time (De Koster et al., 2007; Dallari et al., 2009). For this reason, it could be interesting to focus the researches on the improvement of warehouse manual picker-to-parts picking, and in particular on picking orders processing time reduction and on picking accuracy

*Corresponding author: Martina Calzavara, Department of Management and Engineering, University of Padua, Vicenza, Italy. Tel.: +39 0444 998756; E-mail: calzavara@gest.unipd.it.

improvement, in order to warrant higher efficiency and effectiveness (Hsieh and Tsai, 2006; Grosse et al., 2015). One of the possible strategies to obtain some benefits in this sense is the adoption of a paperless order picking system (De Koster and Van Der Poort, 1998; Baumann et al., 2012). Paperless order picking can be via mobile, handheld or with terminals and printers that are vehicle-mounted. Pickers and warehousemen are connected on-line with the warehouse information system, warranting updated stock information, immediate reaction to particular situations and real-time monitoring of operations status. A new frontier of paperless picking is represented by the use of devices that have been developed to further speed picking activities and to avoid picking errors, like led displays or digital screens, voice-activated devices (voice picking), wireless appliances or lighting systems (pick-to-light). As far as the latter are concerned, pick-to-light systems support the picker during his activities by using different kind of lighting devices that can send clear light signals. Frazelle (1988) and Tolliver (1989) underline the potential of adopting a computer-aided system for manual order picking to simplify the tasks of human pickers; in fact, it has been estimated that a light-directed picking system with automated data entry can reduce human errors by 95% as well as increase productivity by 10%.

This paper describes a new pick-to-light system that relies on RFID (Radio Frequency Identification), a technology that has recently achieved the deserved success in various warehouse applications, especially in managing and controlling the flow of products through the whole supply chain (Lee et al., 2010; Chen et al., 2013). In particular, the new system drives an operator through the various storage locations he has to visit with a set of different coloured lights. These lights can be turned on or off according to the picking list. Furthermore, they are linked to a control system able to recognize whether the operator, who is wearing a particular glove containing a RFID reader, is accessing the right storage location or not and to alert him with a set of visual (and/or acoustic) signals, preventing him from completing the wrong picking action.

Figure 1 reports the main steps that have characterized the development of the new RFID pick-to-light system, reflecting also the structure of the remaining of the paper. First of all, next section illustrates the performed context characterization, starting from the analysis of the currently available technology able to support warehouse picking activities, continuing with a gap analysis of the existing systems and concluding with the study of the possible basic technology useful to be employed in the new system. In the third paragraph the development of the new system is detailed, though the presentation of the new RFID pick-to-light system configuration and of the realized prototype, which has been used also for some important tests that fostered the understanding of the new system strengths and weaknesses. The results of the tests and the critical analysis of the new system have led to the setting of the fourth paragraph, in which the comparison to other already existing solutions from a qualitative point of view and the proposal of some possible system applications are reported. Finally, in the conclusion paragraph some further general considerations are emphasized.

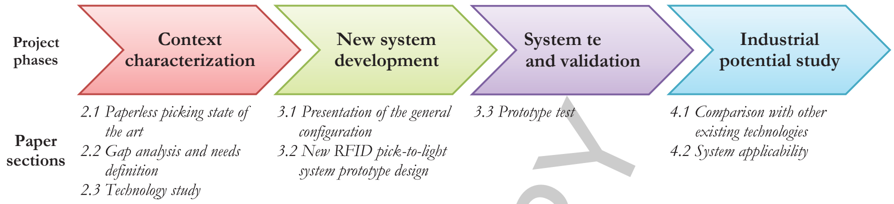

Fig. 1. Project steps corresponding to paper structure.

2. Technological framework

2.1. Paperless picking state of the art

In general, paperless picking systems consist of a set of devices used to support pickers during their work, and are designed to facilitate and expedite picking activities, with a subsequent improvement of the overall performances (De Koster and Van Der Poort, 1998; Gleißner and Möller, 2011). There exist different kinds of paperless picking devices, that mainly differ in terms of applied technology, hence, of possible level of automation (Gleißner and Möller, 2011). Among the others, the present paper focuses on the most widespread solutions, considering also the relative relevance for the presented problem. They are: barcode handheld scanner and barcode ring scanner, RFID handheld scanner, pick-to-voice, pick-to-light, head-mounted device, fully automated system. One of the best known paperless picking systems is certainly the barcode scanner handheld: the operator uses it to confirm his pick, through the scanning of the barcode tag which is put on the various stock locations of the warehouse, corresponding to the different stocked items. Although such system can be used also together with paper picking lists, the recent trend is to integrate the lists directly with the handheld device, so that once an item has been picked, the screen of the handheld device shows the following product to take (Guo et al., 2014). Moreover, an interesting evolution of barcode scanners is represented by the so-called Zebra ring scanner, a particular barcode scanner that can be put on one finger of the operator, so that he has both hands free to perform the picking activities in an easier and more efficient way (Zebra website, accessed on 14 July 2015). In case of employment of a RFID tags scanner handheld system, the stock locations are tagged with RFID passive tags instead of barcodes. The first used working frequencies have been Low Frequency (LF) or High Frequency (HF), hence, the tags are detectable at small reading distances of the handheld device; nevertheless, some recent solutions are also proposing an operation at Ultra High Frequency (UHF). Other examples of task guidance technologies are the ones based on pick-to-voice and pick-to-light systems. In a voice picking system all pickers are equipped with a headset and a microphone to receive picking instructions, and to verbally confirm their actions back to the warehouse centralised system (Berger and Ludwig, 2007; Matopoulos, 2011). The warehouse operator, for example, reads back the last digits of the code corresponding to the item he has picked so that the system can check whether the correct item has been selected, then it can give the next instruction. On the other hand, in a pick-to-light system operators are guided by lights installed on the warehouse shelving: each stock location has one light that turns on if the operator has to pick the corresponding product. In order to complete every single pick, the picker has to press the button of the interested stock location and, in some cases, he has also to scan the barcode of the picked item. If the simultaneous work of more than one picker in the same warehouse area is needed, such system has to be integrated with paper picking lists, with digital displays or with handheld devices, so that every picker can understand which are the lights turned on for his order. A possible evolution of the traditional pick-to-light is represented by the employ of the RFID technology (Friedlos, 2011), while the simultaneous work of several pickers in the same area is possible for example through the adoption of particular systems, like the one presented in a German patent in 2009 (Kusen et al., 2009). Furthermore, another recent frontier for warehouse manual picking is represented by special glasses or head-mounted displays worn by the operator and reporting on the lenses all the needed information, making the picking activity easier (Iben et al., 2009; Weaver et al., 2010; Guo et al., 2014). Finally, some companies are proposing automated pick-to-light configurations, in which picker's activities are fully assisted: even the progress and the stops of the picking cart are guided by the composition of the order (Baumann, 2013).

