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The application of service robots for logistics in manufacturing processes

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A B S T R A C T

The introduction of service robots AGVs (automatic guided vehicles) into manufacturing processes is one of the more important qualitative shifts in the automation of transport operations in the manufacturing, assembly lines, as well as storages. Given the large number of applications, service robots in logistics offer a wide range of different technical and exploitative solutions. Service robots AGVs are primarily used for the realization of internal transport processes. Service logistics robots in the manufacturing processes have a very large estimate of the significance of factors when it comes to physical labour reduction. The investment in installing service robots is amortized much faster provided that the service robots work 24 hours a day. The investment in service robots for logistics is repaid within 2-3 years, and such a system works for about 15 years, operating costs are around 2-4 % annual investment, operation availability is approximately 98.5 %, a high productivity, optimized costs and processing time. This paper presents the annual application of service robots in logistics, as well as applications of AGVs service robots with different structures in the manufacturing processes, in confined areas and open spaces, such as shipping containers in ports.

A R T I C L E I N F O

Keywords:
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1. Introduction

The automation and modernization of manufacturing processes in industrial plants is carried out in part at improving transport operations in the manufacturing itself. The introduction of service robots represents one of the most significant developments in the automation of transport operations in manufacturing, assembly lines, as well storages.

Also, service robots are used in logistics in hospitals, terminals and freight-transport centres. The AGV service robots (Automatic Guided Vehicles) are prominent. These are service robots-unmanned vehicles that move by means of an automatic control system, usually battery-operated or operate by an electric motor. Sensors on the infrastructure and the vehicle provide information on the location and velocities of the vehicle based on which the control system sends the appropriate commands to the vehicle, so that it could follow the proper trajectories and move with an appropriate velocities.

The weight that AGV can transport ranges from light load of several kg up to 100.000 kg of load. The application of these systems increases the efficiency in the working environment and reduces the costs of labour, energy and system maintenance. Basic advantages of introducing AGV vehicles into the automation of transport operations in the manufacturing itself are the following: reduced labour costs and other operating costs, one AGV vehicle that works in three shifts can save three wages of workers who operate a forklift, increased reliability and productivity – AGV vehicle can work without problems in three shifts without breaks and days off, a reduction of goods damage – AGV has a controlled movement of the vehicle with an accuracy of ± 10 mm, increased safety – since the material handling processes do not require human activity and the vehicle always behaves according to pre-programmed instructions, the minimum the possibility of employee's accidents and injuries, flexibility – unlike fixed (stationary) solutions for material handling, the path by which the AGV moves can be reprogrammed very easily.

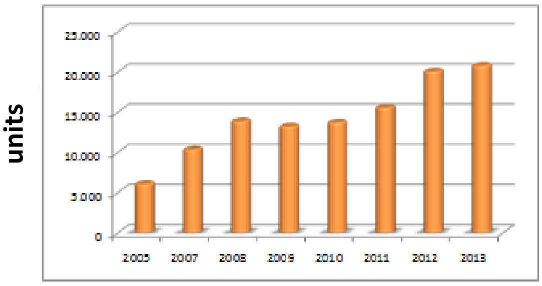
The application of autonomous service robots for logistics involves transport, handling, packaging, sorting and delivery of products. Normally, these robots are installed in industrial plants where they are used to move the working elements, boxes, pallets or tools from machines to machines, shipping areas or storages. Apart from the application in automation of transport operations in the manufacturing itself, these service robots are also used in offices, hospitals, post offices, airports, and other public institutions in which the transport and delivery of various goods is necessary. Equally, they found application in open areas, especially in ports, airports, or transhipment centres [1, 2, 5, 6, 14-16].

2. Review of service robots for logistics in manufacturing processes

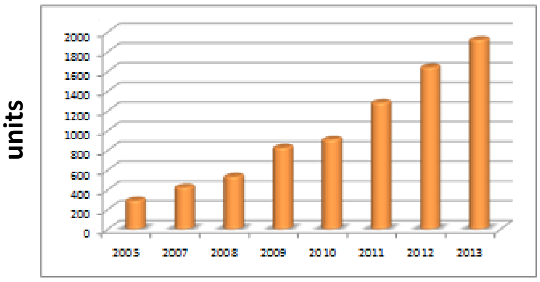
In 1995, the International Federation of Robotics (IFR) and the United Nations Economic Commission for Europe (UNECE) adopted a preliminary system for service robots classification according to categories and the ways of interaction with them. The classification of service robots is made in such a way that the service robots are first divided into two groups according to their role in the community, i.e. service robots for personal/domestic use and service robots for professional purposes.

