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TRACKING SYSTEMS IN LOGISTICS

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Abstract: *With the spread of globalization, there is an increasing need for unique identification and traceability of products. This affects all elements of the supply chain, including warehousing. Identification of products, means of transport and storage facilities is a fundamental need in warehouse processes. Without it, modern industrial operations are unthinkable. With the advance of Industry 4.0, new technologies and new solutions have emerged, which can be applied when modernizing or designing a new system, weighing up the advantages and disadvantages. Our publication tries to help by describing and comparing the different systems. In addition to the three most common solutions, we also look at the developments expected in the near future, which are extensions and improvements of the current systems.*

Keywords: *warehouse tracking system, RFID, RTLS*

1. INTRODUCTION

Nowadays, there is an increasing need for clear identification in manufacturing, services and trade, and for the use of modern technologies. Systems that facilitate workflow and communication for each manufacturing unit and supply chain participant. It is important for all actors that a product is clearly identifiable throughout its life cycle [1]. This is of course important not only for manufacturers but also for end users. If a product has to be recalled due to quality issues, it is important to identify which products are affected [2]. Identification and marking solutions used in warehouses play a role in the whole supply chain, so it is important to know which technologies have advantages and disadvantages. However, traceability is not only understood in terms of products and components. Semi-automated or automated warehouses are becoming more and more common, where the precise location of the means of transport is essential [3]. This is particularly important in warehouses where hybrid operations involve both humans and machines working in a common workspace. In such cases, active devices use trilateration to determine the location of the device within an area of known geometry [4]. There are also hybrid solutions where the combined use of multiple technologies is required [5, 6].

2. INTRODUCTION TO THE MOST COMMON IDENTIFICATION SYSTEMS

In this publication, we would like to present for the first time the identification and tracking systems that are in use in the industry today. In the field of industrial applications, new systems are emerging due to technological progress, but compatibility with existing systems and cost-effectiveness are also important considerations. In many cases, the cost of switching to newer technologies and compatibility with existing systems is a barrier to adoption. It is important to note that training staff and converting systems also generates costs. In the case of a large number of objects to be identified, the time factor must also be taken into account,

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because the identifiers must be changed on each object and mapped to the object in the ERP system. It is therefore important to choose the right identification and tracking system for the task.

In the early days, of course, there were analogue solutions, where paper-based, manual records were used to store the information needed for tracking. Typically, the product or component was identified by a sequence of numbers or a combination of letters and numbers, which were stored on paper in the warehouse or on a handwritten delivery note. Understandably, these solutions had a high potential for error and are no longer in use today. According to a 2005 study in Hungary [7], paper-based data storage was still 24%, which has nowadays decreased to a negligible level. For this reason, these solutions are not discussed in this paper.

2.1. Barcode-based systems

Today's most common digital tracking systems use barcode symbols to identify storage locations and products. Barcodes can be either one-dimensional (1D) or two-dimensional (2D). 1D barcodes can store 8-50 characters, depending on the type, while 2D codes can store up to thousands of bytes of data. Among the 1D barcode types, some allow only numeric characters (e.g. EAN13), while others may contain letters (e.g. Code39) [8]. 2D codes can be divided into two main groups: the 1D code extension (e.g. PDF417), which contains several 1D codes underneath each other, and the so-called 1D code extension (e.g. PDF417), which contains several 1D codes underneath each other. These 2D codes can also contain production data, making them suitable for information retrieval without ERP systems, as well as for product-level identification. The different barcode types are described in [8], Fig. 1**Hiba! A hivatkozási forrás nem található.** shows examples.

Figure 1. *barcode and 2D code examples (Code39, datamatrix, PDF417, QRCode) [9]*

The substrate can be pre-printed on the object, printed on a paper or plastic substrate, post-glued or fixed to the surface of the object during production (laser or burning). Handheld or fixed reading devices are used for reading. Older scanners used laser technology, while modern devices use some form of optical recognition system. Communication with corporate ERP systems is the responsibility of the reader. Even a small blemish or dirt on a one-dimensional code can prevent it from being read, but the light reflection is important for contrast, as is a direct view. Two dimensional codes and code matrices usually contain some kind of error correction technique, so reading can still be successful in the case of minor damage or contamination. For 2D codes, readers based on image processing are usually used, which is less sensitive to position, contrast and light reflectance. However, it is important to note that these codes do not contain textual information in addition to the code, so if there is human involvement in the processes, it is always necessary to read the code.

