The development of small-scale mechanization means positioning algorithm using radio frequency identification technology in industrial plants

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Abstract. The article is devoted to the development of technology and software for the construction of positioning and control systems for small mechanization in industrial plants based on radio frequency identification methods, which will be the basis for creating highly efficient intelligent systems for controlling the product movement in industrial enterprises. The main standards that are applied in the field of product movement control automation and radio frequency identification are considered. The article reviews modern publications and automation systems for the control of product movement developed by domestic and foreign manufacturers. It describes the developed algorithm for positioning of small-scale mechanization means in an industrial enterprise. Experimental studies in laboratory and production conditions have been conducted and described in the article.

1. Introduction
Currently, because of the need to move to new intellectual digital production technologies and implement international quality standards, it is necessary to introduce new science-based approaches to controlling the movement of products and small-scale mechanization of warehouses. This is due to the fact that the warehouses of large industrial organizations, at the current level of hardware and software, cannot fully comply with domestic and foreign quality standards in the field of product tracking, regulated by GOST and ISO. A number of domestic and foreign standards include strict requirements for organizing the process of product traceability. Any unit produced in the enterprise must be accompanied by a detailed history of its manufacturing, starting at the beginning of the production process. Registration processes of materials used in the production of a product unit and the main stages of its movement, at the current level of development of software and hardware automation of industrial enterprises, are documented in electronic document management systems, but the movement of products within the warehouse territories requires greater detail. The lack of detailed product movement information can lead to product re-sorting and theft. Automation of product movement control in the last decade is mainly done with the use of technical vision, however, in the last few years, systems based on radio frequency identification methods are rapidly developing in the market of industrial automation technologies. However, current solutions allow automation of industrial processes in which either the products are transported past a stationary sensor (for example, a conveyor line with a stationary video sensor or radio frequency reader) or manual control of the sensor to identify the stored products (for example, manual portable bar code readers and RFID tags). Using the existing systems to solve more complex problems, where the transportation of products is
carried out by more than one route (for example, transportation by a forklift truck) or using manual identification method is technically impossible or contradicts safety rules. Implementation of these systems won’t help automate the process of controlling the product movement in due to the low reliability of the received results. Based on this, the development of new algorithms, methods and systems for monitoring the movement of industrial products is a substantial scientific and technical task [1–3].

All such developments should be based on the already implemented software and hardware solutions for documenting information on traceability and automated means of transportation and storage. If documenting of information is implemented in almost all industrial enterprises in the form of separate electronic document management systems, the automation of small-scale mechanization often requires a complete replacement of the fleet of transport devices, due to the lack of effective ways to organize their positioning and status tracking, which entails enormous financial and time costs for the enterprise. Therefore, the development of technology and software for the construction of positioning and control systems for small mechanization in industrial plants based on radio frequency identification methods is a substantial scientific and technical task [4, 5].

The purpose of the work is to consider and use a fundamentally new approach to automating small mechanization facilities for industrial enterprises with a complex transport infrastructure. The use of this approach will allow solving fundamentally new automation tasks in which the use of existing solutions does not yield the required result and will provide improvement of known scientific results by revising them with the proposed approach.

2. Subject overview

A great contribution to the development of radio frequency identification technology and product movement control systems in various spheres of life was made by Bondarevsky A.S., Zolotov R.V., Do Zuy Nyat, Kamozin D.U., Manish B., Shahram M., Ke-Sheng Wang, Worapot Jakkhupan, Somjit Arch-int, Yuefeng Li, Mahir Oner, Alp Ustundag, Aysenur Budak and many others [5–10].

Application of these knowledge-intensive technologies makes it possible to automate the processes of controlling the product movement at industrial plants, ultimately, to increase the efficiency and reliability of transportation control and warehouse inventory control of manufactured products.

However, they are not without flaws. The use of existing software and hardware solutions is more aimed at organizing automated warehouse inventory control and less suitable for automating product movement control, in the absence of universal methods and algorithms. In support of this, at a number of industrial enterprises, developers of RFID systems attempted to organize traceability of products by automatic movement control based on radio frequency identification. As a result, it became clear that automatic control of the product movement is possible only in certain areas of the production process. Such areas are conveyor lines and transport tunnels, where the transportation of products is carried out along the permanently installed radio frequency identification equipment (RFID tunnels). In other production and warehouse areas, automatic control over the movement of products is impossible. This is due to the lack of universal methods and algorithms for product identification in the process of its transportation along unmapped routes.

Positioning of objects and people using information technology is quite a substantial task. These technologies can be used to solve social, industrial and other types of tasks. Currently, there are a large number of approaches to positioning using a large number of technologies, among them:

– Satellite navigation technologies (GPS, GLONASS);
– Local positioning technology (infrared and ultrasonic);
– Technology of technical vision;
– Radio-frequency technologies.

The use of satellite navigation technology and positioning are tightly integrated into our daily lives. They are used for navigation and transport tracking, monitoring and coordination of various kinds of events. The accuracy of positioning is 10–15 meters outdoors. Unfortunately, the application of this technology inside production facilities is almost impossible. An exception is the installation of
expensive equipment for organizing GPS-positioning indoors, the unit of which can cover no more than 10 square meters, which is unacceptable for most industrial plants, whose sizes can be tens of kilometers.