Such a classification was adopted by the ISO. A more detailed classification of these two groups of service robot depends on the type of activity, i.e. areas of application for service robots [1, 4]. Considering that the service robots for logistics in the production processes are classified in the group of service robots for professional, an analysis of application of service robots for professional use will be conducted. This group includes: military service robots, field robots (agriculture, cattle breeding, forestry, etc.), service robots for logistics, service robots for medicine, service robots for professional cleaning, service robots for inspection and maintenance, service robots for rescue and monitoring, underwater systems, mobile platforms for general use, service robots for public relations and other service robots.

Fig. 1 shows the application of service robots in the world from 2005 to 2013. Statistical data shown in the diagrams are obtained from the International Federation of Robotics (IFR), the data of the United Nations Economic Commission for Europe (UNECE), the Organization for Economic Cooperation and Development (OECD), and literature [1, 3-10]. Based on Fig. 1a), it can be concluded that the number of service robots for professional use is increasing every year, so that about 5,000 units was applied in 2005, and 20.000 units in 2013. The service robot application increased four times from 2005 to 2013, i.e. 400 %, which is very optimistic.



a – service robots for professional use



b – service robots for logistic

Fig. 1 Annual supply of service robots for professional use and service robots for logistic

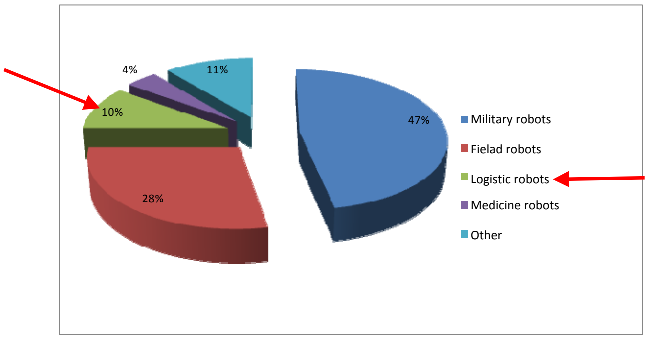


Fig. 2 Perceptual application of service robots for professional use in 2013

It is estimated that the development of information technology, sensor technology, robotic technology, i.e. mechatronics as a scientific domain, will result in a growing trend of service robots for professional use in the future. Service robots for logistics Fig. 1b) have a growing trend from year to year, so that it is predicted that approximately 1,800 units will be installed in 2014 in manufacturing facilities in factories [7-10]. In just nine years, the number of applications for service logistics robots increased nine times. The application of service logistics robots, which are now affordable to smaller companies, aims at reducing labour costs.

Annual analysis of the application of service robots for professional use in 2013, for instance, indicates that 47 % is used for military purposes, 28 % field robots for e.g. agriculture, cattle breeding, etc., 10 % in logistics and 4 % for medicine. The greatest number of robots is currently used for military purposes, agriculture and cattle breeding, which is not a good trend. In future, this trend should go in favour of service robots that are applied in medicine, as well as all other aspects of man's environment in order to help people to get rid of heavy and annoying everyday tasks.

Service robots for logistics in the factories are a very big factor when assessing the significance in reducing the physical labour. The investment to install service robots is amortized much faster provided that service robots work 24 hours a day. Considering the fact that there are 300 beds in one hospital (as it has been estimated) and that 4 million dollars is spent per year to pay workers who push carts (600 work hours is devoted to this task daily), then it can be concluded how much money these institutions would save if they introduced service robot for logistics. The example of investment in service robots for logistics type AGV LTC2-LX is shown in Fig. 3. As it can be seen from the Fig. 3, the investment is repaid in 2-3 years, and such a system works for about 15 years, operating costs are around 2-4 % of year investment, labour availability is approximately 98.5 %, a high productivity, optimized costs and processing time, applicable to all logistics systems, and the maximum load capacity of such a service robot is 450 kilograms. Service robots AGV are equipped with laser, light and sound sensors, which serve to assist in safe transportation, as shown in Fig. 4.