2.2. RFID-based systems

RFID (Radio Frequency IDentification) technology is a solution in which information (unique identification code of objects, devices or living things) is transmitted wirelessly using radio waves, even in a fully automated way [10]. In RFID systems, the identification is based on a tag that uses electricity generated by radio waves from the reader to send identification and other stored data, also using radio waves. The return signal is interpreted by the reader. The identification signal can be the unique production identifier of the tag, which is associated in the ERP system with the object to be identified. In addition, depending on the type, it can store from a few hundred bytes to a few kilobytes of data about the product. In the latter case, the information intended for the tag is recorded by a writing device. Typical read range depends on the frequency of the radio wave used and the environment. The radio waves used for communication can be highly absorbed or reflected by liquids and metals, preventing successful reading [11].

RFID tags can be divided into three categories in terms of power supply. The simplest design is passive. It does not contain a power source, so data is supplied by a circuit that wakes up when the reader signals. One is more advanced, the so-called semi-active, which contains a long-life battery. Mainly used in combination with sensors, the power supply is necessary to operate the sensors and the chip. With sensors it is also possible to measure temperature, humidity and displacement. Since they are powered, they can typically be read from a greater distance. The most advanced type is the active RFID tag. It has its own power supply and is therefore suitable for periodic autonomous data transmission [12]. Fig. 2 shows a pair of pallet-mountable tags.

Figure 2. *Pallet-mountable RFID tags (UHF 915 MHZ, ABS material) [13]*

Reading can be done with mobile or fixed readers. Unlike barcode systems, multiple tags can be read at the same time. In the case of passive tags, the position of the product or storage location is stored by the underlying ERP system, so its correctness depends on the tag being recorded. Incorrectly recorded position data can be corrected manually. When tracking, only the position of the last detection can be determined based on fixed gates or manually recorded positions. With the semi-active and active tags, independent positioning is possible, but the position can only be achieved with an accuracy of about 1 meter. For greater accuracy, it can be combined with other positioning technologies, for example via Bluetooth or WiFi.

An important feature of RFID is the frequency of the radio wave used. We distinguish between low, high and ultra-high frequency communication solutions. The frequency ranges for each type are listed in Table I. Low and medium frequency ranges are less sensitive to metallic environments and can be used in liquid environments, while high frequency RFIDs should be avoided in such places due to their high absorption.

Table I.

RFID working frequency ranges [2]

Applied frequency range	***Low frequency (LF)***	***High frequency (HF)***	***Ultrahigh Frequency (UHF)***
For passive RFID	125kHz, 134kHz	13.56 MHz	9000 MHz
For semi-active RFID	-	13.56 MHz	2.4 GHz
For active RFID	-	13.56 MHz	2.4 GHz, 5.8 GHz

2.3. RTLS systems

RTLS (Real Time Location System) can determine the position of a vehicle using active RFIDs. Indoors, GPS technology cannot be used due to satellite shielding. RTLS systems use antennas and tag signals to calculate the position of the signal source, and thus the position of the object to be tracked, in real time using a trilateration or, for greater accuracy, a multilateral positioning method [4]. This requires the installation of antennas (anchors) at specific locations, which can be used to determine the position of the tag to an accuracy of about 10-100 cm [12]. A general design is shown in Fig. 3.**Hiba! A hivatkozási forrás nem található.** This technology is basically not used for tracking products, but it is very suitable for determining the movements and positions of transport vehicles (forklifts, AGVs) and workers. In addition to the signal from RFID, other radio frequency solutions are used for positioning, usually complementing it. These solutions include Ultra-Wide Band (UWB) radio networks, WiFi networks, Bluetooth Low Energy (BLE) links, 5G mobile networks or Zigbee networks [4, 14].

RTLS can be used to develop optimal routes and analyse data to find critical areas within a warehouse that are critical to operational time. For example, in one part of a warehouse, space is tighter, so forklifts regularly stop while another forklift passes. Or people on their way to the cafeteria may obstruct the free movement of delivery vehicles by crossing a zebra crossing, forcing the delivery vehicle to stop. Also, with RTLS system, collision of AGVs with each other or with operator can be avoided as the information from the system is used to know the exact location of the equipment or operator in the area [14].

