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SELECTED ASPECTS OF INDOOR POSITIONING BASED ON AIDC ELEMENTS IN WAREHOUSE FACILITIES

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Abstract

The article presents classification of automatic identification and data acquisition techniques (AIDC) as well as techniques for indoor positioning of objects supporting logistic processes, including especially warehousing processes. The use of presented solutions and the possibility of combining AIDC technics with indoor positioning systems to increase the efficiency of logistics processes in warehouses were discussed. This combination can make a tool supporting rational decision making for allocation of idling employees and vehicles to warehouse tasks and reducing empty runs on the base of position analyse. Then, the idea of using popular AIDC devices − mobile terminals with and without RFID scanners to track the position of employees was presented and discussed. Mobile terminals can provide information about position, which can be used for the allocation of tasks (the reverse functions of mobile terminals). Review of AIDC techniques in warehouses and industrial facilities, information flow in AIDC techniques, positioning techniques in a closed space, Resources positioning and the efficiency of the warehouse process, typical and new approaches to positioning resources in warehouse, the reverse function of mobile terminals are presented in the article.

Keywords: *AIDC, indoor positioning, warehousing, logistics*

1. Review of AIDC techniques in warehouses and industrial facilities

Automatic identification and data capture (AIDC) technics are used to improve the information exchange between objects of the process (e.g. warehousing) and computer information processing systems. Their goal is to eliminate the unreliable human factor from the process of identification, acquisition and transfer of information. Such systems are the basis for the implementation of all processes in today's logistics systems, as well as production, trade, services and many other areas of the economy and life. In addition to typical identification tasks, they can also be used for indoor positioning of work resources (people and equipment).

The development of AIDC techniques for logistics is associated with the increase of information flow resulting from growing and more and more diverse material flow, as well as modern requirements for customer service and sales processes [8]. The amount of information processed also results from better tools for information archiving and processing. AIDC development is crucial for the logistics systems efficiency, especially for warehouse and production systems, where the most labour-intensive processes requiring identification, tracking and marking are implemented. Each "touch" of the material, regardless of the type and size of the unit, involves the processing of information about this material and its surroundings.

AIDC techniques are mainly for communication between warehouse floor where the flows of materials are physical, IT system and personnel managing the flow (Fig. 1.).

AIDC techniques are most commonly used to identify units of materials (products, goods, raw materials, etc.) and their packing forms, resources (employees, vehicles, trucks, machines, etc.), places (locations addresses, areas, current coordinates in space, etc.).

Each of this elements can be described with information of two basic categories: 1/ alphanumeric string encoded with graphic codes or other media (like EPC), 2/ parameters and features of physical objects, like dimensions, mass, blemishes, position in space etc. read directly from the object.

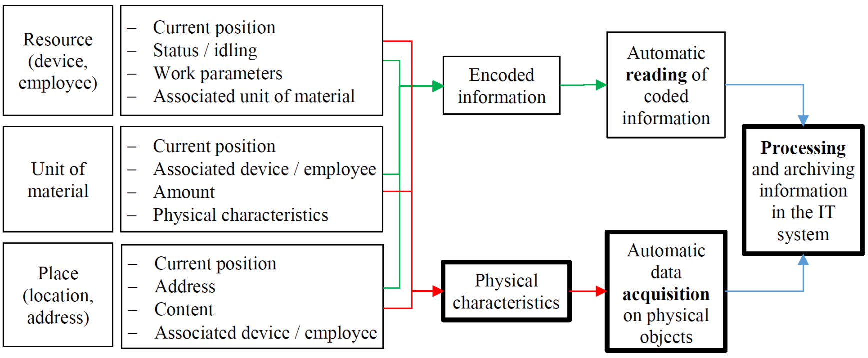

Fig. 1. Information flow in AIDC techniques

Efficient information flow between the place of acquisition (logistic label, electronic tag on the product or device, address label on the location, etc.) and the place of processing (computer application of the IT system, employee), determines the efficiency of the logistics process [15].

A very important application of AIDC techniques is the indoor positioning of resources in the logistic facilities. The dynamic positioning is currently becoming a key way to rationalize warehouse and production processes [2], [17], [18], [20], [25]. Static control mechanisms not requiring information about position of resources in space switch to dynamically reacting (in real time) control models allocating resources to current tasks. This allows better use of installed technical potential of the warehouse.