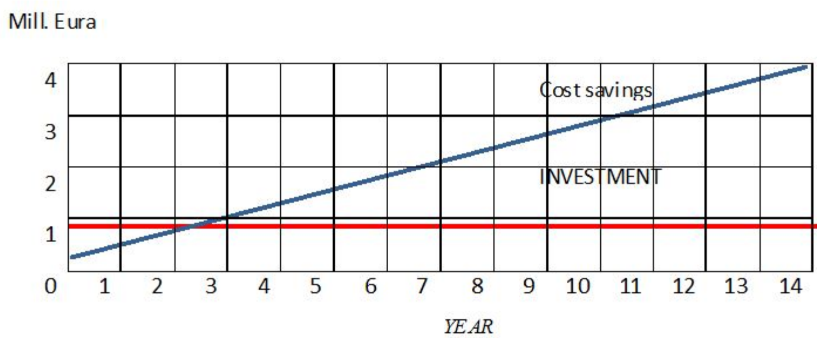


Fig. 3 Investment and amortization of service robots for logistic AGV LTC2-LX

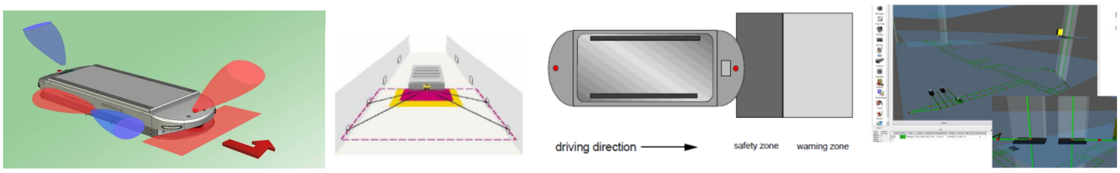


Fig. 4 Service robots for logistics equipped with sensors for communication and guided softer [20]

Due to safety at work, service robots for logistics are equipped with sensors that have a warning zone, which indicates that the obstacle is on the way and reacts with a sound, and a safety zone, where the service robot stops if the obstacle is not removed, as shown in Fig. 4. The safe navigation is a method based on which pathways of automatic guided robots are defined and on the basis of which the robots are controlled to follow a given path.

There are three basic technologies used in commercial systems to guide service robots: imbedded guide wires, with guiding tape, and self-guided robots. In the method with the embedded wire, an electrical conductor (wire) is placed in a small channel that is installed on the surface of industrial flooring. The channel is mostly 3-12 mm wide and 13-16 mm deep. After the wire is set, the channel is filled with cement to align the floor. The guide is connected to a generator that emits low frequency current-voltage signal with a frequency in the zone of 1-15 kHz. The magnetic field is induced along the path which can be monitored with sensors on the leading plate of service robots, as we see in Fig. 5.

