

Automatic Horizontal Container Transshipment System

Richard Hueppi, Einar Nielsen, Christian Neuweiler and Charles Brom

Abstract—To reduce the ever rising road freight traffic, container transport by railway has to be promoted. Since nowadays the intermodal transport of freight containers with railway and trucks is only lucrative on large terminals, new small economical terminals have to be invented.

To save costs the here introduced automatic container transshipment system can be operated by the truck driver himself. The horizontal construction of the system allows transferring the container under live catenary. Due to the fact that extra operating personal is not needed and that the system can handle standard containers without any modifications at the containers, at the trucks or at the railway wagons, the terminal can be operated economically.

This paper first shows the economical aspects of such a small terminal. Then the construction of the machine is explained with focus on the laser scanner sensor system to detect the container fittings for the automatic gripping of the containers. Further the paper describes the control scheme of some of the mechanically coupled electrical actuators needed to run the machine.

Index Terms—terminal automation, container handling, 3d pattern recognition, decentralized controller design.

I. INTRODUCTION

DUE to the rising volume in road freight traffic, intermodal transport of freight containers has to be promoted. Running a conventional terminal for transferring containers between railway and trucks is only profitable on large terminals with a huge amount of transfers per day. To run a smaller terminal with a few transfers per day only, the terminal operating costs have to be reduced. The operations for transferring containers are normally performed by a well trained operator. These have to be automated to enable the truck driver to handle the container transfer by himself. In order to not extra adapt the environment of the mostly

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Richard Hueppi (phone: +41-52-267-78-33, fax: +41-52-268-78-33, e-mail: richard.hueppi@zhwin.ch) and Einar Nielsen (e-mail: einar.nielsen@zhwin.ch) are with the Zurich University of Applied Sciences, Winterthur (Switzerland), Institute of Mechatronic Systems (Prof. Charles Brom), Christian Neuweiler (e-mail: c.neuweiler@neuweiler-ag.ch) is the CEO of the Technology Company Neuweiler AG, Kreuzlingen, Switzerland.

electrical driven railway the transferring machine has to be constructed to handle the containers below the live catenary.

With these conditions, the market has been analyzed to find out, under which circumstances and configuration such a small terminal can be operated profitable. The two Swiss technology companies Neuweiler AG and Tuchs Schmid AG and the Zurich University of Applied Science (ZHAW) met the challenge to develop such a small terminal (Fig. 1) called NETHS (Neuweiler Tuchs Schmid Horizontal System).



Fig. 1. The container manipulator NETHS handling a swap body container

II. MARKET

A. Intermodal Transport

Intermodal transport has been applied in different techniques since the early sixties: In intercontinental transport with cranable ISO containers, in European transport normally with swap bodies or semi-trailers. The techniques are basically distinctive in accompanied and unaccompanied traffic. In the case of accompanied traffic, also known under the term “Rolling Highway”, road vehicles and trailers are transported on special rail cars. The driver rides along in the train from start to destination.

On unaccompanied traffic merely the containers are

transported by rail. Different technologies offer the customer many possibilities to transport freight with standardized ISO or swap bodies. The container transfer can be performed vertically or horizontally from the road to the rail or vice versa. The technologies for vertical transshipment by means of crane or reach stacker are suitable for larger transshipment capacities. In the last years this area has been researched intensively and new, innovative systems such as ACTS [1], Nick [2], Modalohr [3] etc. established themselves in special market segments.

To date no system exists, in which ISO containers and swap bodies can be moved without additional modifications within the defined standards.

B. Market Trends

The transport volume over short and longer distances is constantly rising. In particular over short distances solutions are being sought, which can transfer freight from the road onto rail. ACTS has shown in commercial applications that, with feed distances under 200 km, combined traffic can successfully be operated. With the development of NETHS one hopes to achieve similar success in the handling of standard containers.

Today transshipment technologies are sought, by which the following criteria in a port portfolio of the combined goods traffic can satisfy

- transshipment of standard containers (ISO/swap bodies)
- minimum investment in infrastructure
- minimum space requirement
- transshipment under the rail contact wire
- neither special nor high-tech training required for the operation of the loading equipment
- capacities between 10 - 80 transshipments / day

NETHS fulfills all the points mentioned above. In particular in positioning and controlling of the loading equipment, newest technologies are applied. Target is a high quality transshipment of the load unit from the rail to the road (and vice versa) performed by the truck driver with the highest in safety standards.

