Automation and Steering of Vehicles in Ports

1 Abstract

The introduction of containers was an essential move towards the automation in ports. In order to be able to manage the ever increasing volume of container movements, it will be necessary to further automate the container handling in the future. This requires new sensors for obstacle and object recognition, as well as for track guidance.

This article describes the available technologies, successful projects of port automation and gives an outlook to the near future of process automation.

2 Human beings are intelligent creatures, but...

Humans are extremely intelligent creatures. They recognize complex structures and are capable of reacting to fast changing conditions. Their ability of optical and acoustical observation, e.g. in traffic, are enormous.

However: Unfortunately, a human being tires fast and is unreliable in his reactions. Almost every traffic accident is caused by human error. Its origin often lays within the physical and mental condition of the individual. Generally, a human being is not made for monotonous, repetitive tasks that are to be carried out fast, exact and reliable. This is a field that is looking for automation. Steering cranes and other vehicles in ports are a part of this field.

3 Modern machines and automates are more reliable than workers

During the last 10 years, automation engineering has made considerable progress. This is especially true for actuated and sensor engineering computer and communication technology, as well as specialized electronics. Nowadays components and systems capable of carrying out port specific tasks are more reliable and have a lower cost level. Depending on the level of automation, it is possible to do completely without an operator or at least ease the workload of the operator. The tasks are more or less carried out without errors and under favorable conditions, this means:

- less or no costs for personnel
- utmost reliability in container tracking etc. (EDI)
- optimum and careful handling of vehicle and load
- less energy consumption, less wear and tear
- no accidents, more precise vehicle navigation
- faster vehicle navigation, faster transshipment
- no stress

Of course, it is not (yet) possible to automate every single task, but with increasing transport volume, there is an increasing pressure for automation.

4 Cost – Benefit – Analysis:

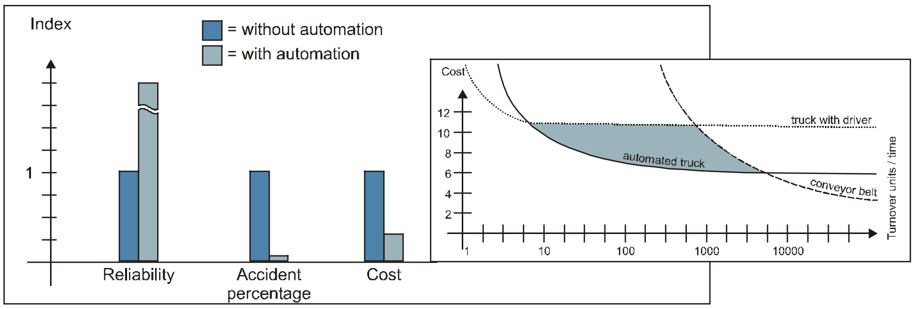


Figure 1 Cost – Benefit – Analysis

For a transportation job, that is to be carried out only once in a while (e.g. once a day) it is still sensible to use a driver-guided vehicle. But for a transportation pattern that is repeated, e.g. 100 times per day, an automatically navigated vehicle will pay off. For this calculation, it is, however, necessary to consider the cost for labor, as well as the technical and organizational circumstances for each project.

For continuous mass transport (e.g. 10.000 units per day, bulk cargo, fluids and gases) conveyor belts or pump systems are usually the appropriate form of transportation.

5 Automation

For industry and ports, a form of partial automation has become established. Actuators and sensors are used for operator support. This is the case with drives, anti-sway-systems, positioning systems, object detection and electronic data interchange (EDI).

It is to be determined for each project, whether it is possible to set up a completely driverless and operatorless system. Fully automated systems are costly, but for the appropriate application they can have considerable advantages (see above). The quality of the sensors have been improved to such a degree, that their performance sometimes exceeds the human abilities. However, improvements, especially in the field of optical obstacle detection, are still possible and necessary.

The task of automatic positioning and steering of vehicles in general and container cranes especially, has proven to be well solved. The only problem still is higher velocity, especially, if there is the danger of having people suddenly standing in the way.

There is still the endeavor to try running industrial processes with even less personnel. Automation proceeds while workers are asking for more challenging jobs. Monotonous tasks are to be carried out by machines.