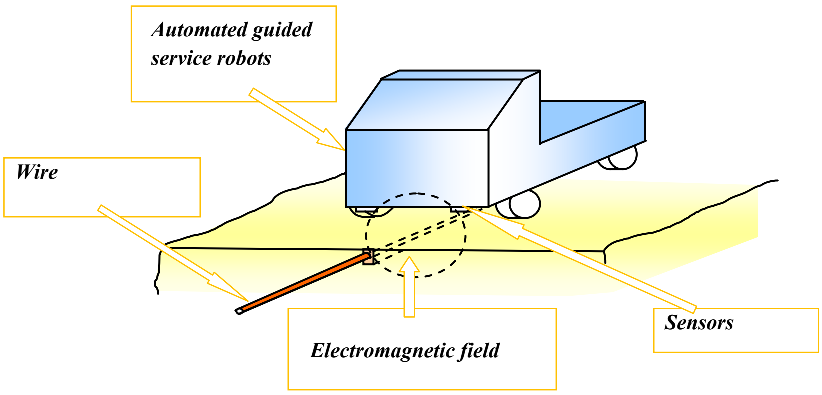


Fig. 5 Sensor with two coils for keeping track of wire magnetic field

Two sensors are installed at the service robot, one on each side of the guiding wire. When the robot is set so that the guide wires are directly between the two sensors, the measured magnetic field is the same for both coils. If the robot moves to one side or another, or if it changes direction of the leading wire, the intensity of the magnetic fields of both sensors will become uneven. This difference of magnetic fields is used to control the motor to guide the robot, which performs certain changes of direction until the signals from the two sensors are re-aligned. When using coloured tapes on the floor to define paths, then service robots use a system of optical sensors capable of tracking colour. The tapes can be glued or painted, or a spray can be used to indicate the path.

The composition of these dyes must be fluorescent components that will reflect ultraviolet light that is sent to the service robot. A sensor installed on the panel of an automatically guided robot detects the reflected light and controls the mechanism for directing the robot to follow the aforementioned tape. These colours have to include fluorescent components which would reflect ultraviolet light sent from the service robot. The tapes are used in conditions where there is electrical disturbance in the plant causing inaccuracy of wire guiding, or when it is not practical to install the wire in the floor. A disadvantage of the taped is that they can be damaged quickly, or dirtied due to the crossing of other vehicles, which causes poor UV light reflection towards the sensor. The good side of the tapes in comparison to the wire is that the tape can be peeled off or repainted, and thus the trajectory of a mobile trolley easily changed.

The introduction of service robots AGV in manufacturing systems is a major qualitative shift in the automation of transport operations in the production, the assembly lines and storages. Given the large number of applications, service robots in logistics offer a wide range of different technical and exploitation solutions. Service robots AGV are primarily used for the realization of internal transport process, so the demand for small space for the movement is of great influence. Objective is to reach the smallest turning radius possible, and therefore special attention is paid to the turning system. With the development of electronics and microprocessor technology, the control unit AGV has evolved as well, which then reduces the need for precisely defined paths through which the service robot AGV moves. For this reason, today's division of service robots AGV based on the navigation system is on systems with a fixed trajectory and systems with free navigation.

Two systems can be used for guiding service robots AGV. The first is navigation using various velocities, most commonly used. In this method, two pairs of wheels are turned, where they may have different velocities. It is similar to the principle of tank rotation, and it is good for operating in a small workspace. The second principle is similar to car guidance. It is more accurate when used in cases of tracking wires, while in that case the automatic guided vehicles cannot make sudden turns. AGV systems with free navigation have a map of the environment in which they operate, which is placed in the memory of microcomputer in a service robot. Path planning is done in a microcomputer based on a preset map of the work environment. Different types of transportation and other tasks that are performed by these systems have given rise to the development of a large number of types of service robots AGV, adjusted to the load or to the working conditions and other characteristics of the applications that are performed. According to the functional characteristics, service robots AVG can be classified into the following groups: tractors, pallet truck, unit load carrier. Service robots AGV tractors are suitable for towing multiple trailers, load bearing capacity is usually 1000-2000 kg, and can be constructed for the capacity up to 20.000 kg. These service robots can be driven by an electro battery, hybrid and combined power with a diesel engine, Fig. 6. In contrast to trucks, service robots AGV dollies for pallets are usually designed to carry a single pallet unit, and can be extended with forks that give the possibility to accept two pallet units, as shown in Fig. 6. Modern solutions have a great autonomy of work, loading and arrangement of pallets, which is a result of the development of microprocessor technology and the support of the management of these systems.

Service robots unit load carrier are autonomous units that are primarily intended for the transport of loads in circumstances where it is necessary to integrate with any other process (acceptance of load from a conveyor belt), or in terms of significantly limited space. These vehicles are not capable to take the load from the floor level, but different solutions are used in such cases, Fig. 6. Special vehicles are based on the same constructive solutions as trucks, except from one difference in adequate adjustment to specific areas of application, as shown in Fig. 7.