C. Market Potential of NETHS

The emphasis of NETHS is placed on the European market. Potential customers are the customers such as rail companies and operators of the intermodal transport, supplementing their existing technologies (crane, reach stacker) with NETHS. With the continual liberalization of the market potential new customer groups are worldwide:

- municipalities
- post office and express delivery services
- production companies (with rail siding)
- transport companies

III. MODE OF OPERATION

The following section describes the mode of operation of the container manipulator NETHS. It is build up of two identical vehicles which are moving on rails in parallel between railway and road. The container transshipment from truck to train is accomplished in the following steps:

1. The truck driver parks the truck parallel to the terminal close to the position of the empty railway wagon.
2. The truck driver gets into the terminal control cabin and enters the container type into the control computer. The two vehicles of the NETHS machine then move automatically to the correct distance to each other.
3. The truck driver controls the machine by joystick to move it near to the pick up position (+/- 0.5 meters).
4. The truck driver starts the automatic load up procedure.
5. In order to detect the container fittings, the system scans the container with a laser scanner while moving along the container.
6. The system grips the container and moves it in its middle position.
7. The truck driver moves the machine per joystick near to the depose position (+/- 0.5 meters).
8. The truck driver starts the automatic depose procedure.
9. The system moves along the railway wagon scanning it with a laser scanner to detect the pins.
10. The system places the container on the railway wagon.
11. The system moves back to its park position.



Fig. 2. The container fittings at an ISO (left) and swap body container

For this task the truck driver does not need any specialized knowledge.

The steps for finding the gripping and depose positions, which are usually performed by a well trained operator, are done automatically by the machine itself.

The machine is capable to transfer two different types of containers: The ISO standard container and the swap body container. ISO containers are gripped by a twist-lock gripping system on the top side and swap body containers are gripped on the side by gripping at the lower edge. The gripping positions of both types of containers are identified by the standardized fittings (Fig. 2). The coordinates of these fittings are searched by the laser scanning system.

For gripping, two different mechanisms are available: Two bars with two twist locks on each side moved by a chain drive for the ISO containers and four scissor mechanisms to grip the swap body containers (Fig. 3).



Fig. 3. Twist lock (at the bar) and scissor gripper

IV. SYSTEM DESCRIPTION

Each of the two identical vehicles contains seven electrical servo drives. Two drives are moving the vehicle on the rails, one is for moving the telescope axis (the motion orthogonal to the vehicle movement), two are lifting the twist lock bars and two are moving the scissors. All fourteen drives are controlled by frequency converters, each of them having own intelligence. They are all connected to an ARCNET [4] real time network with 2.5 MBit per second data rate. This enables the machine to perform coupled movements of drives, e.g. used for the synchronized traction of the four wheels of the two vehicles while transporting a container.

The distance between the two vehicles is measured by a laser distance sensor. The design of the control system for vehicle positioning allows a later integration of a navigation system (e.g. GPS). With the help of an absolute positioning, future systems will be able to transship whole freight trains fully automated.

The master program is running on soft PLC which contains a touch screen for user interaction. It communicates with the frequency converters over an ARCNET bus. Neither the soft PLC nor the link to the ARCNET bus is real-time capable. Therefore controllers and path planners are implemented on the frequency converter level. All the other peripherals are controlled by the PLC over a ProfiBus [5] network.

V. AUTOMATED PICK AND PLACE OF THE CONTAINER

To keep containers in position, trucks and railway wagons are equipped with pins. Due to the lack of overview the

gripping of the container and its placement on the pins are the most difficult tasks of the transshipment. The navigation of the twist locks into the container fittings and to pose the container on the pins needs a well trained operator. To relieve the truck driver from these tasks, they have to be performed automatically. To realize this automation, the fittings and the pins have to be detected. Two different solutions were examined: 3d stereo vision system and laser scanner sensor.

A. Vision System

The 3D vision system is build up with two high sensitive surveillance cameras (Fig. 4). These can handle the high range of light intensity between spotlight in the night and bright sun shine at day. Infrared filters, polarization filters and artificial light sources are used to reduce the influence of the daylight.