2.2. Gap analysis and needs definition

From the state of the art analysis reported in the previous section, it is possible to notice that the existing technologies are often lacking of some smart characteristics that can justify their full and wide application. For example, although they are well widespread in industry, the scanners solutions have the problem that the picker has to keep the handheld in hand, with a consequent lower picking efficiency. Both the pick-to voice and the traditional pick-to-light systems, instead, allow the performing of the picks with both hands, but, while the first one can potentially lead to the reduction of its benefits slowing down the overall picking activity (Baumann, 2013), the second one requires the pressing of the buttons to confirm the picks of the products (Park, 2012). The head-mounted systems are still in a first phase of development; their possible fields of application, together with their limits, are still not so clear (Jäckel, 2013). Finally, the fully automated solutions have the great problem of leading to rigid configurations, also requiring high economic efforts.

Starting from the analysis of the existing systems and considering the main needs that generally characterize warehouse picking activities, a list of different targets has been pointed out, which have been considered as the main drivers to follow in the development of the new solution (Table 1 and Fig. 2). In particular, the identified objectives belong to three different categories: there are targets that reflect the main desires of the business staff, some targets that concern the practical operation of the

Table 1
Definition of the different objectives for the new paperless picking system

Type	Description	Details
BUSINESS TARGETS	Picking time reduction	Need of a system able to speed up picking activity, mainly acting on some picking time components (search time, actual pick time).
	Picking errors control	Need of a system able to prevent (or at least limit) picking mistakes, through a proper control system.
FUNCTIONAL TARGETS	Easy to implement	The system has to be easy to install, and also in an already existing warehouse.
	Wide applicability	The system has to be applicable in different warehouse contexts.
	User friendly	The system has to be intuitive, not requiring a relevant training effort.
TECHNICAL TARGETS	Existing technology employ	In the development of the system it is important to refer to the existing available technology, in order to warrant its easy spread in industry.
	Economical solution	The system should not require a high investment in terms of costs.

system and some other ones that refer to technological aspects. As far as the first category is concerned, the two main criticalities of warehouse picking have been considered: the need of reducing the picking time (De Koster et al., 2007; Tompkins et al., 2010) together with the need of controlling the possible errors while performing the picking of the items (Berger and Ludwig, 2007; Reif et al., 2010; Grosse et al., 2015). Furthermore, the functional targets that should be achieved by the new system concern:

- its ease of implementation, therefore without the requirement of extreme investments in terms of time and resources;
- its wide applicability, that is, the possibility of installation in several warehouse contexts, that could differ, for example, for dimension, for the kind of products stored and/or for the way the products are stored within (Park, 2012);
- its ease of use by the warehouse operators; the more the system is intuitive, the more the time needed for training the picker is reduced.

The last reported targets category is focused on the technology that should be employed in the definition of the system. In particular, it has been highlighted the essential need of exploiting an existing and stabilized technology, easily available on the market and, therefore, easily usable in industry. Moreover, the need of warranting an easy applicability in industry leads also to the definition of the last reported target, that is, the development of a system that does not require excessive economic efforts. Finally, as far as the economic aspect of the system is concerned, it is important to

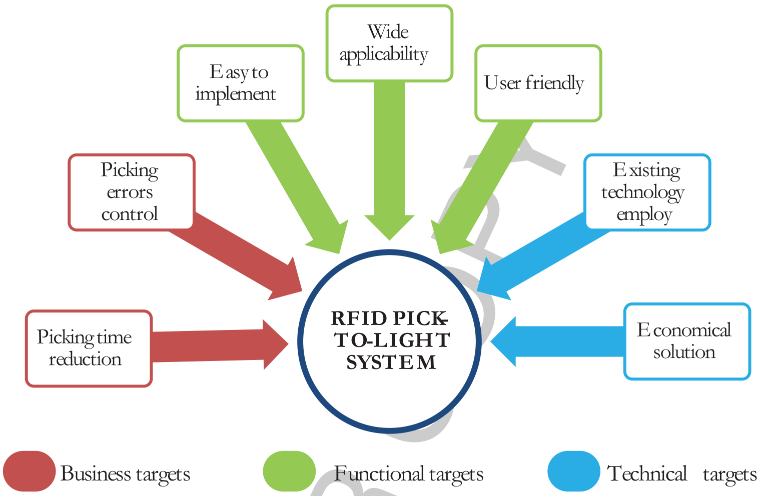

Fig. 2. Drivers for the new system definition.

underline that, of course, such system has to be sustainable from an economic point of view. That is, the cost of the whole system (for example purchase, installation, management, maintenance) does not have to be higher than the benefits and the economic advantages that such system can lead to.

