Proceedings of the International MultiConference of Engineers and Computer Scientists 2011 Vol II,
IMECS 2011, March 16 - 18, 2011, Hong Kong

Development of a Micro Drive-Under Tractor - Research and Application

Lothar Schulze, Sebastian Behling, and Stefan Buhrs

Abstract—**The in-plant transport of goods is increasingly becoming automated. All reasons that argue for automation result in a better cost effectiveness.**

An extended percentage of the load units are lightweight and small goods that often occur either as single parts or as several articles in multiple small load carriers. Modern logistics concepts demand an efficient transport and the delivery within the intended time. To reduce the covered distance a flexible adjustment of the load capacity to single or accumulated transport is beneficial so that the vehicle can carry the required amount of goods without being oversized.

To fulfill these specifications the paper at hand presents the development and realization of a new type of Automated Guided Vehicle that is optimized for the transportation of small goods [1]. The construction is carried out as an omnidirectional drive-under tractor in compact dimensions. The main purpose of the vehicle is the automated towing of trailers. Additionally the transport of single small load carriers can be accomplished by using a lifting table. Therefore it is for the first possible time to use a towing and carrying vehicle with a variable load capacity. For the drive system Mecanum wheels are used to enable omnidirectional maneuverability.

Index Terms—**Automated Guided Vehicle, drive-under tractor, omnidirectional drive.**

I. Introduction

To cut costs of operation the production processes as well as the in-plant transportation of goods are often partly or completely automated in modern companies. It is a common goal to realize the non-profitable process of transportation with few employees over the shortest distance and time possible [2]. Since 75 % of the cost of operation using conventional industrial trucks are personnel costs [3], a comparison with an automated version is recommendable. Especially, for companies with a multi-shift operation, Automated Guided Vehicle Systems, short AGVS, prove their advantages [4].

During the last years an important market for AGVS was developed caused by the increasing trend of transporting small and light parts. An analysis from the database "Worldwide AGV-Systems of European Producers" shows that light transport goods up to 200 kg have significantly increased its ratio [5]. Industrial producers as well as mail order businesses contribute to this development.

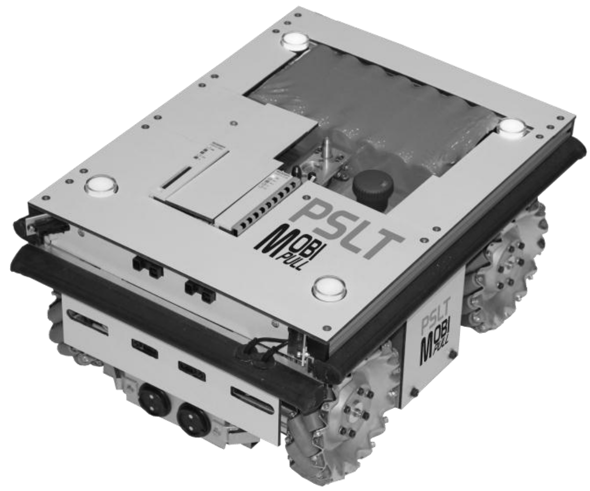

Fig. 1. Drive-under tractor

The presented concept supports the ongoing trend of modern transport controlling to arrange multiple transport patches with lesser volume and weight [6]. For the same total amount of transport goods more vehicles are needed that carry fewer articles each.

To fulfill these requirements, it was the aim to develop an Automated Guided Vehicle as a drive-under tractor in very compact dimensions (fig. 1). The development and realization of the vehicle are optimized for the transportation of small goods [7]. The primary goal is a small vehicle at low cost [8]. Furthermore the vehicle has to be able to transport variable amounts of containers in an economic way. An innovative approach is to accomplish accumulated and single transports by towing a trolley or by carrying one container with the same vehicle.

For the project the conceptual development of an AGV with the specifications for small goods was in the focus point. After completion of the theoretical planning the project was transferred to construction design. The test vehicle on the way to the final design was used to improve and validate the progress [9]. Both the technical functionality in all relevant situations and the implementation into the logistic chain were targeted.