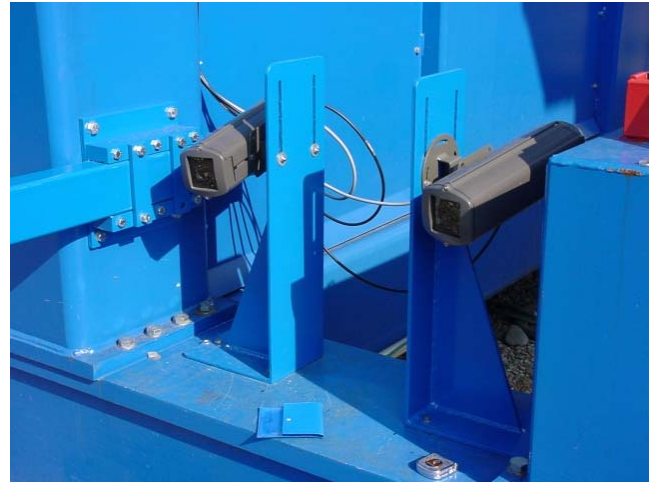


Fig. 4. The cameras of the vision system

The powerful software tool “model finder” which is part of software package matrox inspector [6] is used to search for the fitting in the camera pictures. In ideal weather conditions the recognition rate of the container fittings was only about 80% during the examination period. Bad weather would even lower this result. On top a complex calibration procedure is necessary to obtain sufficient accurate target positions. Thus this solution is not suitable.

B. Laser Scanner

The laser scanner measures only two dimensions. In order to get a 3d data set of the container area where the fitting is searched, it has to be moved along the container by moving the vehicle on the rail (Fig. 5).

The SICK LMS220 laser scanner [7] delivers 18 scans per second over an angle of 100 degrees with a resolution of a quarter degree and an accuracy of ca. 15 mm.

The sensor is moved along the container for 1 m with a speed of 180 mm/s. Thus a data set of 40000 (100*400) measurements is produced (Fig. 6).

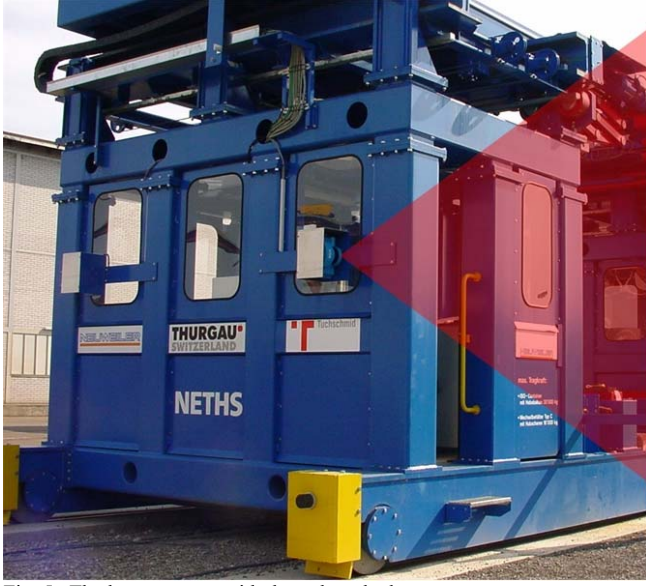


Fig. 5. The laser scanner with the red marked measurement range

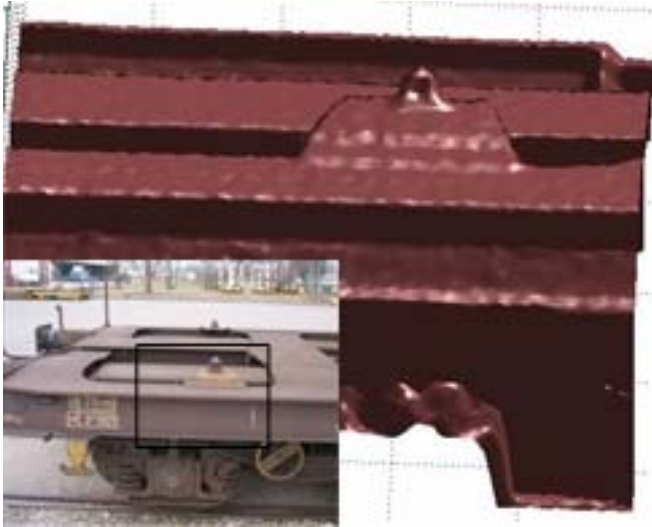


Fig. 6. An empty railway wagon (small picture) and the scanned 3d data

A 3d pattern matching algorithm searches through this data set for a predefined pattern of the fitting (or pin). The search pattern is defined by a subset of the measured data. This subset is the region which is the standardized part of the container (fitting), truck or railway wagon (pin). Several such subsets are averaged for the finally used search pattern.