2.3. *Technology study*

The choice of the most proper technology for the new system has been driven by the needs already detailed in the previous sections. In particular, it has been observed that RFID (Radio Frequency Identification) technology can perfectly meet such requirements. First of all, it represents a widespread technology that has been already successfully applied in industry for various applications (Raza et al., 1999; Zhu et al., 2012). Among the others, one of the main advantages of RFID is that it does not require the direct contact or the perfect alignment between the reader and the tags to retrieve the needed information that are stored in the tags (Baudin and Rao, 2005). According to the context of operation, the tags can store data related to the products but also, more simply, a unique serial number that creates the connection to the actual data in a database, which can be easily accessed even with a wireless connection (Battini et al., 2009). Finally, the employ of passive tags can lead to the development of economical but, at the same time, very effective practical applications (Dobkin, 2012).

In fact, the transponders can be of two types: active or passive. The first ones have an own power supply (a battery) that enables them to transmit at higher power levels, hence to be read and written at greater distances (also over 100 m). On the contrary, passive tags obtain their energy from the electromagnetic field of the reading device, so they are very small and economical, and, hence, easily usable also when their application requires the presence of a high number of tags. A RFID system can differ in terms of the frequency range in which it operates, too. In particular, there are three worldwide established frequencies: Low Frequency (LF),<135 kHz, High Frequency (HF), 13.56 MHz and Ultra High Frequency (UHF), between 850 and 960 MHz. Every frequency is more suitable for some applications than for others: when a RFID project is under development it is important to perfectly understand what are its needs (Zhu et al., 2012). Low Frequency systems are well-suited to industrial use, above all when working near metals and water is required. High Frequency systems are characterised by greater ranges and higher reading speeds. The simultaneous reading of multiple tags is possible, but it could be influenced by the presence of metal objects. For warehousing and goods tracking, UHF systems are more suitable: they enable very high data transfer rates and long ranges (up to six meters), even if signals typically do not pass through most of the materials (Miles et al., 2008; Dobkin, 2012). The basic principle, however, is that full advantages of RFID are obtained when the application, the manufacturing process and the supply chain are considered as a whole (Weinstein, 2005; Karagiannaki et al., 2011; Busato et al., 2013). In warehousing and manufacturing passive tags and UHF readers are the most widespread; this certainly happens because passive tags are very cheap and versatile. They are often used as an alternative to barcodes, but with better performances. In particular, they have a high reading capacity without needing of line-of-sight and a good writing/modifying capacity for storing data. According to Baudin and Rao (2005) it is possible to obtain more benefits in the contexts in which a high rate of scanning is needed, hence, where warehouse operators or workers have to scan a lot of tags in a very short time, exactly as in the case of warehouse order picking. Hence, for the development of the new paperless picking system it has been chosen to adopt RFID technology working at UHF with passive tags.

3. New RFID pick-to-light system

3.1. Presentation of the general configuration

The background idea of the solution presented in this paper is the desire to create a pick-to-light system able to drive the picker through the locations he has to visit in a smart as well as simple way. In particular, the main objective is to exploit the benefits of RFID technology, according to which there is no need of direct contact between the reader and the tag to obtain the information stored in the tag. Another important aspect that has been considered is to give the picker a RFID reader that does not need to be kept in hand, so that he can perform the picks using both hands. To do this, a wearable RFID reader is needed. The best found solution is to provide the operator with a particular glove containing the RFID reader. Some examples of similar solutions have been already developed, for various applications, such as iGlove and iBracelet, invented by the Intel Research Seattle group (Fishkin et al., 2005) or the SCIPIO WInspect

Glove proposed by the Technologie-Zentrum Informatik of the University of Bremen, (SCIPIO WInspect Glove Datasheet, 2006). These devices not only are able to interact with unobtrusively tagged objects, but in some cases the glove can also report whether the grasp of the object is with the palm or with the fingerprints. Medynskiy et al. (2007) use a wearable RFID reader for gaming applications. Muguira et al. (2009) propose the RFIDGlove system, consisting of a glove with an integrated RFID reader, an organic micro display and a communication system. They also highline the usefulness of such device for inventory and warehousing activities, as all the movements performed by warehouse operators are completely traced. Lee et al. (2010) created a wireless RFID glove for interactive learning and for a meal aid system useful for blind people. Most of the existing devices can be used with passive tags and work at high frequency (13.56 MHz), which means that the read distances cannot be much larger than 1 meter. The application of a RFID glove in an order picking system has then been presented and studied also by Wölfle and Günthner (2011) as well as by the Fraunhofer institute for factory operation and automation (IFF website, accessed on 14 July 2015). Furthermore, the RFID-enabled glove developed by Deister Electronic GmbH, was initially designed mainly for research purposes, but it was then also appreciated by some practitioners (Collins, 2006). However, all these presented systems do not consider the possible integration of the RFID glove with a pick-to-light system.