The innovation project was supported by the German ministry of economics and technology BMWi with the program ZIM. The partners "E&K AUTOMATION GmbH", one of Europe's leading companies for AGVS, and the

Manuscript received December 28, 2010 to ICCA'11. This work was supported by the German ministry of economics and technology (BMWi) with the program ZIM.

Prof. Dr.-Ing. L. Schulze: Head of Department Planning and Controlling of Warehouse and Transport Systems (PSLT), Leibniz Universität Hannover, Germany (phone: +49(0)511/7624885; fax: +49(0)511/7623005; e-mail: schulze@pslt.uni-hannover.de).

Dipl.-Ing. S. Behling: Research assistant, Department Planning and Controlling of Warehouse and Transport Systems, Leibniz Universität Hannover, Germany (e-mail: behling@pslt.uni-hannover.de).

Dipl.-Ing S. Buhrs: Research assistant, Department Planning and Controlling of Warehouse and Transport Systems, Leibniz Universität Hannover, Germany (e-mail: buhrs@pslt.uni-hannover.de).

ISBN: 978-988-19251-2-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

"Department Planning and Controlling of Warehouse and Transport Systems", short PSLT, of the Leibniz Universität Hannover, Germany, have a cooperation to realize the project.

II. Development of the Tractor

The objective target of the project contains the demonstration of the technical operability. With a vehicle and multiple load handling devices the functionality of the concept is presented and tested.

Due to the restriction of the vehicle size many established components, like a wheel hub drive, cannot be used. Furthermore laser technology for navigation or safety systems has to be excluded because of its high costs. Therefore new components have to replace their functionality.

A requirement for the vehicle is an omnidirectional drive. As a result of its positive characteristics a Mecanum drive is selected. A Mecanum drive features the use of four independently and electrically driven Mecanum wheels [10]. A real time control system for rotation speed and direction is needed. The realized drive is assembled of the construction groups Mecanum wheels, drive section, suspension and brakes.

A Mecanum wheel comprises a wheel body and multiple not driven rollers that are mounted freely turnable in a 45° angle onto the body (fig. 2). Neighbouring wheels are set up inversely so that the rollers compose a 90° angle. All forces on the wheels are represented by a vector [11]. The direction of the vehicle is a result of the summation of the vectors. Since every wheel can be controlled individually the vectors can point in any direction on the ground. Therefore the vehicle has omnidirectional movement making it possible to rotate or translate without restrictions in the plane.

For a purposive movement every AGV needs a navigation system. After evaluating all the possible navigation technologies the magnet point navigation is found to be the best option. The route can be changed flexibly and without high cost. Another advantage is that the sensor is cheap and relatively small.

The route is established by a sequence of small cylindrical magnets that are embedded into the ground close to the surface. Under the vehicle perpendicular to the defined main direction is a sensor that detects the position of the magnets.

Fig. 2. Omnidirectional Mecanum wheel

Fig. 3. Connector for towing trolleys

By the sensor a value relatively to the horizontal distance between a vehicle reference point and the magnet axis is generated. The vehicle controller compares the measured position with the required position and consecutively corrects the vehicles motion. The width on which the sensor can detect magnets is 100 mm. If the vehicle deviates from the route more than the sensor width a magnet cannot be detected and a correction is not possible. Therefore this navigation method requires a good directional stability.

For the handling of loads two concepts are possible. During accumulated transports the vehicle uses a connector to tow a trolley. To carry a single container a lifting platform is used.

To be able to join, the connector on the vehicle has to have a matching part on the trolley. The connector comprises six elements (fig. 3).

A linear drive enables the vehicle to move the connector up and down for at most 50 mm at 7 mm/s. The drive has a maximal upward force of 1,300 N so that the lifting of single containers can be ensured. Within the linear drive there are two switches that control the starting and ending position of the linear motion.

Two connector pins are used to adjust forces and torques during the towing.

