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INTELLIGENT MATERIAL HANDLING MACHINES

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Abstract: *Automatic material handling is basically used to implement the automatic movement of goods, but due to today's expectations, this technically requires high-level computer control of various sensing, control, and monitoring tasks. Due to flexible service needs, these tasks require dynamic implementation, which may require the use of intelligent solutions. In this article, the interpretation and role of intelligent material handling in modern service systems are reviewed, and the concept and levels of intelligent material handling machines are outlined in terms of different device versions. In addition, intelligent solutions and their application areas encountered in logistics activities today are presented through examples.*

Key words: *material handling machines, automated material handling, intelligent solutions.*

1. INTRODUCTION

The development of material handling machines can be seen as a kind of evolution, during which certain directions become stronger or even die out. The material handling devices used in today's industrial environment are the results of this evolutionary process, currently automation is the strongest development direction.

Automatic material handling basically serves to implement the automatic movement of goods, but due to today's expectations, this technically requires high-level computer control of various sensing, control, and monitoring tasks. Due to flexible service needs, these tasks require dynamic implementation, which may require the use of intelligent solutions.

In this article, the interpretation and role of intelligent material handling in modern service systems are reviewed, and the concept and levels of intelligent material handling machines are outlined in terms of different device versions. In addition, intelligent solutions and their application areas that occur in logistics activities today are presented through examples.

2. MATERIAL HANDLING MACHINES

Material handling is understood as a simple or complex sequence of activities that are performed during the implementation of a given service task [1]. Each material handling activity sequence consists of different or identical operation elements, in a given sequence and quantity [2]. The task of material handling machines is to realize material handling tasks during the implementation of a given service task.

For a long time, humans played the most important role in material handling processes, simultaneously in a controlling and executing role (manual material handling). With the appearing of material handling machines, the role of humans changed fundamentally, and various driving forces and technical solutions were incorporated for the application of force, in addition to the use of appropriately trained operating personnel (Fig. 1).

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Figure 1. *Toyota human driven forklift [3]*

This solution was sufficient for industrial tasks until the end of the 20th century, but due to operational safety and efficiency advantages, automatic material handling devices appeared in more and more places, which are easier to control and monitor. During automatic material handling, the equipment is operated and controlled without operating personnel, according to a given control program [4].

3. AUTOMATED MATERIAL HANDLING

The fundamental goal of automation is to ensure and enhance safety (protection of people and goods), operational reliability, process controllability and productivity, and to reduce human resources. During automation, various sensing, control and monitoring tasks must be solved individually, in many cases using separate devices, which require a complex device and connection system. At the same time, today's performance and efficiency-centric expectations increasingly require the use of automated equipment.

There are process elements that are difficult or impossible to automate (due to technical or cost constraints), in which case semi-automatic equipment is used [5]. During semi-automatic operation, one or more of the equipment functions (e. g. gripping) are performed by some kind of operator (e.g. semi-automatic order picking truck).

Since material handling processes consist of different, interconnected movement tasks, the goal of automation is their automatic, computer-controlled implementation. In terms of the complexity of the automation task, it is necessary to distinguish between the automation of intermittent and continuous operation devices.

Complex automation can only be considered for intermittent material handling equipment, where the task is significantly more complex and difficult, since their movement includes different elements and movement sections. In some cases, the intermittent service system includes several autonomous units (e.g. AGV), which may require individual control and management [4]. Gripping, lifting, moving and other functional tasks (e.g. load control) appear as independent automation elements.

The most important automated intermittent material handling machines are the automatic guided vehicles (AGV – see Fig. 2), automated cranes, overhead monorails, automated warehouse service machines and robots.

In continuous material handling equipment, goods are traditionally moved without human intervention, so only the service and auxiliary operations require automation [7]. In many cases, we can encounter mechanical loading and unloading of goods (conveyor belts, trolley conveyors, etc.), which also does not require separate automation. Due to the above characteristics, the automation of continuous material handling machines is a much simpler task than mobile handling equipment. The main areas of automation are usually loading, unloading and transfer, as well as other ancillary tasks (starting, stopping, weighing, etc.).

Figure 2. *Schaefer Weasel AGV [6]*

4. INTELLIGENT MATERIAL HANDLING

There are several definitions of intelligence. Some researchers associate it with advanced perception and sensing, while others prefer to understand it as thinking and problem-solving abilities. From a practical point of view, it is a general mental ability that includes inference, planning, problem-solving, abstract thinking, understanding complex ideas, rapid learning, and the ability to learn from experience [8]. Based on the above reasoning, when applied to machines, the content of intelligence can be most appropriately summarized as follows: the cooperation of perception, thinking, and action that enables problem solving, consideration of possible effects, and learning.

There are several different approaches to defining artificial intelligence (AI). From the perspective of computers, it is the behaviour in which computer systems simulate human thinking using mathematics and logic. Such as reasoning, learning, creativity, and planning skills. They learn based on new information, process data, draw conclusions from it, and then integrate these into decision-making processes and react to them. Their novelty lies in the fact that by analysing the effects of their previous decisions and operations, they are able to modify their behaviour in such a way that they achieve the given goal more and more effectively [9].