For every x/y -position the search pattern sp is laid over the scanned data sd and the normalized cross correlation is calculated. In order not to give outlier measurements to much weight, the median value is used to calculate the average values \overline{sd} and \overline{sp} . The normalized cross correlation ncc at this x/y position is then calculated as defined in (1).

$$ncc_{x,y} = \frac{\sum_{y_s=0}^{y_s=y_{sp}} \sum_{x_s=0}^{x_s=x_{sp}} \left(sd_{\frac{y_{sp}-y_s}{2}, \frac{x_{sp}-x_s}{2}} - \overline{sd}_{x,y} \right) \cdot (sp_{x_s,y_s} - \overline{sp})}{\sqrt{\sum_{y_s=0}^{y_s=y_{sp}} \sum_{x_s=0}^{x_s=x_{sp}} \left(sd_{\frac{y_{sp}-y_s}{2}, \frac{x_{sp}-x_s}{2}} - \overline{sd}_{x,y} \right)^2 \cdot \sum_{y_s=0}^{y_s=y_{sp}} \sum_{x_s=0}^{x_s=x_{sp}} (sp_{x_s,y_s} - \overline{sp})^2}} \quad (1)$$

The plot in Fig. 7 shows the result matrix ncc of a successfully found railway wagon pin. Near the matching position the correlations build a peak with the highest correlation value.

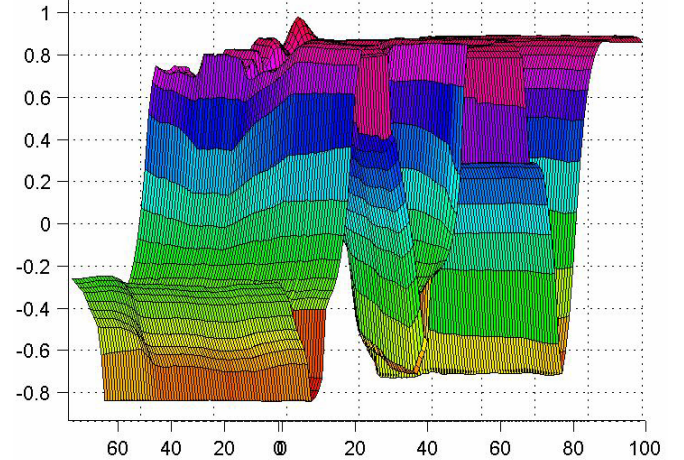


Fig. 7. The correlation matrix ncc with a peak at the position where the pattern has matched the scanned data (correlation with 97%)

If there is a peak found with a sufficient correlation, the coordinates of the fitting (or pin) are calculated and transmitted to the machine controller.

Due to a lot of different standards of truck- or railway wagon pins, a search pattern has to be defined for each of them. The algorithm then searches consecutively with all search patterns until one is matching.

This algorithm turned out to be sufficient to reach a recognition rate higher than 99% for the tested containers, trucks and rail wagons.

VI. CONTROLLER ASPECTS

In an automated operation mode a high control quality for the positioning is needed. After detecting the gripping points by the sensor system, the target position has to be reached with an accuracy of 10-20 mm.

Each of the two vehicles use two drives for travelling on the rails. The distance measurement between the two vehicles is done by a laser sensor (Fig. 8). Depending on the traveled distance, the position information of the vehicles includes a slippage. This leads to a contradiction between the distance calculated from the encoder values of the two vehicles (encoder distance d_{Pos}) and the measured value of the laser sensor (laser distance d_{Laser}). These facts had to be taken into account for the design of an appropriate controller.