6 Sensors

In order to ensure reliable function of the system, it is essential to use the most suitable sensor technology as applicable. It is common knowledge, that optical systems with high capacity computers are very reasonable in pricing while highly reliable in their operation, as long as they are used in extremely clean environments (indoor). They are especially well suited for complex applications. Unfortunately, they fail if confronted with dirt, snow, rain, etc. In these cases they need at least special (cleaning) care.

Inductive sensors are usually more rugged, but they are limited in their range.

6.1 One - dimensional Sensors

For quite some time already, wheel encoders, magnetic reference marks and distance measuring laser scanners have been used for the position determination of vehicles or machines along rails. It is useful to combine different sensor systems in order to avoid some of their disadvantages:

- wheel encoders are sensitive in general and especially with regards to slipping
- magnetic marks are not absolutely coded
- lasers are easily effected by dust, rain, snow, etc.

Transponders or tags as they have been available for approx. 10 years now, have significant advantages.

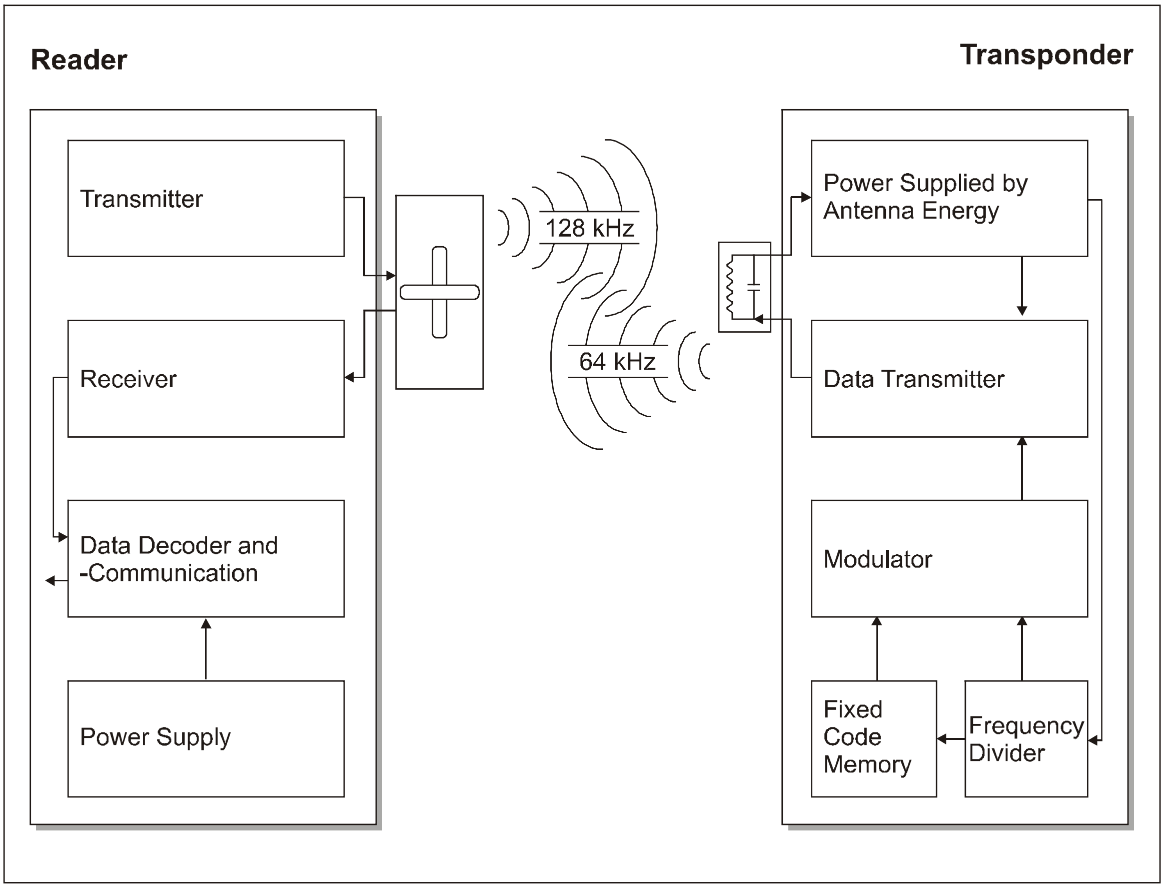


Figure 2 Outline: Principle of Transponder Function

The system basically consist of two components:

1. **The Transponder** (code carrying) is installed within the runway, near the rail or on an object. It is not battery powered and protected from damaging environmental influences by an airsealed casing. Transponders are completely maintenance free and have an almost unlimited life. Their permanently programmed code is unique. There are various models and configurations of transponders available, all suited for different applications.