AIDC techniques in warehouses can be divided according to the following applications:

1. Acquisition of alphanumeric data from logistic labels:
   - stationary and mobile scanners of graphic codes (one-, two- and three-dimensional, in various reading technologies),
   - stationary and mobile RFID systems (passive, active, different frequencies),
   - text recognition systems (OCR – optical character recognition).
2. Saving data to logistics labels:
   - logistic label printers,
   - graphic printers of logistic labels equipped with RFID tags programming,
   - stationary and mobile RFID systems (passive, active, different frequencies).
3. Identification of physical characteristics of material units (DWS – dimension and weight scanning):
   - weight scales,
   - dimensions, shape and symmetry scanners,
   - automatic detection systems for defects and material errors,
   - image recognition systems.
4. Picking and put-away supporting systems:
   - pick-to-light,
   - pick-by-voice,
   - pick-to-point.
5. Resource positioning systems and access control:
   - indoor GPS location,
   - RFID-based positioning,
   - infrared (IR) technologies,
   - ultrasonic and sound technologies,
   - frequency technologies of various types,
   - magnetic technologies,
   - technologies based on image analysis.
6. Systems for recognizing biometrics:

- fingerprint scanners,
- face image scanners,
- voice recognition,
- iris pattern scanners.

These techniques are used in the industry and logistics, but commonly adopted solutions are based on graphic (bar) codes, which are very cheap and universal. Automated systems widely use integrated DWS systems to identify physical aspects of material units. RFID-based solutions are mainly used for specialized applications and where the high value of products justifies the use of relatively expensive RFID systems.

The techniques of indoor positioning of employees and equipment gain a great importance for the implementation of modern warehousing processes. The reliable information about current position of resources allows for their dynamic allocation to tasks with regard to anticipated realization time. Such techniques primarily contribute to shortening the time of task completion and reducing the labour-intensity of the overall process. The security aspects related to avoiding collisions and spatial separation of vehicles and employees are also important.

Spatial indoor positioning is a highly developed branch of technology and goes beyond the general definitions of AIDC. However, in many cases (especially in warehousing facilities), the same technical solutions, as for indoor positioning e.g. networks and hardware, are used to support AIDC systems. This is why they can be considered together.

2. Positioning techniques in a closed space

The positioning can be of two types depending on the environment: outside and indoor. Positioning techniques use a variety of approaches that vary in accuracy, maintenance costs, precision, technology, scalability, resilience, and security [1], [2], [4], [17], [18], [20], [25].

Indoor positioning in space of warehouse and industrial facilities gained popularity along with the development of teleinformation techniques and increased computing power of servers capable of using location data in current planning. Especially the development of Automated Guided Vehicles (AGV) capable of moving autonomously in industrial facilities triggered indoor positioning research. For security reasons reliable techniques for position tracking and securing traffic were developed to protect people and industrial environment from potential adverse interaction [18]. Along with the development of AGV, wireless communication techniques became the basis for positioning systems. In comparison with the external environment, indoor position detection requires more precision, and it is a more difficult, in part because of various steel made objects reflecting and distract signals [1].

There are five main measures of the quality of indoor positioning systems [1]: 1 / accuracy and precision, 2 / range and resolution, 3 / delay in location updates, 4 / influence of infrastructure and building elements, 5 / random effects (interference, reflection of signal). In case of warehouse facilities, the range and resolution of the method and its delay are particularly important because determine the suitability of the method for the ongoing control of the logistics process.

In general, wireless local positioning systems, appropriate for logistics processes, consist of at least two hardware components: a measuring unit (usually including the system's intelligence) and signal transmitters. Depending on the functionality of these components and their interactions, classification of local positioning systems can be performed [22]:

- Independent positioning (measurement performed from positioned object on the basis of fixed orientation points in the space transmitting a signal – transponders), requires computing unit and power supply installed on positioned object.
- Remote positioning (measurement performed from the side of fixed installation, the signal is transmitted by a positioned object), requires a backbone network capable of collecting and transmitting a signal to the central site.
- Indirect remote positioning (positioning system transferring data about positioning result from

the moving object to the central unit).
- Indirect, independent positioning (positioning system transferring data about positioning result from the central unit to the moving object).

The following popular position measuring mechanisms based on signal analysis (mainly electromagnetic waves of different lengths) are used [2], [22]:
- Measurement of the angle of the received signal arrival (AOA – angle-of-arrival) with directional antennas,
- Signal strength measurement (RSS – received-signal strength), with possible including of signal shielding by elements of the environment;
- arrival time propagation (TOA – time-of-arrival);
- propagation of the round-trip time signal (RTOF – roundtrip-time-of-flight);
- TDOA − time-difference-of-arrival.