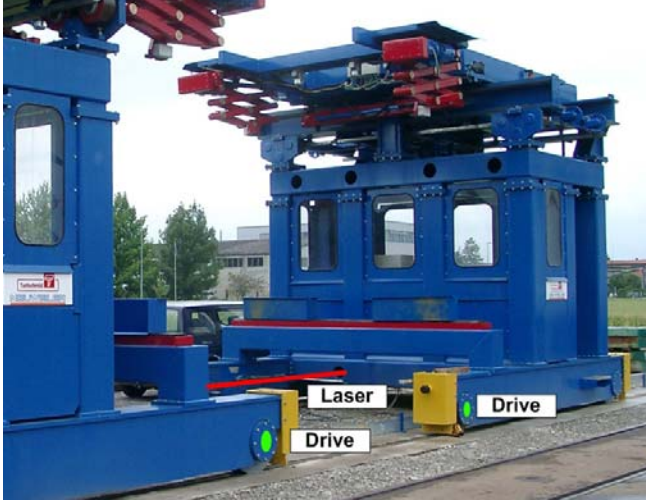


Fig. 8. Travelling drives and laser sensor of NETHS

A. Master Slave Control Concept

Commonly, if several actuators have to move the same part, a master-slave control concept is applied. In a first approach, this classical concept was realised as follows:

- Speed control of a master drive
- Actual current value of master drive as current set point for the slave drive
- Superposed distance controller to solve the contradiction between the encoder distance and the laser value
- Mechanical construction with elasticity to reduce shocks

There where in practise several weak points with this solution. If the load is extended and a drive-wheel is partly unloaded the wheel slips on the rail.

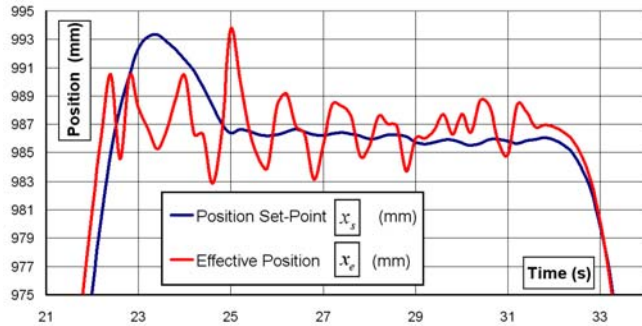


Fig. 9. Positioning with Master-Slave Control Concept, distance 1000 mm

If the slipping wheel is at the master drive, the master controller reduces the current to hold the set speed. At the same time the current in the slave drive is reduced with the effect that there is no more torque to move the vehicle.

Another difficulty is the elastic construction of the drive mounting, which makes it impossible to control the position stiff and accurate. Moreover, stiff control settings cannot be applied by using master-slave control since the sec-

ond actuator is far away from the position sensor of the first drive, which leads to instability by collocation problems. Those effects are well known in robotics science [8, 9].

In Fig. 9 the positioning behaviour of the first control concept is shown. The amplitudes of the vibrations are approximately 5 mm. The set point is calculated by adding the output of the trajectory generator and the superposed distance controller. It is obvious, how the dynamical behaviour of the overall system (vehicle with all drives) affects the control of the drives.

B. Decentralised Control Concept

To allow a stiffer control, in a first step the elasticity of all drives had to be reduced. Because of the gliding problem caused by the extended load, the master-slave concept had to be given up.

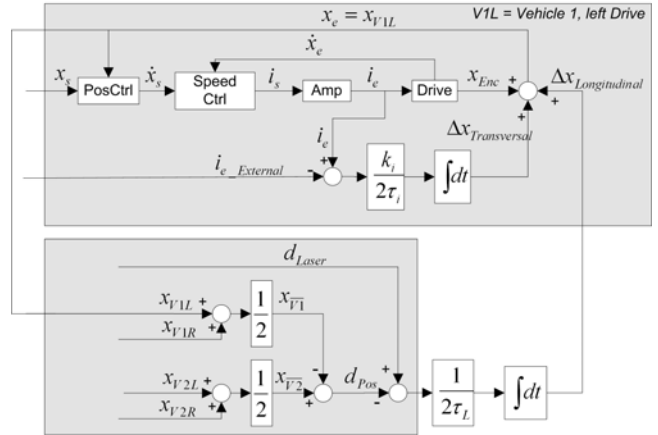


Fig. 10. Control diagram for the left drive of vehicle 1

A very different approach was taken to realize the function of a limited slip differential in software (Fig. 10). This was done by

- Independent position controllers on standalone servo drives for every wheel
- Synchronous started independent trajectory-generators
- Compensation of position differences between the drives with low bandwidth (differential function)
- Instead of using a superposed distance controller the encoder position of each wheel is corrected by adding correction values for slipping errors

There are two kind of slipping effects which have to be taken into account. One is the distance error between the drives of one vehicle since boot-up of the system, here called Transversal Slipping ($\Delta x_{Transversal}$). The second is the distance error between the positions of the vehicles since boot-up of the system, here called Longitudinal Slipping ($\Delta x_{Longitudinal}$). Transversal Slipping can be calculated from asymmetry of the current load ($i_e - i_{e_External}$) while

Longitudinal Slipping can be calculated from the difference between the distance calculated from position values (d_{Pos}) and the laser measurement (d_{Laser}).