2. **The Reader** supplies the transponder with energy by emitting an electromagnetic field. In return the transponder ‘transmits’ its code, which is then ‘received’ and processed by the reader. This contactless communication between the transponder and its reader is an inductive effect using a low frequency magnetic field.

Since the mid 90’s transponders have also been used for positioning in ports, because a special antenna reader enables us to register the position of the transponder at a distance of up to 80 mm with an accuracy of approximately 1 - 5 mm. Larger reading distances (200 mm) decrease the positioning accuracy to approximately 5 - 20 mm. The accuracy of each measurement also depends upon the environment. When installing transponders, it is essential to maintain a certain distance to large metal constructions and steel reinforcements in the ground.

Antenna readers of a length of up to 1 m enable the determination of the postion of a railbound vehicle at any time, provided, that the transponder spacing is ≤ 1 m. This ensures that at any time there is at least one transponder within the antenna readers field of view.

This system is extremely accurate and does not show the disadvantages of optical systems. It is even possible to varnish or concrete these systems without effect on their performance.

A transponder positioning system is also suitable for synchronization control of very large cranes, such as goliath cranes (see below). Here it is essential to install transponders on both sides of the rails. With one antenna on each side of the crane, the simultaneous crossing of a transponder on each side is registered. In case the spacing between the transponders is rather large (e.g. 3 m), it is recommended to use wheel encoders for in-between positioning, as described above. The first systems of this kind were commissioned in 1996.

6.2 Two - dimensional Positioning/ Navigation and Vehicle Guidance

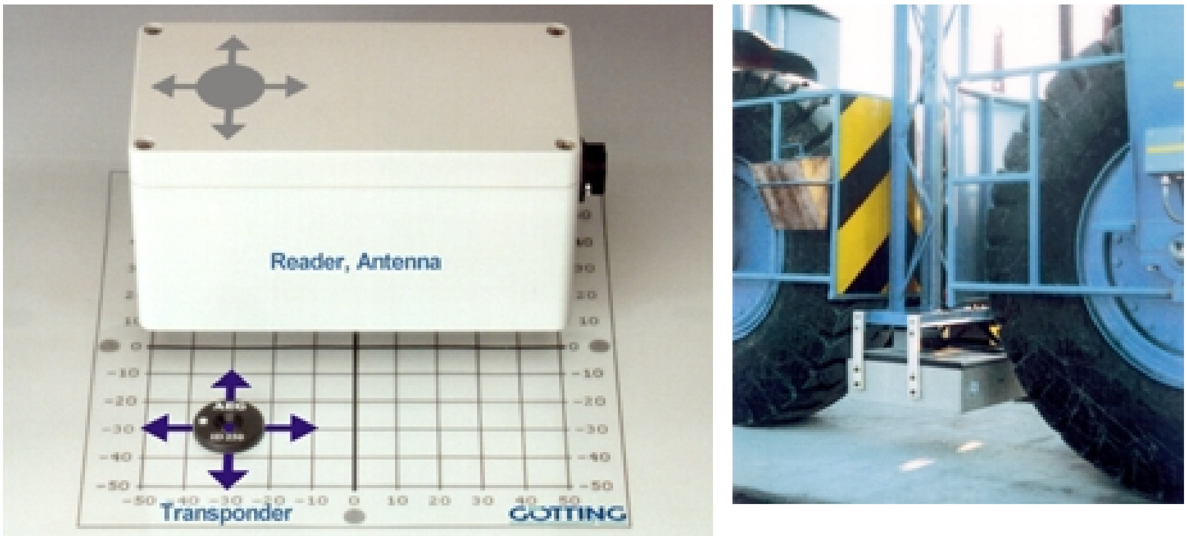


Figure 3 Transponder Positioning, crane mounted antenna

For more than 20 years now, inductive guide wires or optical lines (optical contrast) have been used for automatic guidance of industrial and port vehicles, e.g. RTGs, etc. This system is either used for the support of the driver or for driverless so-called Automated Guided Vehicles (AGVs). Nowadays, there are approximately 20.000 AGVs in operation in industrial applications. For AGVs, usually additional sensors, e.g. wheel encoders, are used for the support of the guidance system.