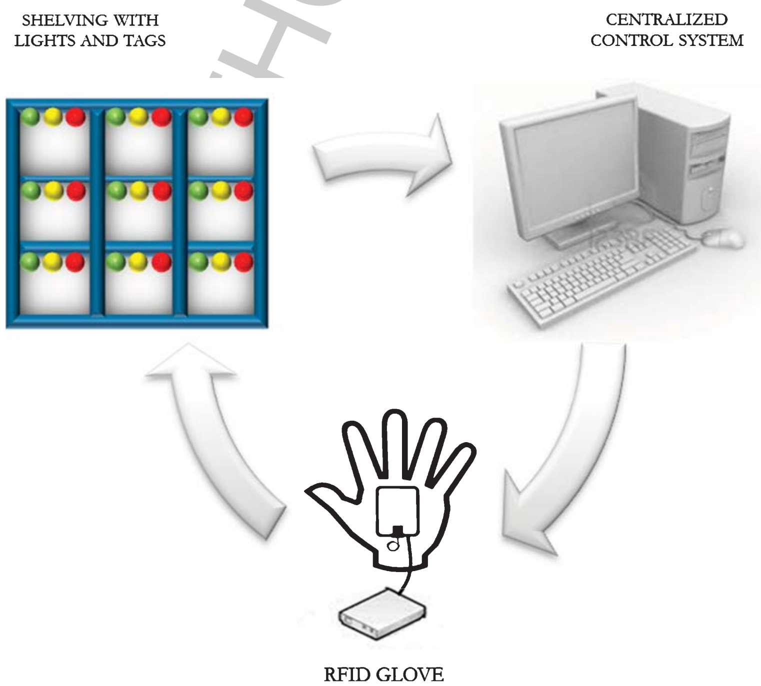

Fig. 3. RFID pick-to-light system main units.

As far as the proposed configuration is concerned, it is composed of three main units (Fig. 3). The first one is a system of lights and tags installed on the shelving, so that every stock location has one UHF passive tag (or more, depending on the available storage room and on the kind of product stored) that identifies that particular stock location, one red light alerting the picker in case he enters the wrong location and as many different coloured lights as the number of pickers that are working at the same time in the same picking area, so that every picker follows only the lights of a particular colour, turned on or off according to the picker's picking list. Even with several pickers working in the same area, it is sufficient to have only one red light in every stock location. This because the red light turns on only if the corresponding location is entered by a picker by mistake, so the picker understands unequivocally that who is wrong is exactly himself. The second unit consists of a wireless UHF RFID reader that every warehouse operator wears thanks to an appropriate glove, so the picker has both hands free afignd can pick the items he needs in a better and faster way (Grosse et al., 2015). The system of lights installed on the shelving and the reader are managed and controlled by the third component of the configuration, a centralized control system (CCS). The operating principle of the system is reported in the diagram of Fig. 4, corresponding to the case of a picker which has to follow the blue lights.

The CCS takes as input the various picking lists (one for each picker) coming from the warehouse information system and sends the signals to turn on and off the appropriate lights on the shelving, each colour corresponding to a specific operator. Furthermore, such system is able to monitor the pickers' activities, in order to highlight possible picking errors by turning on red lights. According to the routing policy that is adopted in the warehouse, the light of the first location the picker has to visit is turned on, so that the picker can easily and immediately understand where the item is located. When the picker, wearing the glove that includes the RFID reader, reaches the particular location there are two possibilities: he enters the right stock location or he enters a wrong stock location. In both cases, the reader reads the tag corresponding to the stock location and sends via Wi-Fi the read code to the CCS, that acts accordingly. In case of correct access, once the system has verified that the code received from the RFID reader is the right one, corresponding to the stocking location in which there is the item the operator has actually to pick, it sends the signal of turning off the coloured light of that location (for example, the blue one) and of turning on the coloured light of the following location, corresponding to the following line of the picking list or to the same one, in case of a multiple pick of the same product code (Fig. 5). In this case, it could be useful to associate an acoustic signal to confirm the correct picking. If the picker makes a mistake in the stock location and tries to pick the wrong item, the CCS receives from the RFID reader a code corresponding to a stock location of a product different from what it expects, and it sends the signal of turning on of the red light for the wrong stock location, so that the picker immediately realizes that he is not in the right place (Fig. 6). When the operator pulls out his hand