Many classifications of indoor positioning systems can be introduced. One of the most interesting and wide classifications was provided by Alarifi et al. [1]. It presents the most popular solutions in this area that have a potential in warehousing facilities:
- Technologies depending on the building (structure, layout, maps):
- Technologies requiring a separate infrastructure:
  - Radio Frequency Identification (RFID) – based on the passive or active tags and stationary or mobile readers equipped with transceiver antennas. In most cases, the moving object is equipped with a single tag, which is then detected by stationary antennas according to the response to the search signal.
  - Ultra WideBand (UWB) – using the measurement of the time difference of arrival / sending a radio signal from and to a localized object.
  - Infrared – based mainly on the proximity, differential phase shift and angle of arrival of infrared waves.
  - Ultrasounds – basing on the reflection of mechanical wave moving in the air.
  - Zigbee – a short-range and low-power wireless private network based on the measurement of the phase shift of the reflected signal and the time delay between the object and the transmitter.
  - Laser – using systems of laser rangefinders.
- Technologies using the building infrastructure:
  - WIFI – most often based on the fixed locations of wireless routers available in the operating area. The most popular method of WLAN-based positioning is measuring the RSS, which is easy to isolate in 802.11 networks and can operate on public WLAN equipment. Methods TOA, TDOA and AOA are less commonly used.
  - Cellular networks – indoor use requires the building to be covered by one or more base stations with a strong RSS feed. The most popular method of internal GSM positioning is RSS.
  - Bluetooth – uses proximity and RSS methods to estimate the position of the object.
- Technologies independent of the building (structure, layout, maps):
- Dead reckoning – position estimation with respect to the last known location, including the motion vector.
- Image Based Technologies – image recognition and processing.

Other classifications of location systems:
  - Based on and not based on network solutions [4].
  - Based on the use of ultrasounds, radio frequencies, magnetism, vision and sound analyse [4].
  - Camera systems, infrared, touch and polar systems, sound, WLAN and WiFi, RFID, ultra-wide bandwidth, high GNSS sensitivity, pseudo-satellites, other radio frequencies, inertial navigation, magnetic systems and infrastructure systems [19].

3. Resources positioning and the efficiency of the warehouse process

The information about resource position in the warehouse space can be a key factor in increasing the efficiency of the logistics process through shortening empty runs [3], [23]. This applies, in particular, to heavily loaded, non-automated storage facilities with wave managed. In such facilities, the frequency of supply or shipment orders may be periodically higher than the average time of single work-order processing, which will cause a pile-up of work [9]. Reducing empty runs leads to shortening the time of work-orders completion and reduces process delays with fixed warehouse resources. The very organization of most warehouse processes assumes the approximately 50% of empty runs for the majority of travels. While the case is not crucial in case of short repeatable serial transport cycles performed by forklifts, the order picking and replenishment processes (the most labour-intensive) together with put-away and retrieval operations can be significantly improved by shortening the empty runs.

The empty runs can be reduced in several ways, including *tasks interleaving* and by *eliminating the need to move an employee to the place where the next task starts*. Both methods require a favourable layout and work organization in the warehouse. The first method assumes combining several transport cycles or handling operations into a continuous technological line; while the second one assumes choosing the idling employee who is closest to the place where the next task starts, (it was assumed that the work is not on a material-to-human basis). In both cases, the position of the employee in the space of the facility is crucial. The four attributes of task interleaving must be satisfied simultaneously to decide about interleaving [16]: 1 / availability of a free resource at a given moment, 2 / similar priority of tasks, 3 / short (acceptable) waiting time for the next task in the cycle and 4 / proximity of places of tasks realization. To assess the proximity and waiting time between tasks in the series, it is required to determine current position of available resources. In the second case, the assignment of the employee to the task follows the criterion of time that will pass between order recipient and task realization, and whose estimation requires information on the employee's position in space.

A certain difficulty here is from the specificity of storage facilities space. The determination of travel time between two points in space must take into account the topography defined by shelving systems, mezzanines, internal transport systems and the mobility of resources. The problem of cutting the empty runs must be considered concurrently with the problem of shaping the three-dimensional space of a warehouse ([6], [7], [14], [21]).

It is assumed that the execution time $t(v, L)$ of a single warehouse task is dependent on distance L and average velocity v of the resource. Reducing this time will lead to reduction in the total number of work resources (n), and consequently costs, or increase in the productivity λ of the system in a given working time t_d in accordance with the formula (1):

$$n = \left[\lambda \cdot t(v, L) / t_d \right]. \tag{1}$$

Another way of increasing the quality of warehouse process by analysing the position of technical and human resources is avoiding potentially hazardous (traffic) situations [11] and avoiding congestion at particularly loaded locations [10].

4. Typical and new approaches to positioning resources in warehouses

In general, the problem of positioning resources in the space of warehouse facility can take two forms: 1 / continuous tracking of position of devices (mainly automatic, mostly by methods presented in chapter 2.), 2 / positioning of resources with high freedom of movement (employees) in order to make an operational decision about current tasks assignment [12]. While autonomic devices are constantly tracked due to the way they are run, hence their position is known on a regular basis, the employees have the freedom to move, which makes the position of the employee at a given moment uncertain if it is not constantly tracked. This uncertainty increases over the time passing from the last known activity, impeding estimation of the employee position and lowering the positioning accuracy below any rational level after approx. 1.