Fig. 6 Service robots AGV trucks and pallet trucks [22,23]

Fig. 7 Service robots AGV transportation and special vehicles [27]

Nowadays, big production companies keep finding solutions of AGV system with the possibility of completely autonomous operation in the storage zones, as well loading and arrangement at arbitrary locations, which is accomplished using a set of solutions for the precise positioning and identification both at AGV and in storages. Due to their autonomy, service robots AGV with the possibility of integration in production and assembly lines represent in some way a mobile job posts, which deliver or ship work items properly, according to the technology and work speed in certain areas. Vehicles with possibilities of integration in manufacturing and assembly lines represent in some way a moving work stations, Fig. 8.

Automated vehicles greatly depend on digital data related to jobs and environments in which they operate – mostly small companies which are very difficult to secure. To navigate in the open unlimited space, wireless AGV systems need to know their position at all times and be able to determine the path towards the end point.

Fig. 8 Service robots AGV applied in assembly process [28]

Automated and rail vehicles can be used for transport in industrial plants. Rail system may consist of one or two parallel rail tracks. The existence of rails to navigate such vehicles differs substantially from the automated guided vehicles. A power supply of rail vehicles, as opposed to automatic guided vehicles which have electricity-powered batteries, use the power supply from the electric railway tracks. Apart from automated vehicles, floor and overhead conveyors are used in the transport in a manufacturing process, Fig. 9.

Fig. 9 Rail guided vehicles, floor and overhead conveyers [28]

Conveyors are used when the material must be moved in large quantities from specific locations on a fixed path. This fixed path can be installed on an industrial floor or suspended on a certain structure. Thus, we mostly have floor conveyors and overhead conveyors. There are many different designs of floor ad overhead conveyors. We will mention only some which are used in the process of automation of the production processes: roller conveyors, wheel conveyors, belt conveyors, chain conveyors, and overhead conveyors. Floor roller conveyor moves by means of friction, which is realized between the rollers and the load. In automatic production, the movement is obtained via electric motor.

These motors are usually asynchronous. Since this transport often demands a change of speed of the load, motors are connected to the frequency converters that regulate the speed, and the whole transportation process is most often controlled by the PLC device. Chain conveyors operate on the same principle, with the only difference that the load is placed on the plate and the contact surface is much bigger. Overhead conveyors, Fig. 10, consist of a rail through which the moving chain is driven by a big motor and transmission system, to which different transport carriers are bound or some other forms of material loading. In a continuous transport, we have only a chain that shifts the load from one place to another, i.e. from one treatment to another. Or certain processing demands continuous transit of materials (painting). When one wants to perform more flexible transport, two rails are used, Fig. 10.

Vehicles with telescopic forks, as well as forks with other structures, provide much greater autonomy of handling materials and performing virtually all storages and transport activities such as loading, lifting/lowering, transport and location. Nowadays, big production companies keep finding solutions of AGV system with the possibility of completely autonomous operation in the storage zones, as well as loading and arrangement at arbitrary locations, which is accomplished using a set of solutions for the precise positioning and identification both at AGV and in storages. An automatic storage which is often combined with a distribution system is an automatic version of standard storages.

The transport system delivers material in the system in storage, or takes material from the storage system in sale. A single automatic storage can serve as a repository of both raw materials and finished products. Storage takes place in such a way that a large rectangular robot, so called storage machine, moves through the warehouse. The robot moves between storage racks and lifts cargo on an estimated height designated for a particular product. The systems are fully automated, i.e. all movements and material handling is automated.

Many manufacturers of automated heavy-cargo trucks offer platforms that can be applied in various areas: transport of aircraft parts, containers, building constructions, Fig. 12. Australian Centre for Field Robotics (ACFR) is one of the centres with experience in the production of automated robots for the handling of cargo, including vehicles for carrying containers, cranes and hoists for freight, that are already on sale. An example of this technology transfer is Brisbane AutoStrad terminal, where 14 robotic driverless straddle carriers, called Kalmar E-Drive, are installed.