For the verification if a tolerable relative position between vehicle and trolley is given so that the connection can be initiated, two reflection photo sensors are mounted on the device. Under the trolley reflecting circular discs are attached in the corresponding position.

Another element is a push-button that signalizes the mechanical connection of the vehicle with the trolley. The operation distance can be set up by a cam switch. When the push-button is activated the upward motion of the linear drive is stopped even if the ending position of the gear has not been reached. By the use of the two switches and the push-button the necessary information for the automation of the connection process can be monitored and send to the vehicle controller.

On top of the common safety equipment [12] with four signal lamps and a manual emergency stop button, a detection system for obstacles in the area in front of the vehicle is installed. The measuring of distances to certain objects is an important factor for many applications of mobile robots. The assignment of the detection system as a safety

ISBN: 978-988-19251-2-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

device is the collision avoidance with obstacles on the track. In this project two independent systems are implemented.

As a tactile obstacle detection four pressure sensitive bumpers on all sides of the vehicle are utilised.

Additionally a module of contact-free infrared sensor arrays monitors different planes around the vehicle.

III. Towing of Trolleys

The main purpose of the vehicle is the towing of trolleys along a certain route. The trolleys can contain multiple small goods containers (fig 4.). The technology of the trolleys is adjusted to the logistic concept that is targeted in this project. Therefore an optimized use for every operating company can be established. To enable a completely automated process along the logistic chain an autonomous connection algorithm was developed. With the algorithm the vehicle can detect the position and angle of the trolley and navigates to the connection position without manual assistance.

The trolleys are designed with a construction kit from a supplier. Such systems allow a low priced solution that can be flexibly adjusted to the needed dimensions. The trolleys are comprised of the elements chassis, rollers, vehicle connector, control devices and the assembly for transport goods.

The setup of the rollers is elemental for the functionality of the trolley and is adapted to the demands of the application. As the main component rotatable and fixed supporting wheels can be used that are attached to the chassis.

The connector is needed for the mechanical contact between vehicle and trolley. Connectors for omnidirectional as well as regular movement have been realized. For omnidirectional towing the connector needs to be fixed relative to the trolley chassis.

The second option includes a rotatable connector under the trolley. Longitudinal and transverse forces can be transferred with this design. However it is not possible to adjust torques between the vehicle and the trolley. Due to the motion characteristics this option of the connector has to be mounted displaced in the direction of the towing movement. Otherwise the trolley would not steer into the desired direction since the unwanted torques cannot be absorbed by the vehicle. To enable the autonomous connection algorithm the connector needs to be aligned to the trolley. To assure this position two springs keep the connector in place during the connection process. The main advantage of the rotatable version is that the connection pins cannot be damaged by high torques induced by heavy weight trolleys during the towing movement along a curved trajectory or while rotating. Therefore this option allows bigger trolleys or heavier goods to be transported.

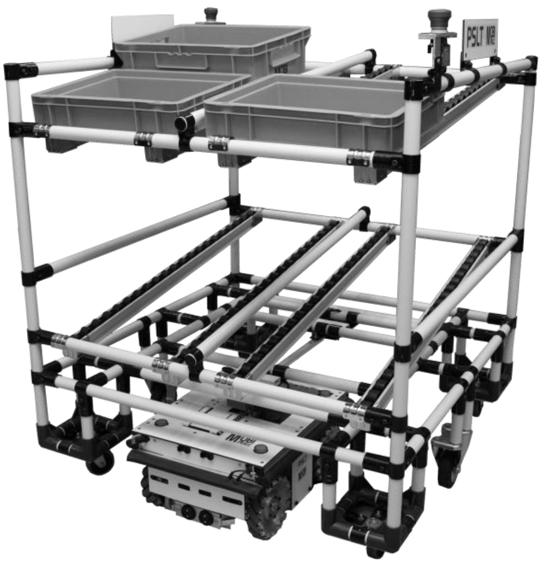

Fig. 4. Vehicle with trolley

Fig. 5. Vehicle with small goods container

On the trolley control devices can be used to start and stop the towing process. If a manual input is desired for the application the control devices have to be mounted in a reachable area since the vehicle cannot be manually accessed during the towing movement. To submit the state of the control device to the vehicle controller there are electric contacts in the connector.