Optical systems are often not suitable for port applications (see above). The well known AGVs used for container transport in the port of Rotterdam are, for example, using transponders as reference marks within the runway. In the last few years, GÖTTING has even equipped several Transponder Positioning Systems for RTGs:

Koahsiung / Taiwan
Göteborg, Stockholm, Malmö / Sweden
Termi / Italy
Salalah / Oman

Due to the different requirements for the large variety of vehicles, e.g. RTGs, RMGs, Bridge Cranes, and VCs or AGVs, there are fundamentally different systems available for automatic positioning and guidance.

6.2.1 Electromagnetic Lines: Guide Wire etc.

A metal band within or on the runway can be used for AGV guidance within the appropriate environment. The sensors located in the front part of the vehicle recognize the influence of the metal bands on the magnetic field and thus determine the left or right deviation from the intended track. However, these signals are rather weak and easily influenced by other metal parts in the vicinity (e.g. metal reinforcements within the runway).

Much stronger signals can be generated by using AC current-carrying guide wires (approx. 10 kHz; 100 mA). Therefore this technology has been adapted for industrial applications as well as for People Movers. This guide wire system is extremely accurate and provides positioning information without interruption.

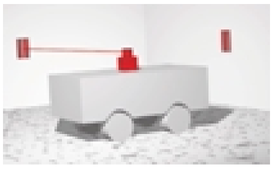
6.2.2 Electromagnetic Reference Marks: Transponders etc.

Vehicles that are equipped with wheel encoders and steering potentiometers and/or inertial sensors, do not need continuous track guidance. In this case it is sufficient to install electromagnetic reference marks at defined spacings (e.g. 3 m). Magnets or inductive transponders are suitable reference marks.

When the antenna is crossing one of the reference marks, it is capable of determining the reference mark's deviation to the left or the right from the center of the antenna. This measurement then enables the correction of the vehicles deviation.

Inductive transponders have to be activated by the alternating electromagnetic field of the antenna. Only then are they able to transmit their permanently programmed code via a miniature transmitter to the antenna, which then transfers this signal to the interpreter unit for decoding and processing. This is a significant advantage to uncoded magnets. Electromagnetic reference marks are recommended for track guiding vehicles (two-dimensional) as well as for positioning rail-bound vehicles (one-dimensional), e.g. conveyor monorails. It is possible to achieve extremely high accuracies.

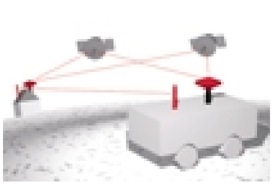
6.2.3 Optical Systems: Laser etc.



Optical systems are especially well suited for clean environments with free sight connection between sensor and reference patterns. Some of the very first AGVs were guided by lines on the runway. Nowadays cameras and image recognition systems enable the recognition of relatively complex patterns and reference marks.

Especially the Laser Scanners have become extremely important. Among these, the barcode scanners are most commonly known. For navigation systems, the Laser Scanner rotates around its vertical axis (approx. 8 circles per second). The beam is reflected by reference marks and returned to the scanner. Then the system determines the angle between the reference marks and the vehicle's longitudinal axis, which is used for the trigonometric calculation of the position. A navigation laser enables free navigation.

6.2.4 Satellite Navigation: GPS etc.



Since the mid 90s, reasonably priced and reliable satellite navigation systems are available. The mobile participant (Rover) can determine its position anywhere in the world.

However, unfortunately, there are locally differing errors in the signal transmission. The use of a reference station (differential GPS) basically eliminates this error. In this case, the Rover will receive the correction data via RF transmission from the reference station. This way, accuracies of approx. 3 to 5 m can be achieved.

Even higher accuracies are possible through additional carrier phase evaluation (approx. 2 to 10 cm). The integration of external sensors on the vehicle generates stabilized positioning values, which has lead to a general acceptance of satellite navigation in suitable environments.