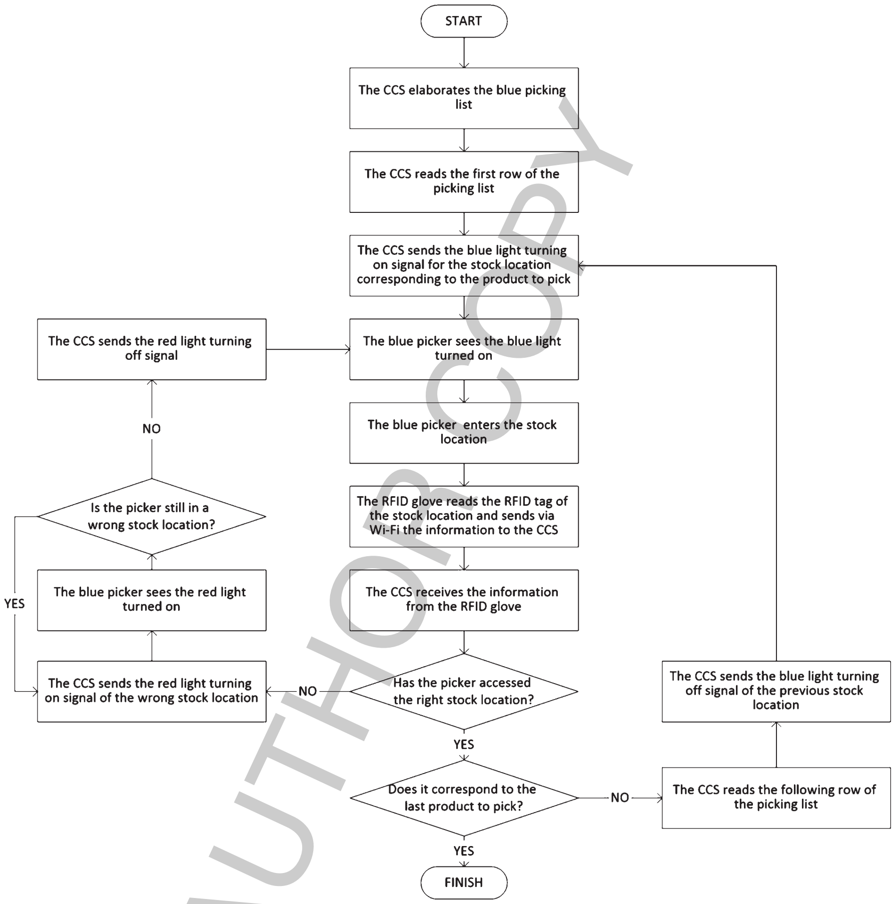

Fig. 4. Operating flow chart of the new RFID pick-to-light system.

from the wrong location the centralized control system does not receive the wrong code from the RFID reader anymore, so the red light is turned off.

It is important to underline that every picker can perform his work independently, as every operator wears his own RFID reader, and the centralized control system can perfectly recognize the different signals coming from the various pickers, hence, is perfectly able to manage separately the different lights.

3.2. New RFID pick-to-light system prototype design

In order to properly assess the potential of such configuration and to test the various technologies that have been used, a prototype of the new RFID pick-to-light system has been developed, to manage two operators that work simultaneously, in a warehouse

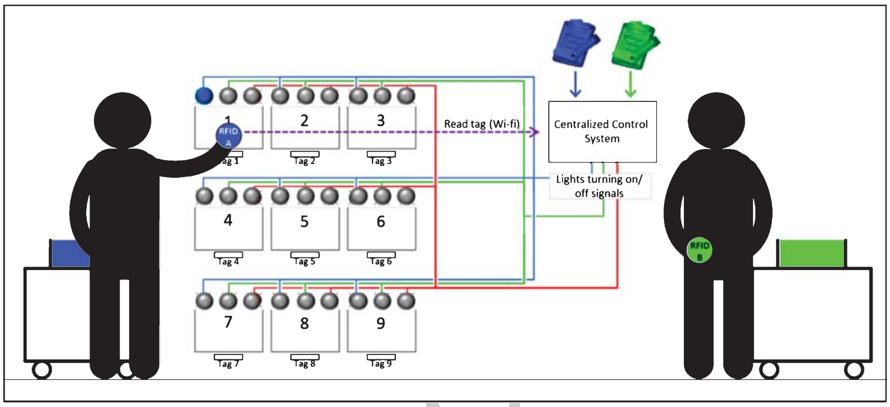

Fig. 5. Operating scheme of the new RFID pick-to-light system: the picker enters the right stock location.

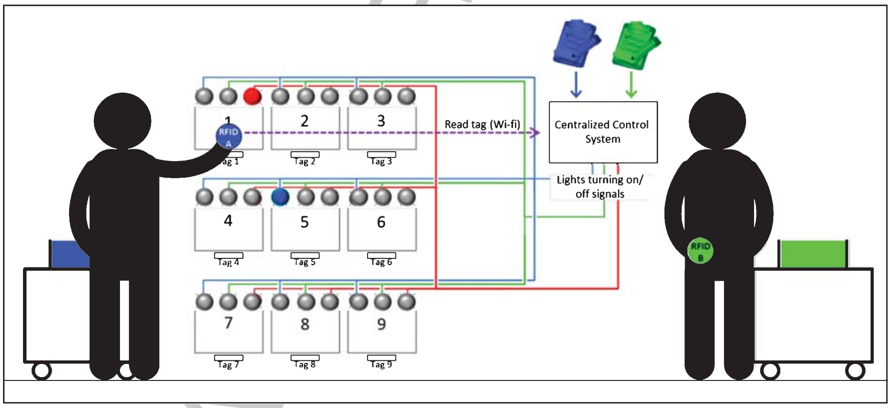

Fig. 6. Operating scheme of the new RFID pick-to-light system: the picker enters the wrong stock location.

with steel shelving and nine stock locations, each of which has three leds, green for the first operator, yellow for the second operator and red to indicate the picking errors. All the leds are connected to a microcontroller that sends the signals of turning on and off of the lights. Every stock location has also one passive tag, used to identify every stock location and, hence, the corresponding products stored. The UHF RFID readers are composed of a wireless reader unit, of a linear polarized UHF antenna and of a 12 V lithium battery (Fig. 7), and is worn by the operator through a glove, where the antenna is on the upper part of one of his hands and the reader unit is on his forearm, and the battery can be hooked, for example, at his waist. The data read by each reader are sent to a personal computer via Wi-Fi. The PC represents the centralized control system: in addition to receive the information of the RFID readers