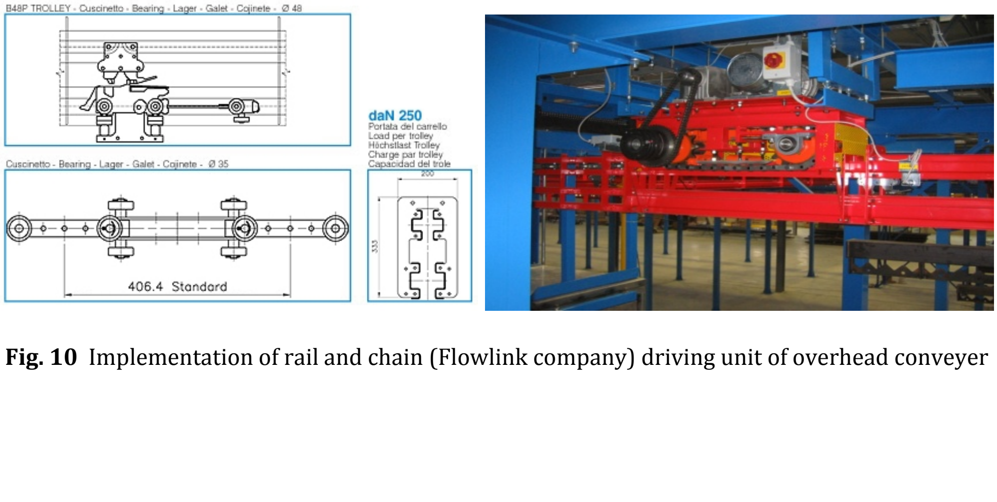


Fig. 10 Implementation of rail and chain (Flowlink company) driving unit of overhead conveyer

Fig. 11 Service robots – AGV with telescopic forks

Fig. 12 Service robots – AGV with telescopic forks

The company "Neobotix" produces service mobile platforms for automation of transport in production processes, and thus a service robot Mobile Manipulator MM-KR16 has been produced [18]. This service robot is configured so that the KUKA industrial robot with six axes is integrated with the mobile platform, as shown in Fig. 13.

The combination of a robotic arm and stable mobile platform enables automation of demanding decentralized tasks, which allows the robot to operate independently up to ten hours.

Service robots in „KIVA Systems" are presented in a bit different approach to business logistics: manufactured goods should not be placed in one specific location, but the pallets, crates and shipments are put on a special bench, and then collected and distributed by many mobile robots. As a result, any product is available to each of the workers at any time. These robotic transport units move with the help of a network of optical markers on the floor, and are in constant contact with the server which enables coordination. When the batteries are low, the transport unit is automatically placed on the charger located in the floor [23].

Automated vehicles greatly depend on the digital data related to tasks and environment in which they operate, which is in most cases very difficult to secure for small companies. Although automated vehicles have not reached the expected level, they can provide their users with safety improvements and business novelty.

Fig. 13 Service robots MM-KR 16 for automoton of manufacturing processes

Fig. 14 Service robots – KIVA systems [23]

Many manufacturers are trying to reduce the individual cost of automated vehicles by offering customers the option of renting these products. This is to reduce investment in business logistics, which in fact does not make any profit for a company. Also, when renting a robot, companies are not required to provide the complex data for robots that perform tasks.

3. Conclusion

By automating and constant modernization of production processes in all industries, the conditions for service robots application are becoming more demanding and complex. Due to the development of new methods and technologies, the use of new materials in all industrial production processes requires new product lines, where service robots are applied in maintenance of certain machines, the transport of materials, assembly and maintenance.

The number of service robots for professional use increases each year, so that about 5.000 units of service robots was applied in 2005, and 20.000 units in 2013. Service robots for logistics demonstrate a growing trend from year to year. Thus, we estimate that approximately 1.800 units of service robots for logistics will be installed in manufacturing facilities in the factories in 2014. Annual analysis of the application of service robots for professional use in 2013, for instance, indicates that 47 % is used for military purposes, 28 % field robots for e.g. agriculture, cattle breeding, etc., 10 % in logistics and 4 % for medicine.

Basic advantages of AGV service robots are: reduced labour costs, increased reliability and productivity, a reduction of goods damage – AGV has a controlled movement of the vehicle with an accuracy of ± 10 mm, increased safety and flexibility – unlike fixed (stationary) solutions for material handling, the path by which the AGV moves can be reprogrammed very easily. The investment in these robotic systems is cost-effective because the investment is repaid in 2-3 years, and such a system works for about 15 years, operating costs are around 2-4 % of year investment, operation availability is approximately 98.5 %, high productivity, optimized costs and processing time, applicable for all logistics systems.

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