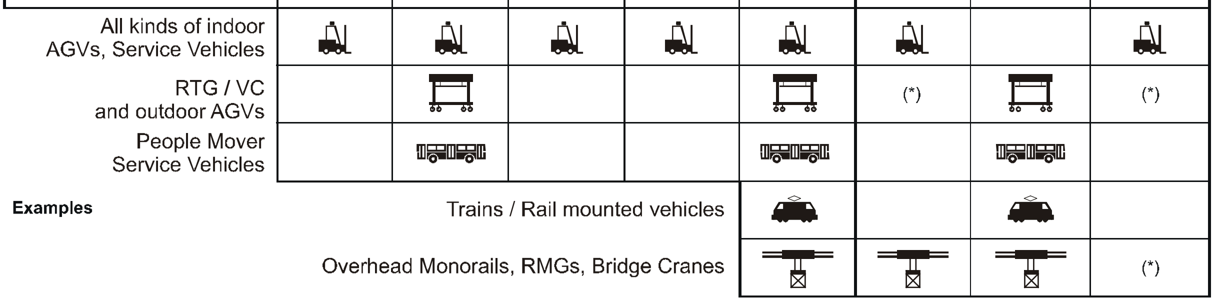
This means, that it is essential for the antenna of the Rover to have a permanent sight connection to the satellites. In case there is an interruption of this sight connection, it is essential to integrate inertial and/or odometric sensors.

The GPS technology is a very elegant solution to the positioning problem, however, it is not entirely unproblematical. It is necessary to point out once more, that positioning may be impossible in situations where there are signal reflections or satellite shadings. It is recommended, to determine for each project, whether GPS is the suitable solution.

GÖTTING manufactures, supplies and integrates all four of the above described systems:

- Guide Wires since 1982
- Transponders since 1985
- Laser since 1996
- GPS since 1997

System / Criteria	Continuous Guidelines			Reference Marks (Virtual Guidelines)		Entire Area		
	Optical Systems (e.g. Lines)	GuideWire	Metal Band	Optical Marks	Transponders (Magnets)	Laser Scanner	DGPS (Realtime Kinematic)	Object Recognition
Indoor / Outdoor	ind.	ind. & outd.	ind. (outd.)	ind.	ind. & outd.	ind.	outd. only	ind. (outd.)
Suitability in dirty Environment	-/--	++	++ (•)	--	++ (•)	-	++	+/•
Reliability / Security	+	++	+	+/•	+	+	+/-	-
Infrastructure Installation Costs	++/+	•/-	•	++	++/+	++	++/+	++
Flexibility	+/•	•	+/•	++/+	+	++	++	++
Typical Accuracy (+/- mm)	2	2	3-20	3-10	3-30	20	<= 50	<= 50



Suitability ++ = very good, + = good, • = average, - = rather poor, -- = poor

(*) Optional Sensors for Positioning e.g. Container Locating etc.

Figure 4 Comparison of Track Guidance Systems

6.3 Sensor Fusion

It is normally not possible to realize a Track Guidance Control System with only one sensor. A combination of different sensors is necessary (sensor fusion).

The sensors are used for position coupling (translation and rotation sensors) and position bearing (physical lines or bearing marks, ground marks). Figure 5 shows an exemplary model:

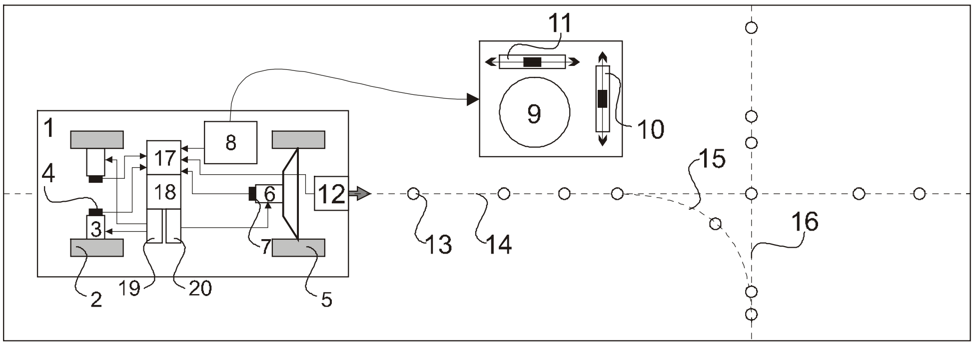


Figure 5 Example: Sensor fusion (AGV / AGT (Automated Guided Truck))