IV. Transport of Small Goods Containers

For the transport of single small goods containers a lifting platform is used (fig. 5). The platform can automatically be picked up with the same connector used for the trolley.

During pickup the containers are located in a transfer station. The vehicle can drive into the station and under the container. In the second step the container is lifted from the station so that the vehicle can leave the station in four directions. Outside of the station and during the transport process the lifting platform should be lowered to improve the balance point.

The size and content of the small goods container can be chosen freely as long as the maximum carrying load of the vehicle is not exceeded. To exclude the risk of an uneven loaded container to tip over, the size of the lifting platform is adjusted to the container dimensions. Equally the width and length of the transfer station is related to the biggest container in use. Smaller containers can be transferred with the same station utilizing cantilever arms. The minimal size of the station is also dependent on the width of the vehicle.

In contrast to the trolley, a transfer station has a fixed location along the route so that the autonomous detection of position and angle doesn't have to be executed. Instead the magnet point navigation is used to position in the station. Dependent on the distance to the last reference point it can be

ISBN: 978-988-19251-2-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

reasonable to put one magnet directly under the determined transfer position for the vehicle. The vehicle can stop and adjust at that point for better accuracy. The correct alignment and existence of a small goods container can be verified with the implemented photo sensors. The containers are modified with a reflecting tape on the bottom at the expected position of the sensors.

V. Targeted Applications

For the available functions transport and providing of small goods, defined applications are targeted. Options for the implementation in a logistic chain as well as requirements of the technology are analysed. The following applications are found to be the most promising: Floor block storage, order picking, assembly and production.

The trolley can be used to build a very compact storage called floor block storage. Since the trolleys can be stored next to each other in an array on the floor with only very little space in between, the density of the goods is relatively high. An advantage of the omnidirectional drive is the possibility to access the array not only in a straight line as is commonly practiced but also transverse over different storage rows. Consequently trolleys inside of the array can be accessed without relocation of other units if the adjacent row is available.

Furthermore trolleys that block the way for a requested unit can be towed to a free position in a short time. A reorganization of the trolleys can be accomplished on a minimized area compared to common systems. All units of the floor block storage can be accessed with only one free position in the array. Any additional free positions lower the average time needed for transferring a trolley. With this concept the last in - first out principle doesn’t have to be used necessarily.

Another advantage is that the vehicle can take the direct way to the required position. This is accomplished by driving under the trolleys that are currently not in use. Due to the shorter distance time and energy is saved by this concept.

The use of the drive-under tractor also greatly benefits for order picking applications with a dynamic allocation and manual picking [13]. With this concept the dynamic allocation has the advantage that the order picker can stay in one position and the vehicles supply the required goods. The goods are stored in multiple containers within a trolley. Therefore one trolley can contain various articles of small goods dependent on the size and weight. If one of the articles is needed for a picking order the vehicle will bring the trolley to the picking station with the designated picker. The picking can be executed directly into another trolley so that the material flow system is consistent.

The drive-under tractor supports the requirements of fast order picking since the utilization of the same trolley for storing, transportation, supply and order picking many manual transfer operations can be avoided. To produce the necessary speed of the material flow numerous vehicles and trolleys can be used simultaneously.

The concept is additionally applicable for assembly operations with the two principles as a taxi or as a mobile work bench. The taxi principle is commonly used for production processes, too. Transport orders are generated by a supervising control system and executed by the vehicles that transfer the goods from a given source to the demanded destination [14].