Local positioning technologies are highly accurate – about 2 centimeters, but with a short range of 5–10 meters. With these attributes, they are used to achieve local accurate results and, in general, are used for flaw detection (analysis of welds, detection of chips, dents, etc.). The use of local positioning technology for small-scale mechanization is not economically effective and will lead to huge financial costs.

The use of vision technology for solving positioning problems is a relatively young concept. Currently, there are a huge number of methods and algorithms for solving localization and positioning problems, but their effectiveness depends a lot on meeting a large number of requirements, which include the quality of materials used for production of visual labels, cleanliness and lighting of premises, staff attentiveness, etc. Failure to comply with even one of the requirements can lead to a significant reduction in positioning accuracy or make it completely inoperative.

Radio-frequency technologies have found wide application in sales (organization of security in stores). Positioning based on radio frequency technologies can be divided into two categories: positioning on passive RFID tags (distance up to 5 meters) and active RFID beacons (distance up to 80 meters), but all of them are based on the principle that the moved object is marked with an RFID tag and the reading equipment is stationary. This approach allows to effectively automate production processes, where the product movement routes are strictly limited, for example, conveyor lines. However, for the positioning of chaotically moving small mechanization means, this approach will lead to a significant increase in the cost of the positioning system. Instead of a few readers they would need ten times as many.

Considering all the information stated above it is possible to draw a conclusion, that development of technology and software for the construction of positioning and control systems for small mechanization in industrial plants based on radio frequency identification methods is a substantial scientific and technical task.

The development of software and hardware for movement control systems is carried out by: PCT-Invent (Russia, Saint-Petersburg), AiTiProject (Russia, Moscow), Impinj (USA, Seattle), Motorola (USA, Morrisville), Nordic ID (Finland, Salo), FEIG (Germany, Weilburg).

Development of positioning systems based on radio frequency identification is carried out by the following scientific organizations:

– Human positioning systems, in particular patients in medical institutions: Shonan Institute of Technology (Japan, Fujisawa), Institute of Medicine (Kathmandu, Nepal), National Patient Safety Foundation (USA, Boston) and others.

– Systems for positioning moving non-metallic objects: East China Jiaotong University (China, Nanchang), Universiti Sains Malaysia (Malaysia, Nibong Tebal), University of Adelaide (Australia, Adelaide), Wellness Convergence Research Center (Korea, Daegu) and many others.

However, the tasks of developing and implementing automatic systems for tracking products in production are still unresolved. Currently, industrial enterprises still have a number of problems, the solution of which is not realized with the help of modern product movement control systems.

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3. The development of small-scale mechanization means positioning algorithm using radio frequency identification technology

In order to determine the current position of the transporting device for continuous automatic control of the transported products, an algorithm for determining the current storage area was developed.

Let \( M \) be the set of tags on the racks:

\[
M = \{ m_i \}
\]
The data coming from the reader is accumulated in the sequence F, consisting of the data sets received from the reader.

\[ F = \{ f \}, \]
\[ f = \{ s, m, t \}, \]

m is the identifier of the tag, s is the level of the signal from the tag at time t.

To calculate the average signal level from the tag for a time \( \tau \), use the following formula:

\[ \bar{s}_i = \frac{1}{n} \sum_{k} \begin{cases} s_k, & \text{if } m_k = m_i, t - \tau < t_k < t, \\ 0, & \text{else} \end{cases} \]

Where \( n \) is the number of readings over a period of time \( \tau \), defined by the formula:

\[ n = \frac{\tau}{t_c}, \]

Where \( t_c \) is the time interval that regulates when the reading takes place.

To determine the current rack, you need to select the label identifier of the rack, as \( m_i \), where \( i \) is the index of the maximum value \( \bar{s}_i \).

4. Experimental research

During the pilot studies, a large number of different typical close to production situations were modeled (Figure 1). Among them:

- movement between two storage areas;
- movement between three or more storage areas;
- movement between storage areas with the presence of "noise" (other radio frequency tags that are not tags of storage areas);
- movement between storage areas with partial overlapping of non-metallic and metal barriers.

Figure 1. The results of experimental studies.
Experimental research was carried out at the industrial enterprise of JSC Vyksa Steel Works. During the research, the labeled metal products were moved between the shelves by means of small-scale mechanization, in particular a bridge crane with a load-carrying beam. The technological map of the product movement is shown in Figure 2.

Figure 2. A technological map for the transport of products by overhead cranes with a load-carrying cross-beam.

Figure 3 shows the interpreted data on four experiments on beam movement between racks.

Figure 3. The results of experimental research at JSC Vyksa Steel Works.

Experimental studies have shown the correctness of the algorithm for determining the current storage zone in laboratory and production conditions.

5. Conclusion
The article is devoted to the development of technology and software for the construction of positioning and control systems for small mechanization in industrial plants based on radio frequency identification methods, which will be the basis for creating highly efficient intelligent systems for controlling the product movement in industrial enterprises. The main standards that are applied in the field of product movement control automation and radio frequency identification are considered. The article reviews modern publications and automation systems for the control of product movement developed by domestic and foreign manufacturers. It describes the developed algorithm for positioning of small-scale mechanization means in an industrial enterprise. Experimental studies in laboratory and production conditions have been conducted and described in the article.

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