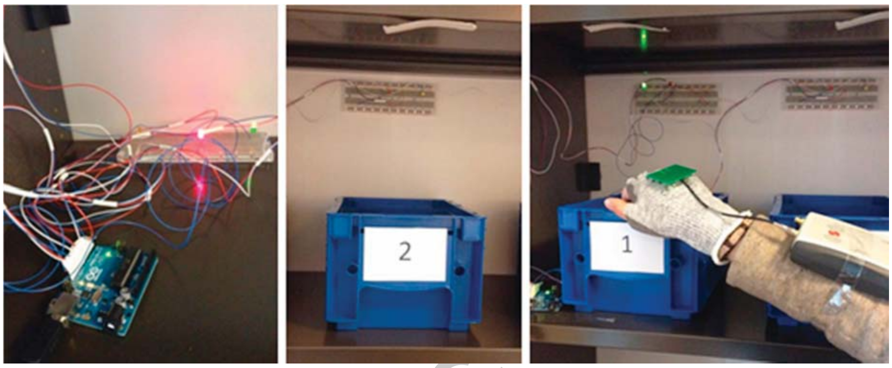

Fig. 7. Details of the RFID pick-to-light system prototype (Left: Microcontroller and lights; Middle: stocking location with lights system and RFID tag; Right: operator wearing the RFID glove while entering a stocking location).

it has a LabVIEW™ project that has been developed to manage all the control logic. In particular, the program is able to read two different picking lists from a Microsoft Excel™ file and to send the appropriate signals to turn on the green and yellow leds according to the order lines. The RFID readers are interfaced with the LabVIEW™ project through a TCP/IP Socket that receives the information of the read tags as a Wi-Fi input and transmits them to the rest of the LabVIEW™ project. The remaining logic is necessary to compare the tags read by the RFID readers to the order lines of the picking lists, in order to understand whether the picker is picking the right product or not. If the operator picks the right item the system sends to the microcontroller the command of turning off the led corresponding to that product and of turning on the led corresponding to the following line of the picking list. Otherwise, it makes the red led come on to indicate that the picker has entered a wrong stock location.

3.3. Prototype test

The prototype, also characterized by a relatively low overall realization cost, has been used to perform some interesting tests: above all to estimate the possible interferences due to the employ of the UHF RFID technology, but also to evaluate whether the performances of the communication via TCP/IP are acceptable for the application in a picking context. The tests have focused on the picking of different kinds of products by an operator wearing the RFID glove reader, and has revealed that the function is not affected by items containing liquid substances or metal objects. Furthermore, it is exactly the material of the shelving that helps to shield the signal and to avoid wrong tags readings. As far as tags reading and lights turning on and off speeds are concerned, the test has revealed that the data are practically real-time. Table 2 reports the scope and the description of the performed tests, together with the obtained results and some comments.

Table 2
RFID pick-to-light tests summary

Scope	Description	Results and Comments
UHF RFID Antenna/Picker hand interference	Reading of RFID tags with the RFID glove	The tested antenna is quite affected by the proximity of the picker hand; however, by inserting in the glove a proper shielding the reading distances stay acceptable, up to 20 cm
UHF RFID Antenna/Shelving interference	Picking of objects from a metal shelving with RFID tags, the picker wearing the RFID glove	The metal shelving suitably shields the RFID signal, allowing the RFID glove to read the correct tag, corresponding to the proper stocking location
UHF RFID Antenna/Picked material interference	Picking of metal objects and of products containing liquids from a metal shelving with RFID tags, the picker wearing the RFID glove	The RFID pick to light system is not affected by the well-known operational limits of UHF with liquids and metals, since in the present configuration the RFID glove reads the tag just before the picking of the products
Reading distance	Reading of RFID tags with the RFID glove, progressively distancing the RFID glove and/or the tags	The distance mainly depends on the presence of the picker hand; however, it has been observed that the distances are acceptable for the considered application.
Reading speed	Reading of RFID tags with the RFID glove	The information of the read tag is sent to the centralised control system in real time
RFID reader battery duration	Reading of one RFID tag by the RFID glove with a notification via Wi-Fi to the centralized control system every 2 seconds	In such operating conditions the battery has lasted 9 hours and 30 minutes; it derives that the battery does not represent a critical aspect of the system

In general, from the analysis of the reported prototype tests and of the corresponding results, it turns out that the new RFID pick-to-light system can represent a smart and interesting solution for paperless picking. In fact, the overall proper operation is confirmed by the various performance measurements: the reading of the tags is in real-time, the picked objects do not interfere with the RFID reader reliability and the RFID reader battery life does not represent a working issue. The main open problem concerns the interference arisen between the hand of the operator and the RFID glove: the RFID glove reading range significantly decreases due to the presence of the picker's hand. However, the reading range remains acceptable when the system is employed for small objects picking. On the other hand, in case of picking from pallets or from other bigger containers, it would be necessary to work on the power of the RFID antenna to improve its reading distance. Finally, it is important to underline that the tests refer to a laboratory prototype, developed to test the technology and the effective possibility of connecting the different components of the new RFID pick-to-light system. Consequently, next researches should focus on a further study to understand its applicability in an industrial context.