In the principle of the mobile work bench the vehicles tow trolleys that are specially designed for the assembly operation (fig. 7). Since the vehicle stays connected to the trolley while the assembly is in process at least the same number of vehicles is needed as assembly stations exist. The vehicles can connect the different stations in a straight line or in complex routes. The sequence of the stations is typically constant. However the automated tractors can also flexibly change the sequence if a special operation is necessary. For example an assembly unit that needs rework can be towed to a repair station and back into line after the rework is done. Another advantage is that the assembly sequence is not stopped if one vehicle has a malfunction. Instead the affected vehicle is pulled aside and another tractor can take over.

Once the assembly worker has finished his process, a signal is sent to the vehicle controller. Afterward the tractor will bring the trolley to the next station in the sequence given by the material flow system. After all necessary stations have been accomplished the trolley is brought to the defined destination and stored there.

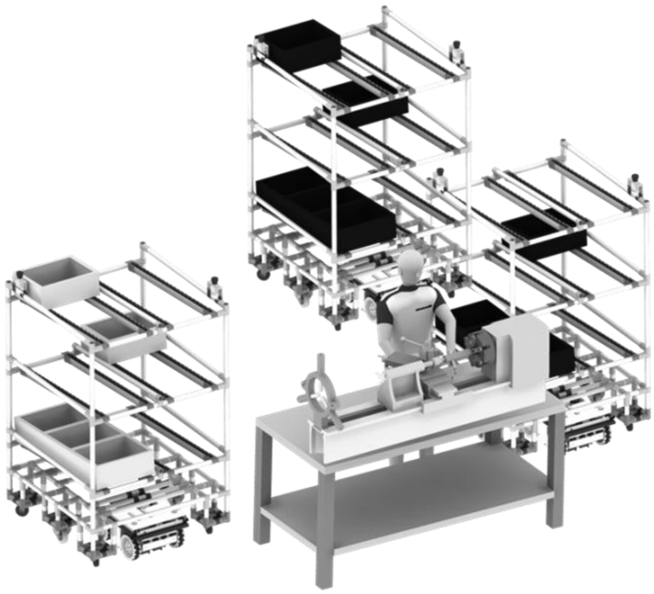

Fig. 6. Production application

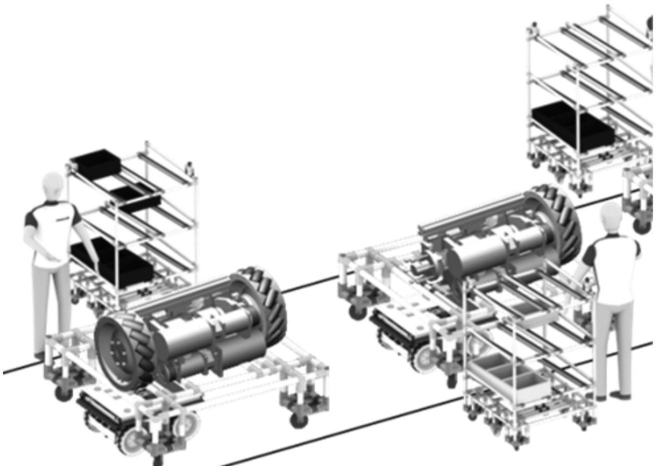

Fig. 7. Line assembly application

VI. Conclusion

The paper presents the development and realization of a new type of Automated Guided Vehicle that is optimized for the transportation of small goods. The omnidirectional drive-under tractor has the main purpose to tow trailers. Additionally the transport of single small load carriers can be accomplished by using a lifting table. The concept features an adaption to variable load capacities.

The accomplished prototype is smaller than any vehicle that is available at the market in Europe. As a result the needed space for logistic operations, like the width of the track and stations, can be minimized compared to common solutions. Especially the height of the vehicle is very low so that an efficient use as a drive-under tractor is possible. Along with the compact dimensions of the vehicle a relatively small battery capacity is included. The nickel metal hydride battery has shown a total driving time of 3.8 h during laboratory tests.

A real time vehicle controller enables the synchronization of the four drives. The movement along the route is achieved by the combination of an odometer and a magnet point navigation. Cylindrical magnets in the floor are used every 0.5 m as a reference point for the navigation sensor.