The vehicle (1) (AGV or AGT) has two driven wheels (2), rotary encoders (4) are located on the drive motors (3) for position determination (position coupling). In addition, there is a steering potentiometer (7) on the servomotor (6) or front axis (5) for dead reckoning. Alternatively / optionally it is possible to use an inertial system (8) with an angular acceleration sensor (e. g. gyro (9)) and a longitudinal (11) and a transversal (10) inertial sensor. This example uses a mark detection system (transponder reader antenna (12)) for location updating. This mark detection sensor (12) creates a new position reference above each mark (13). Then the position coupling (odometry) is used for guiding the vehicle via the virtual track (14) towards the next mark. Since these marks are coded, it is possible to select new tracks (directions) at certain predefined points. This enables turning onto the crossing track (16) via the branching track (15). In order to be able to also reverse the vehicle, it is necessary to mount an additional antenna on the rear end of the vehicle. Within the sensor fusion controller (17), position and heading are determined. Then the Navigation Controller (18) will calculate the new steering instruction if necessary. Steering amplifiers (20) or drive amplifiers (19) finally close the loop for the control circuit with the motors. In addition, there is usually a vehicle computer, which controls features like load handling and other operative functions.

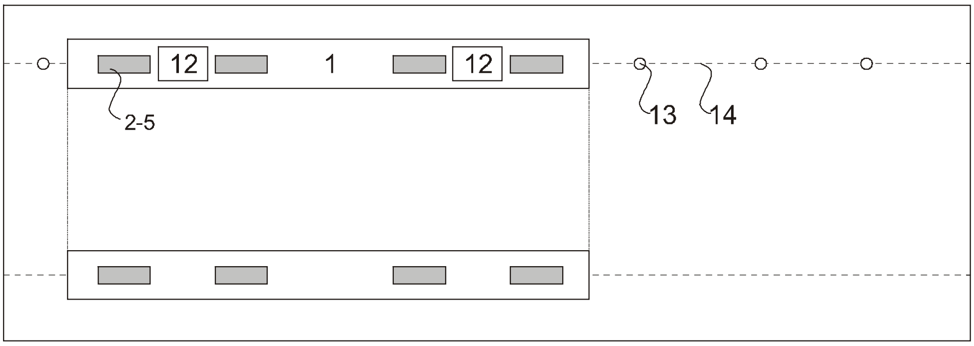


Figure 6 Example: Track Guided RTG

Figure 6 shows a Van or Straddle Carrier or even an RTG viewed from above. The wheels (2 - 5) are used for steering and driving. In order to be able to guide the vehicle in forward and reverse direction, it is essential to install two antenna readers (12) on the guided side of the vehicle.

6.4 Object Recognition

The industry uses automatically driven vehicles that are able to hitch and unhitch a trailer automatically. In addition there are systems available which are able to recognize objects, like pallets and containers in their position and size. Optical systems with image processing are especially suited for these applications.

For ports, however, the use of cameras is dependant upon the application and not always recommended (see above). For suitable applications, these systems have considerable advantages, e. g. for the recognition of container corner-castings.

Object recognizing sensors may be used for fine positioning or even for track guiding the vehicle. In the latter case, the navigation is no longer based on optical marks, but on the objects themselves (e. g. containers).

6.5 Obstacle Recognition

As soon as people are allowed to interfere within an automatically operated complex, it is essential that their recognition is guaranteed. For indoor applications, laser scanners with 5 m range have proven reliable for this task. For outdoor applications, however, these optical systems create problems especially if they are used in snowy, rainy and dirty environments. But due to extensive efforts of the automobile industry, which is working eagerly on the development of new radar, laser and ultra-sonic sensors, there are improvements to be expected in the near future.

In order to avoid that obstacles in the way do not unnecessarily stop the flow of transportation, the Navigation Controller is able to decide whether it is possible to drive around a certain obstacle (reactive navigation).

6.6 Data Communication

For terminal automation wireless data communication systems have become irreplaceable. GÖTTING supplies broad band as well as narrow band wireless data communication systems of varying frequency and output power for these applications. Depending on the application, large band width, large range and interference immunity are required.

	Wireless data communication in close conditions		
	inductive loop 30 to 120 kHz	150 / 433 to 434 / 460 MHz	2,45 GHz
indoor / outdoor	ind. & outd.	ind. & outd.	ind. & outd.
typ. error	broken cable	radio shadow	radio shadow
typ. range of operation	0.1 to 1 m	10 mW: 100 m	100 m
		500 mW: 2000 m	directional: 2000 m
typ. data rate [kBaud]	1.2 to 4.8	4.8 to 19.2	2000
reliability	very good	good - fair	fair
flexibility	no	yes	yes
infrastructure installations / costs	high	minimal	medium
price of vehicle system (€ ~ $)	300 - 1500	500 - 1000	500 - 2000

Figure 7 Comparison of Wireless Data Communication Systems (near range)

Wireless RF connection is one of the conditions for vehicle automation. This RF connection enables the transmission of instructions, status and service data.