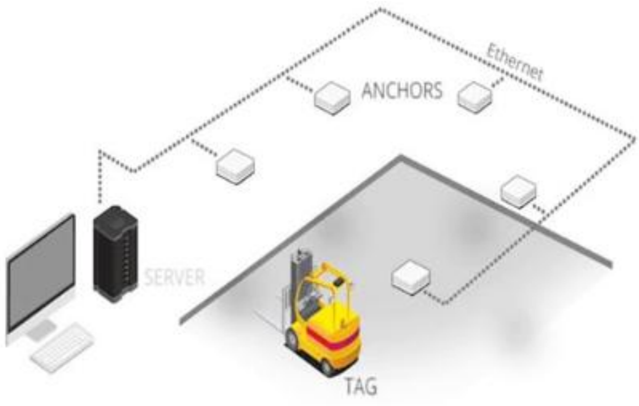

Figure 2. *RTLS system general architecture [15]*

3. COMPARISON OF SYSTEMS

As we have shown, the 3 systems have different technologies and primary applications. In the following, we will describe the differences between the systems according to the main criteria.

Table II.

Comparison of identification systems

	Barcode	***RFID***	***RTLS***
Deployment/operating costs	low	Medium	high
Reading distance	0.1..10 meters	0.5..15 meters	Depends on the system
Visibility	Direct view	Not required	Not required
Technology	Optical	Radio wave	Radio wave
Suitable for positioning	No	In part	Yes
Typical data storage capacity	8-50 bytes (1D), a few 100 bytes (2D)	1-2kb	Not relevant
Reading accuracy	If it works, it will be 100%	Reading is not always successful	Reading is not always successful

A Table II. presents a comparison of the characteristics relevant to the schemes. The cost of a system can be divided into two parts: the cost of designing and building it, and the cost of operating it. Based on these, barcode systems have the most favourable cost. Simple, passive media, ease of use and a wide range of devices are the main features. The majority of the deployment costs are for fixed and mobile readers and barcode printing devices, while the majority of the operational costs are for printing supplies and maintenance of the devices. Compared to the other two traceability systems, this solution is still low cost. Barcodes cannot be overwritten and the data content cannot be changed once they are created [16]. For RFID-based systems, tags are at least an order of magnitude more expensive than the materials needed to print the barcode. The price is highly dependent on the requirements of the location of use: reading distance, ambient temperature range, chemical and other influences, and the type of RFID. Semi-active and active tags not only have a higher initial cost, but also require maintenance during operation (charging, reprogramming, replacement), but the information stored on them can be overwritten if necessary [4][16]. Mobile and fixed readers and writing equipment for reading are also more expensive than barcode systems. In terms of cost, the deployment of RTLS systems is the largest. In general, existing networks are not suitable for RTLS systems, so the installation of fixed antennas, which are essential for positioning, requires planning, development and construction of an internet and power supply network. These costs can significantly increase the investment cost when covering a large area. The cost also depends largely on the intended use, as RTLS tags typically use more expensive active or semi-active RFID technology.

From a reading point of view, it is important for barcode-based tracking systems that the label containing the barcode is visible, as the reader needs to "see" it. If the reading is successful, the stored data can be read at any time. It is important to note that barcodes, except for some special readers, can only be read one at a time. If there are several barcodes in the reading area, misreading may occur [17]. RFID can be read from a distance depending on its technology and frequency, but it is important to note that especially when reading several tags at the same time, successful reading of all tags is not guaranteed. This is due to interference or absorption of radio waves. For UHF tags used in metallic environments, this is particularly important to bear in mind. RTLS systems may also be unable to determine the tag signal due to shielding or interference due to the properties of the radio waves. There may also be a problem if the number of antennas required for positioning is less in a given area - this can be caused by the installation of a new machine, or by moving materials in a warehouse. In such cases, the installation of additional antennas can improve the problem.

If one of your tracking needs is to know the exact location of the product or means of transport within the warehouse, then the best solution is to use an RTLS system. It is the only one of the three types that can provide the location of the tag in real time. When using a barcode or RFID tag, only the location of the last reading is known. If the material has moved without being read, even due to a reader gate failure, its exact position will only be known the next time it is successfully read.

If we want to store data on the product itself (or on the label or tag) independently of the ERP system, we need to consider the data storage capacity of the identifier. 2D codes can be used for up to a few hundred bytes of data, but care should be taken that as the data content increases, the size of the dots per unit decreases dramatically. This reduces the reading accuracy and reading distance. Radio-based systems typically store 1-2 kb of data, but active RFIDs can store more.