To raise the level of automation an autonomous connection process has been implemented. It enables the vehicle to find the connection point for trolleys that have not been positioned exactly. Two photo sensors and a reflective material under the trolley are used for the algorithm. The innovative procedure is low cost and features a robust functionality.

With the realized prototype the functionality of the development can be verified. The methods used for navigation and load handling demonstrate a good performance. The results show an efficient approach for an automated transportation of trailers and small load carriers. The prototype proves to be an important base for the conversion into an industrial version.

References

[1] S. Behling, “Development of an Automated Omnidirectional Micro Drive-Under Tractor”, *Materialfluss und Logistiksysteme*, vol. 7, Editor: Schulze L., Aachen, Germany: Shaker Verlag, 2011.
[2] T. T. Allen, “How new technology is impacting the specification and performance of AGV Systems”, *in Progress in Material Handling Practice: 2001*, Charlotte (NC), USA: The Material Handling Institute.
[3] H. Martin, *Transport- und Lagerlogistik*, 7th edition, Wiesbaden, Germany: Vieweg+Teubner, GWV Fachverlage GmbH, 2009.
[4] L. Schulze, “Planning and Operating - Automated Guided Vehicle Systems as Efficiency Driver, in *Proc. of the AGVS-Conference 2008*, Hannover, Germany.
[5] L. Schulze, S. Behling, S. Buhrs, “People Following with Automated Guided Vehicles - Research and Application”, in *Proc. of International Multi Conference of Engineers and Computer Scientists*, Hong Kong, China, 2009, pp. 1.310-1.314.
[6] L. Schulze, and L. D. Zhao, “Worldwide Development and Application of Automated Guided Vehicle Systems”, in *Proc. of the International Conference Greater China Supply Chain and Logistics Conference*, Hong Kong , 2006, pp. 130-137.
[7] K. Furmans, M. Schleyer, and F. Schönung, “A Case for Material Handling Systems, Specialized on Handling Small Quantities”, in *Proc. of 10. International Material Handling Research Colloquium*, Dortmund, Germany, 2008, pp. 185-197.
[8] L. Schulze, S. Behling, and S. Buhrs, “Automated Guided Vehicle Systems: a Driver for Increased Business Performance”, in *Proc. of International Multi Conference of Engineers and Computer Scientists 2008*, Hong Kong, pp. 1275-1280.
[9] B. Trebilcock, “The Materials Handling of Tomorrow”, *Modern Materials Handling*, vol. 63, no. 5, pp. 26-27, 2008.
[10] N. Tlale, M. de Villiers, “Kinematics and Dynamics Modelling of a Mecanum Wheeled Mobile Platform”, in *Proc. of 15th International conference on Mechatronics and Machine Vision in Practice (M2VIP08)*, Auckland, New Zealand, 2008, pp. 657-662.
[11] P. Viboonchaicheep, A. Shimada, Y. Kosaka, “Position Rectification Control for Mecanum Wheeled Omni-directional Vehicles”, in *Proc. of the 29th Annual Conference of the IEEE Industrial Electronics Society (IECON '03)*, Roanoke, USA, 2003, pp. 854-859.
[12] DIN EN 1525, Safety of industrial trucks - Driverless Trucks and their Systems. Berlin, Germany: Beuth-Verlag, 12.1997.
[13] I. Malton, “Efficient Order Picking - The Need For it and Possible Solutions”, in *Proc. of the 11th International Conference in Warehousing*, Helsinky, Finland, 1991.
[14] L. Schulze, S. Behling, and S. Buhrs, “Intelligent Transportation Sytems: Automated Guided Vehicle Systems in Changing Logistics Environments”, *in AIP Conference Proceedings Volume 1019: 1st Mediterranean Conference on Intelligent Systems and Automation (CISA 08)*, Annaba, Algeria, 2008, pp. 53-58.

ISBN: 978-988-19251-2-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)