From the above definition, it can be seen that AI is not an artificial version of intelligence in the human sense, but a computer science concept that is primarily related to the processing and evaluation of data and the production of the algorithms necessary for this, considering the self-development ability of the algorithm to be of paramount importance. Some researchers also interpret it as a kind of machine consciousness [10].

In terms of active machines (e.g. a loading machine), it is essential to distinguish between control and the structures performing physical operations. Artificial intelligence is basically only possible in the case of control software, with structural elements only connected to the control system through their sensors and actuators.

In terms of automatically operating machines, AI is not a development option, but a control alternative. The development of machines is not tied to AI; improving the nonintelligent control system of machines with given physical capabilities can also significantly increase, for example, production efficiency. Of course, the capabilities of the sensors and actuators can limit the operation, but their development is not directly linked to AI developments.

The actual application of AI in material handling processes is still only a possibility, but intelligent solutions are already occurring in industrial service systems.

4.1. Intelligent material handling machine

The first question is what do we consider an intelligent machine? According to the definition described in the previous chapter, which was applied to machines, we can consider intelligence to be the appropriate combination of perception, thinking and action. If a machine is able to search for an alternative solution in response to environmental influences and change its operating characteristics to implement it, then it operates intelligently.

If an autonomous device performs all its tasks intelligently, then we can speak of an intelligent machine. In simpler cases, if the device has one or only a few related tasks (e.g. a heating control thermostat), we can easily consider it an intelligent machine or process. In complex devices, it is possible that only some task elements are implemented intelligently, while simpler solutions are used for the rest. In such cases, we can speak of intelligent solutions.

Intelligent operation is always implemented automatically, so it is important to clarify when we are talking about automatic and intelligent operation. The essence of automatic operation is that all its elements are implemented automatically, without human intervention, according to a predefined logic. Intelligent operation is always automatic, but the execution of the operational elements depends on the state of various influencing factors. Intelligent control is able to evaluate the state of the elements (sensors) that monitor the effects and choose from the possible action options based on a predefined algorithm.

Since the majority of continuous material handling machines have a simple structure (Fig. 3), their automated versions usually contain different, independent automatic solutions (e.g. transfer and waiting devices of roller track systems), which in some cases meet the conditions for intelligent operation (e.g. in complex sorting systems).

Figure 3. *Cognex pallet scanning solution for roller conveyors [11]*

The automation of mobile material handling units is a significantly more complex task, where the implementation and coordination of individual operational elements may also require the use of intelligent solutions. The complexity of the operational elements that require intelligent or automatic implementation is determined by the device and the tasks to be performed.

If at least one operational element is implemented intelligently, then we must speak of an intelligent material handling machine. As a result, we can also define intelligence levels, which depend on the number of operations implemented intelligently. The material handling machines with the highest level of intelligence are automatic mobile loading devices (e.g. forklifts).

Fig. 4 shows the functional physical and control elements that can be operated intelligently in the case of automatic forklifts.

Figure 4. *Elements of an intelligent forklift*

4.2. Intelligent solutions for material handling machines

In the case of material handling machines, intelligent solutions can basically be linked to automation tasks (Fig. 5), and by implementing or combining these, subtasks can be created that may require intelligent implementation.

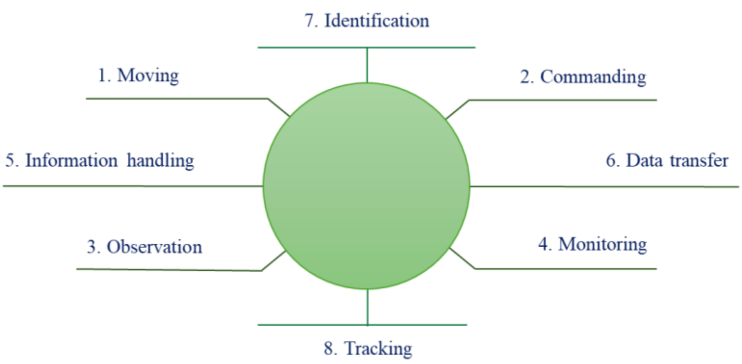

Figure 5. *Tasks of the automated operation of a material handling machine*

In the case of currently used automatic serving machines, the following intelligent solutions related to physical and control operations occur:

- route finding,
- goods identification,
- movement and lifting positioning,
- goods inspection,
- warehouse assistant solutions,
- cooperative robots,
- sorting systems,
- warehouse location identification and control,
- device stability control solutions, etc.

In the case of disturbances occurring on the path of automatic movement, the intelligence level of the control has great importance in problem-solving. The problem can be handled with simple tools (e.g. evasive manoeuvre, route change), which can be integrated into the machine control (specific instructions and built-in technical solutions). In the case of a higher level of automation and autonomy, the simple method is no longer sufficient, intelligent solutions are needed. In such cases, the sensing, decision-making and action process requires a higher level of machine thinking, possibly with multiple modifications. Object recognition and route correction can also be performed with predefined algorithms, but the process can be further refined by applying AI, which can increase the evasive speed and minimize the route growth [12].