Implementation of employees' position tracking is, therefore, necessary to increase the efficiency of the system. These techniques are used mostly when no fixed starting and ending depots are established. Fixed depots do not require employees positioning since tasks start and end in the same place, but only the registration of employees who are idle at the moment. Where the starting and ending tasks in not bounded by any central depot to be visited, the following approaches to determining the position of an employee in space are applied:

1. Fixed allocation of employees to working zones (zone logic).
2. Estimating the current position on the base of the place of last activity (dead reckoning).
3. Technical systems to track the position of an employee (Chapter 2.).
4. Tracking the position of the employees with **the reverse functions of mobile terminals**.

Fixed allocation of employees to working zones (usually limited and small) eliminates the need to position an employee in space. The processes performed in limited zones usually are the loop type (the same point for start and end) or the line type (pick-and-pass systems). No need for positioning is occupied with empty travels included into transport cycles, which must be made in order to start a new task in the zone.

Positioning based on the last known position of the employee captured during task realization is only valid if the next task is assigned just after the completion of the previous one or during its course. Only in these cases, the final position of the employee is known. Otherwise, the employee will move and after less than a minute, the last registered position will not have any operational value.

Solutions for tracking employees indoor position in warehouse facilities, mostly based on RFID technology [20], [25], require purchase and implementation of a dedicated technical system adaptation of systems embedded in the building (Chapter 2.). It may be expensive or its use may not be justified. In connection with above, a solution based on common technical infrastructure and popular warehouse IT solutions was proposed. This solution assumes the reversal use of the handheld terminals.

The reverse function of mobile terminals assumes tracking the user's position with the support of the database of coordinates of warehouse locations (addresses) and pre-calculated transition times between any two locations [5]. This function can be based on:

- Mobile terminals equipped with RFID readers operating in automatic mode to detect product tags located nearby, and querying the material and address databases determine the position in which are located to estimate the position of the employee. It is possible to check more than one product tag in the surrounding area to increase the accuracy of the location; however, such operations would demand resource-intensive calculations. To reduce the server load, positioning operation would be required only when system searches for implementators of current tasks.
- Mobile terminals equipped with bar code readers, which, on a system command, instruct idling employees to scan the label of the nearest warehouse location. On this basis, the position of the employee is fixed and the task is assigned. Lack of response within a specified time results in omitting the employee in assignment of the current task. Such an activity requires a certain amount of manual work, however, it is limited to a simple scan of a label, and so it does not require additional focus and is carried out in the time between tasks.

The above methods should be used together with classic methods of tasks queuing and zone allocation and should be considered for peak periods.

Referring to standard measures of the quality of indoor positioning systems [1], it can be shown that proposed solution is:

- accurate to the extent required for warehouse process control since there is no need for automatic guiding of vehicles in cluttered space which can lead to dangerous situations,

- available according to the share of activities related to positioning in total time of the process (especially when using an RFID-based solution)
- completely covers the area of warehouse if only the RFID tags or address labels are in places associated with tasks,
- scalable to any needs because it does not require any dedicated technical infrastructure,
- cost-effective when introduced together with IT and WMS solutions,
- insensitive to unauthorized access.

5. Conclusions

The indoor warehouse positioning of work resources can be implemented in many ways, depending on the needs and technical possibilities. While all solutions require the existence of an appropriate software layer and additional computing capabilities of servers, some solutions will not require an additional hardware layer (structural and mobile) and can be implemented as part of updating existing WM and WMS information systems.

Indoor positioning provides additional data for operational decisions about tasks dispensation, tracking performance and work quality, errors search and bottlenecks in the system. Under certain conditions, it can also be a stimulus for work efficiency, but from the other side the potential negative consequences associated with constant tracking and mental load must be considered.

Reducing empty runs in the warehouse is a difficult task due to the characteristics of warehouse tasks being simple transport operations and handling activities. The time for completing a single operation is very short (from a few seconds to several minutes), which makes the time intended for planning the next steps very limited [13], [23], [24]. This limitation imposes the necessity to quickly make operational decisions on the allocation of resources to tasks, which in turn requires up-to-date information (e.g. on the indoor position of resources), efficient computations for assignment algorithms (or simplified algorithms in this respect) and exact procedures for controlling the implementation of tasks. These requirements may prevent implementation of proposed solutions, so basically it should be considered in large, heavy loaded and strictly controlled warehouse installations, whose information systems are not set to "minimum requirements".

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