4. RFID pick-to-light system potential discussion

4.1. Comparison with other existing technologies

The new RFID pick-to-light system has been compared to some existing solutions (barcode scanner handheld, RFID tags scanner handheld, pick-to-voice, traditional pick-to-light, fully automated pick-to-light), considering some technological and practical aspects (Table 3 and Fig. 8). The values reported in Table 3 and, then, displayed in the radar plot of Fig. 8 derive from a qualitative analysis that has been done from the authors considering the evaluation of the usability of the devices, as well as their efficiency and effectiveness, based on the authors' practical experience, on some laboratory tests and on the existing literature (Miller, 2004; Baudin and Rao, 2005; Zhu et al., 2012; Battini et al., 2015c). The proposed criteria have been grouped according to the main scope they can have impact on, referring to warehouse general characteristics, to the picker and to the device. In particular, these criteria are:

- Flexibility: possibility of easily changing the configuration of the warehouse, in terms of number of operators, items allocation and assignment
- Modularity: ease of increasing or reducing the dimensions of the system, in terms of number of racks and of pickers
- Ease of use: device ease of handling, both in terms of practical usage during the picking and in terms of its real operation understanding
- Picking time: time needed to perform the pick of the products
- Pickers simultaneity: possibility of simultaneous picking by different warehouse operators in the same area
- Environment influence: work environment side effects on the whole picking process
- Reading distance: average distance at which the picked product data are readable from the device
- Errors interception: capability of identifying a picking error

Each paperless picking technology presents various features, with different strengths and weaknesses (Battini et al., 2015c). In particular, as far as the impact on the warehouse is concerned, the flexibility of each paperless picking system in terms of number of operators is particularly ensured when every warehouse picker has his own device. The changing in the items assignment and allocation, instead, is easier when the warehouse shelving is equipped with simple systems that can be quickly adapted or programmed (barcode tags and RFID tags). Then, the paperless systems that rely on such tags, as the new RFID pick-to-light system, turn out to be the more

Table 3
Comparison of the new RFID pick-to-light system with other paperless picking systems

	WAREHOUSE		PICKER			DEVICE		
	Flexibility	Modularity	Ease of use	Picking time	Pickers simultaneity	Environment influence	Reading distance	Errors interception
Barcorde handheld	High (5)	High (5)	High (5)	Medium (3)	Possible (5)	Medium (3)	Few centimeters (1)	After barcode scanning (3)
RFID tags handheld	High (5)	High (5)	High (5)	Medium (3)	Possible (5)	Medium (3)	Up to 2 m (4)	After tag scanning (3)
Voice picking	High (5)	High (5)	Medium (4)	Medium (3)	Possible (5)	High (2)	Not applicable (0)	After code communication (3)
Traditional pick-to-light	Medium (4)	Medium (4)	High (5)	Medium (3)	Difficult (3)	Low (4)	Not applicable (0)	At the end of picking (1)
RFID pick-to-light	High (5)	High (5)	High (5)	Short (5)	Possible (5)	Medium (3)	Up to 2 m (4)	Immediate (5)
Fully automated pick-to-light	Very low (1)	Medium (4)	Medium (4)	Short (5)	Not possible (0)	Low (4)	Not applicable (0)	Immediate (5)

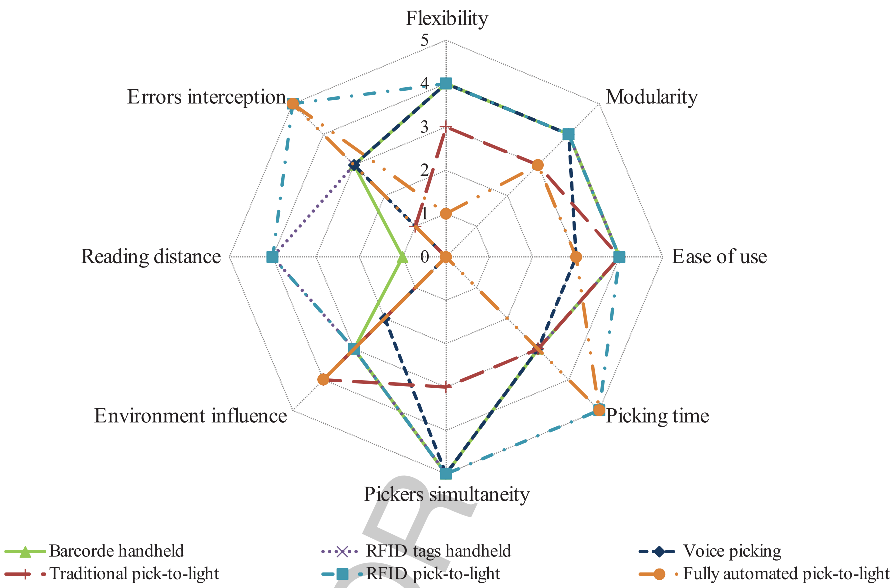

Fig. 8. Comparison radar plot of the six paperless picking systems (higher scores assigned to positive values of the features).