The position of a wheel (x_e) is calculated by adding the Transversal Slipping ($\Delta x_{Transversal}$) and Longitudinal Slipping ($\Delta x_{Longitudinal}$) to the encoder positions (x_{Enc}). While the encoder position is taken into account by the position controller with high bandwidth, Transversal Slipping and Longitudinal Slipping are only adapted very slowly and with very low bandwidth.

C. Results

In Fig. 11 the positioning behaviour of the decentralised control concept is shown.

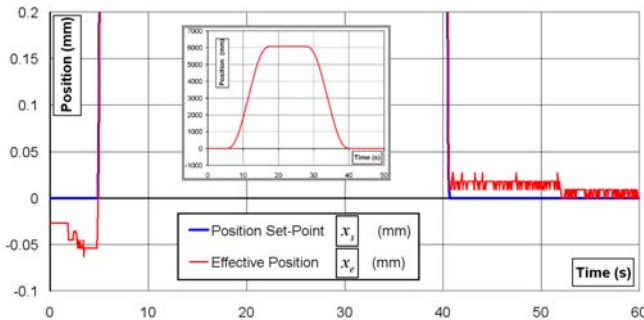


Fig. 11. Positioning with Decentralised Controller over a distance of 6000 mm. Positioning error in the range of 0.02 mm!

The control error is approximately 0.02 mm. This proves the stiffness and quality of the controlled position reached by using independent position control of the drives. The dynamical behaviour of the overall system (vehicle with all drives) does not affect the control of the drives any more.

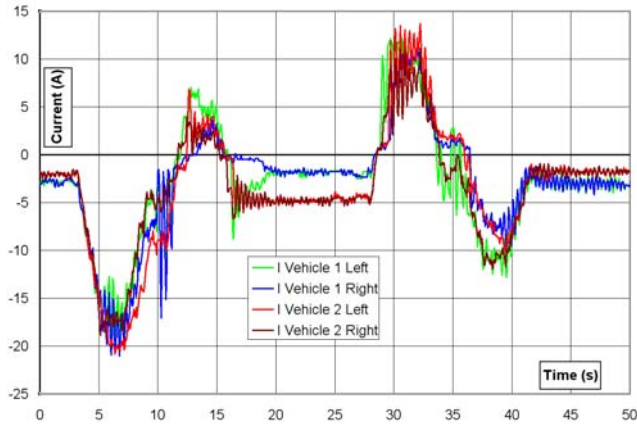


Fig. 12. Currents of the four involved drives

In Fig. 12 the currents of the four involved drives are shown. While the currents of the drives of a vehicle adapt to the same value (green to blue and red to brown), the average current of the vehicles are not the same (green/blue and red/brown), since the inclination of the track is not exactly the same.

The remaining slip is around 1 mm per bi-directional 5m travel which is not even 1 m per day!

In the presented concept one problem has to be seriously taken into account. The timing between the distributed position set points has to be accurate. The main problem is to start the path generators at the same time. The delay times of the ARCNET-bus and the delay resulting out of the asynchronous clock of the distributed controller tasks lead together to a not negligible delay of about 7 ms. At a speed of 1m/s this leads nevertheless to a position difference of 7 mm.

VII. CONCLUSION

The detection of the container fittings or the pins on the railway wagon or trucks is basically feasible with a laser scanner sensor or a 3d vision system. The laser scanner sensor data were more robust against environment disturbances than those of the vision system. For this reason, we successfully implemented the solution with the laser scanner. With this technique we achieved a recognition rate of over 99%.

Using a pragmatic combination of industrial available drives and a smart, generalized distributed controller concept, a solution has been developed, with a much higher robustness and accuracy than in a master slave configuration. The vehicles can now be moved with the necessary precision to the target position. Furthermore an asymmetry in load does not lead to wheel spin.

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