4. DESCRIPTION OF SOME APPLICATIONS

The following are some examples of applications for different monitoring systems. The most common application of barcode-based identification is in commerce. Every product or package placed on the market contains a barcode, which is used for inventory, stocktaking, and revenue and sales. Typically, 1-dimensional barcodes are used, but in the near future the use of 2-dimensional codes will become mandatory, due to the unique identifiability and traceability of products. Currently, in Hungary, the pharmaceutical industry requires that, in addition to the barcode, a 2D code of the datamatrix type is also placed on the packaging for prescription medicines [18]. In addition to the commercial sector, many manufacturers and assemblers of course use barcodes, but hybrid solutions are becoming more common, where the label also contains an RFID tag that allows unique identification. One example of a hybrid solution is the use of tags for patient identification in hospitals. When patients are admitted to the ward, they are given a wristband with a barcode and text information, and other patient details (e.g. ward number) are recorded on the tag. Dechatlon's stores are an example of RFID applications [19]. The store has a unique RFID tag on all its products, so that product information can be retrieved and payment made contactlessly. Each tag contains a unique Electronic Product Code (EPC), which is combined with the product's unique SKU identifier. This allows shoppers to scan and go without human intervention [19]. It also helps store staff in inventory and stock taking, as tens or even hundreds of tags can be scanned simultaneously using handheld scanners.

Today, the car manufacturing process is also becoming increasingly automated. Unique, unambiguous identification of parts is essential. Although barcode identification is the most common method, automation requires the use of RFID to identify parts [20]. Just think that in the case of assembled parts, the barcode is placed inside, out of sight, so that it cannot be read. With an RFID tag, on the other hand, it is easy to read all the identifiers, even in an already assembled part. For example, once the dashboard has been assembled, it can be checked that all the necessary parts have been installed. When barcodes are used, especially in areas exposed to the weather or contaminated with oil and other liquids, the barcodes are easily damaged and become illegible. This makes subsequent servicing and identification of sub-assemblies difficult or impossible. The use of RFID tags can also facilitate subsequent repair work by identifying the exact type of component installed without disassembly.

A common everyday use of RFID technology is in building access control and security systems [21]. RFID cards assigned to employees and visitors can be used to determine which areas of the building they can and cannot enter. In office buildings and universities, there is usually a reader next to the door in front of the room or part of the building to be protected, which, when touched, is authorised and the system electronically authorises or denies the door. It also allows the control of the use of other networked devices. Just think of the multifunction printers in universities. The RFID reader on the printer allows the employee to identify himself and, as long as he is authorised to use the device, the printer authorises the execution of operations (printing, scanning, copying). These systems are also often used, especially in factories, to automatically keep records of working hours. In this case, the card scanned at the time of entry and exit is sent to the HR system, which records the time of arrival and departure. From this data, a report can be generated at the end of the month.

5. THE FUTURE

Artificial intelligence is one of the most emerging sectors of our time [22]. Companies are announcing a series of products in which AI helps processing and communication. Industry 4.0 can help in many areas, especially in the application of machine learning. In the identification of corrupted barcodes, 2D codes, learned neural nets can recognize and interpret tags, so that information can be recovered. Also with machine learning, the detection of defects in product recognition and manufacturing can be automated, provided that a sufficient number of correct and incorrect samples are available for teaching. Instructions compiled from current human-machine communication recorded voice material, augmented with ChatGPT or other language models, can even provide instant product information to the worker.

In addition to artificial intelligence, another important future development is the use of the Internet of Things (IoT) in industry [23]. IoT devices can also be used to modernize existing systems in the areas of supply, storage, packaging and delivery at relatively low cost [24]. Devices equipped with sensors can transmit the characteristics they want to monitor in real time during production and storage, providing instant, accurate information on temperature, humidity, pressure, etc. An interesting area of future research is the combination of IoT and artificial intelligence, which can make warehouse processes more efficient and accurate.

6. Summary

In our publication we described the three most common warehouse tracking systems and the identification technologies they use. We have discussed the advantages and disadvantages of each technology, the principle of operation of the system components, and examples of practical applications. The comparative analysis shows that none of the systems solves all the problems. When choosing or developing a system, the objectives, costs and available resources must be taken into account. A really good solution can be found after assessing the needs and knowing the above. In practice, companies often use a hybrid system rather than one or the other technology. With the advance of Industry 4.0, more and more data and information will be needed in all areas of production, warehousing and transport, so passive tools will be replaced by active systems capable of providing immediate data. In our view, the dynamic growth of the economy in the near future will require the interoperability of different systems, which can only be achieved through the use of smart devices, which are becoming more and more widespread, and complex systems using an integrative, unified communication platform.

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