A critical element of identification is readability, which is primarily a problem in optical identification. In the case of damaging of the barcodes, part of the information content of the code may be lost, or the incomplete code line may become unidentifiable. In such cases, the goods are usually set aside and attempts are made to identify them manually or in other ways. This can cause significant losses in high-productivity automated systems, so it is important to find solutions that can reduce disruptions. This is what intelligent solutions are for, which automatically try to restore the lost information content without interrupting the process. These methods are less tied to the physical operation of the equipment, but they use intelligent solutions during recognition and correction, with the help of some software that can restore the lost information content. Since this is a random phenomenon, it is necessary to use complex algorithms, which can benefit from the use of AI [13].

Positioning in the case of a moving device means arriving at the expected position precisely. During a complex positioning task, it is necessary to perform sensing, decision-making and movement in a coordinated manner, which requires intelligent implementation. The level of intelligence of positioning and the solution depends on the type of task, it is simpler for a single degree of freedom movement (e.g. lifting), but in the case of multiple directions of movement (e.g. taking up a gripping position) the process is significantly more complex. In the case of automated loading equipment, an intelligent positioning solution is a critical element, because taking into account the differences resulting from wear (e.g. abrasion) and various disturbing effects requires continuous and intelligent environment sensing and motion correction [14]. There are simple algorithms and technical solutions for implementing precise positioning, but fast and efficient implementation may also require the application of AI.

During the inspection of goods, a property of the goods is checked and information on the handling is linked to it (e.g. load limit). Simple solutions (e.g. scales) are also used for this process in automatic systems, but in some cases more complex, possibly intelligent solutions may be required. For example, when loading bulk materials with a grab, the weight of the lifted load can be controlled by the opening angle of the grab. When loading different materials, different weights must be lifted for the same volume due to different densities. The Liebherr Smart Gripper is able to determine the ideal opening size for a given material after a few trial grips, maximizing loading performance [15].

The task of warehouse assistant solutions is to make human warehouse service and picking processes faster and more efficient. In this case, a computer-controlled voice-based or optical aid can free up the hands of operators to speed up physical work and reduce the possibility of errors. In the case of Vocollect “Voice Picking”, the employee performing the warehouse picking operation does not check the items to be picked on paper or by holding a handheld terminal in his hand, but by using a headset and the microphone connected to it [16]. Instead of the information displayed on the mobile terminal screen, the operator receives the necessary response information or hears the work instructions in the form of a human voice in his earphones. The operator can notify the system of his physical location and the completion of the operation by speaking short answers into the microphone as an acknowledgement. Smart glasses also provide hands-free communication between operators and the controlling device/person [17]. They enable quick identification of warehouse locations and goods, rapid implementation of service tasks, rapid navigation through warehouse aisles, etc.

Cooperative robots are those that interact with human operators during their operation. In such cases, the robot is able to monitor the movements of the operators and adjust its operation to the environmental conditions. Doosan cobots have highly sophisticated torque sensors that can detect obstacles in the work area, so that people can work with the cobots in maximum safety. The lightweight cobot boasts a 6-axis joint and can reach up to 1700 mm, so it can be mounted on various surfaces, such as walls, ceilings and floors [18].

Nowadays, the sorting of different packages and palletized shipments is a huge challenge and task for every logistics centre. AI-based robotics equipment provides a great solution to this task. By combining machine vision and learning, these can be able to precisely sort the shipments arriving at the centres with a much lower error rate than humans. With the increasing number of online purchases, this process is becoming increasingly difficult, thus almost requiring the continuous application of the latest technologies (e.g. AI) [19].

In logistics processes, not only goods need to be identified, but also fixed or moving objects (service devices). The identification and control of warehouse locations can be of paramount importance in the case of automatic or semi-automatic order picking systems, where in the case of identification of incorrect locations or types of goods, it may be necessary to modify the processes and make movement corrections. Intelligent solutions can reduce incorrect operations and increase the efficiency of service processes [20].

Instabilities may occur during the movement of mobile transport and loading equipment (e.g. movement on slopes, turning curves, accelerations, etc.), which can lead to damage to the equipment or goods, operational problems (slipping), or accidents. In a constant operating environment, the negative effects can be prevented by appropriately sizing the material handling equipment, but in a stochastically changing environment, this is not enough. In such cases, we can monitor the boundary parameters (e.g. load) or control the operational characteristics (e.g. speed) by using intelligent solutions. For example, the freedom of movement of forklifts can be limited with various sensors and control solutions [21].

5. Summary

Automatic material handling is basically used to implement the automatic movement of goods, but due to today's expectations, this technically requires high-level computer control of various sensing, control, and monitoring tasks. Due to flexible service needs, these tasks require dynamic implementation, which may require the use of intelligent solutions.

In this article, intelligent material handling was defined, and the concept and levels of intelligent material handling machines in terms of different device versions were outlined.

Beside these the intelligent solutions and their application areas that occur in logistics activities today were presented through examples. Of course, the list of intelligent solutions and devices is expanding day by day, as a result, the application options of modern material handling machines are also constantly changing, which represents a constant challenge for experts in the field.

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