flexible ones. Furthermore, all such paperless technologies are also more modular, referring to the meaning that has been presented at the beginning of the paragraph. Focusing on the characteristics that mostly are depending on the picker, since the new RFID pick-to-light configuration does not require for the operator the using of any particular device, it proves to be very easy to use. In fact, the RFID reader is directly integrated within the glove, so the picker has only to focus on the physical picking of the products, without scanning barcodes or, as in the case of the pick-to-voice, without any other kind of picking confirmation (Wölfle and Günthner, 2011). Moreover, given their diffusion in the everyday life, both the barcodes handheld and the RFID tags handheld can be by now considered as familiar devices; on the other side, also a traditional pick to light system is easy to use since the operator activities are typically settled by the turning on and off of the lights. The only system that could be slightly more difficult to use is the voice picking system: it generally requires a particular training in order to understand its actual operation (Helo and Szekely, 2005). The simplicity of the new RFID pick to light system also implies that the picking time is short, because the picking action is just limited to reaching for the required item and to putting it in the picking cart; in other systems, instead, every pick could be associated to other operations, for example the scanning of the barcode or of the RFID tag. The possibility of simultaneous work of more pickers in the same warehouse area depends on the picker equipment and on the shelving hardware: it is possible for barcode and RFID handhelds and for voice picking systems, as well as for the presented RFID pick-to-light system (every stock location has as many different coloured lights as the number of operators working in such area). Working at the same time in the same area can be quite hard, instead, in a traditional pick-to-light system, as for the pickers it is difficult to understand which are the lights that are turned on for him and which are not, even if the most recent pick-to-light solutions have the possibility of mounting more than one light. As far as the performances of the different devices are concerned, in some cases operators' activities can be influenced by the environment they work in. This is particularly true for voice picking, as surrounding noises could prevent a correct communication between the system and the operator of the code to pick and of its following confirmation. Besides, for such systems a wrong pronunciation of the numbers could cause a useless delay in picking activities. Also the scanning of barcodes could have some problems, since it requires a clean, high-contrast environment, and often more than one attempt (Baudin and Rao, 2005). On the contrary, pick-to-light is generally not affected by its context of application. For the RFID pick-to-light system the only issue concerning the application environment could derive from the interference of RFID waves with the shelving, the products stored and with the body of the operator. It is therefore fundamental to carefully study the configuration of the whole system, in order to prevent some side effects and/or take advantage of some other ones. The reading distance of the different solutions varies from the few centimetres of the barcodes to the two metres of the RFID handhelds (particularly the UHF ones) and of the UHF RFID pick-to-light system presented in this paper. This feature can be more or less relevant according to the considered application of the system. For example, the systems that have such a reading distance can be suitable for being applied also for a picking performed directly from pallets (Bartholdi and Hackman, 2011; Battini et al., 2015c).

Last evaluation criterion proposed in the present analysis is the possibility of recognizing and signalling a picking error. Such feature is definitely crucial considering its possible impact on the overall picking performances (Tompkins et al., 2010; Grosse et al., 2015). In this sense, the best result is obtained by the RFID pick-to-light system, in which the picker can understand right away whether he has picked the right product or not. In case he puts his hand in the wrong stock location, the red light turns on in order to prevent him from completing the wrong picking action. In some other configurations, instead, there is the risk for the picker of discovering picking errors only once the item has been picked, the order is complete, or, even worse, when the order is delivered to the customer.

Finally, another great benefit of the presented pick-to-light solution is that it uses RFID technology and the data are available in real time, since the handheld devices are connected to the centralized control system: this way, it is quite easy to obtain useful data about all pickers' activities, for example the number of picks per hour, that could be used as a starting point for possible improvements of the whole system (Hou and Huang, 2006; Poon et al., 2009).

4.2. System applicability

The use of paperless systems for supporting warehouse picking is described in literature as one of the most effective solutions to speed up picking activities and reduce picking errors (Frazelle, 1988; Reif et al., 2010). Moreover, several case studies showing the practical application of such solutions have confirmed their validity, which sometimes is also accompanied by a short payback period (Hou and Huang, 2006; Yeow and Goomas, 2012; Dobkin 2012). However, it is important to highlight that not all paperless picking solutions are appropriate for all the possible warehouse picking needs. In fact, each context could require different configurations and applications, considering also the expected performance and, hence, the possible technological limits. For example, barcode handhelds are easy to use but they could cause some delays during the picking of the items if the barcode is not sufficiently readable by the scanner. Voice picking is widespread since it has no particular limitations concerning both the kind of warehouse and the kind of product stored. On the other side, a fully automated solution is more suitable when the picking activity is quite stable and concerns objects with similar physical volume (Baumann, 2013).

Considering its characteristics, the here introduced RFID pick-to-light system results to be applicable in different warehouse contexts and for different kinds of picking: pallet pick, case pick, and broken-case pick (Park, 2012). Moreover, the great potential of such a system turns out to be fully used in the case of intensive picking in small areas. An example could concern the picking for feeding an assembly line, in which some operators are dedicated to the creation of the assembly components kits accessing the related supermarket warehouse (Battini et al., 2010, 2013, 2015a). However, thanks to the employed technology and to its particular overall configuration, it is important to point out that such a system is perfectly usable also for warehouse picking in wide areas (Battini et al., 2015c).

5. Conclusions

Manual picker-to-parts order picking represents a crucial activity for every warehouse since it is particularly time and labour intensive, and it requires great attention and efforts in terms of picking order processing time and errors reduction (De Koster et al., 2007; Grosse et al., 2015). A possible way of obtaining improvements is represented by the employment of devices able to support and help the pickers during their work, such as the paperless picking systems. In this paper a new low-cost paperless picking technology, which combines the benefits of RFID to the simplicity and effectiveness of pick-to-light, has been presented: the so called RFID pick-to-light system. Every warehouse operator wears a glove in which a UHF RFID reader is installed, while every stock location has a RFID tag to identify the corresponding product stored. When the RFID reader reads the tag, a signal is sent via Wi-Fi to a centralized control system that checks whether the picker has taken the right item or not and that sends the signals of turning on and off of the appropriate lights. Some of the benefits that such support device can typically provide are the increased accuracy and errors reduction, since pickers can quickly understand whether they are collecting the right item or not; the increased productivity, as picking is made easier and more focused on other activities; a reduction on the time needed to look for the right picking location or to remedy errors; and the reduction of training time: finding the various locations is more intuitive and immediate and pickers don't have to learn to use complex devices. The new system has also been compared to other manual picking supporting devices from a qualitative point of view, highlighting its validity and its great potential, also for a real industrial application. Next steps of this research will exactly concern the testing of the RFID pick-to-light system in a real manual picking warehouse.

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