7 Different Automation Models for Ports

7.1 AGVs in Rotterdam

Well known is the world-wide first extensive application with container carrying AGVs in the port of Rotterdam (NL). Since none of the bidders had been able to supply the full scope of automation for the overall system, the supply was subdivided into the fields ‘vehicle’, ‘track guidance system’, ‘vehicle computer’ (navigation) and ‘traffic control system’. A long period of time had to pass, before finally HHLA at the port of Hamburg (D) decided to introduce a similar concept.

Since this kind of vehicle is required to drive underneath the quay cranes for container pick-up and directly next to higher container stacks, GPS is not suitable (shadings, reflections). Optical systems are not suitable due to the weather conditions at Hamburg. Guide wires may break due to setting sections of concrete. Therefore it was decided to use transponders for positioning the AGVs.

7.2 RTGs

The first RTGs equipped with the GÖTTING Transponder Track Guidance Systems were located in Göteborg / Sweden and Kaohsiung / Taiwan (in 1995/1996). In the beginning there were a few problems with humidity within the antennas and EMI from the drives, but they were defined and overcome by a complete replacement of components. Since then, these and several other applications have been successfully set into operation.

Year	Qty.	Location
1995	1	Göteborg / Sweden
1995	8	Kaoshiung / Taiwan
1996	1	Stockholm / Sweden
1996	1	Malmö / Sweden
1999	15	Salalah / Oman
1999	3	Termi / Italy

Currently are being commissioned:

15 RTGs in Nhava Sheva / India
24 RTGs in Tanjong Pelepas / Malaysia
9 RTGs in Hamburg / Germany, etc.

Figure 8 Transponder Positioning System in Göteborg

7.3 Automated Standard Trucks

AGVs, like the ones used in Rotterdam, are usually especially designed vehicles. Thus the costs per vehicle are correspondingly high. Therefore, it was obvious, that the use of standard vehicles, like e. g. terminal tractors, could reduce these costs. However, until just recently, the automation of such vehicles failed due to the expenses for the conversion of the actuators (e. g. gearshift assembly).

The new DaimlerChrysler Trucks, however, now indicate a breakthrough: Apparently the new Mercedes-Benz Actros Truck is the world-wide first to be equipped with the new CAN bus vehicle components like steering motor, speed control, transmission configuration, brakes etc. These vehicles require little effort for the conversion to automatic operation. In addition, it is at any time possible to switch from automatic operation to manual operation, which enables the use of the automated vehicles also in manual mode as normal public road vehicles.

Advantageous are the low purchase costs and the similarly low operational and maintenance costs. They are approximately 40 – 50 % lower than those for the known container AGVs. These trucks are mass produced and therefore extremely well tested. Mercedes-Benz, together with Freightliner (USA), is part of the DaimlerChrysler Group, which is currently the world's largest truck manufacturer.

GÖTTING was the first to equip one of these Actros trucks with GPS for track guidance, which was then presented to a large international press audience in July 1999. For this demo the truck was not only able to automatically steer forward at a relatively high speed, but also reverse the truck with trailer into its parking position at an accuracy of approximately 4 cm! For port applications the use of transponder positioning systems for track guidance will be more suitable than GPS (see above). In this case the accuracy of the track guidance system will be approx. 2 cm. AGVs and AGTs both have their different advantages.

- AGV: better maneuverability
- AGT: low purchase, maintenance and operation costs, good reselling value, automatic or manual operation possible, higher speed.

The most important fields of application for AGTs are, however, outside the port environments.

Figure 9 Automatic DaimlerChrysler Actros during demo in Papenburg, Germany

7.4 GPS Guided RTG

Genoa will be the first port to have GPS guided RTGs (6 units). For this system, the GPS position will be supported by rotary encoders. The positioning system is designed for an accuracy of +/- 5 cm. Since the system itself is again a sensor system which will output the position (similar to the transponder positioning systems), for us it is essential to cooperate with competent partners for assembling the complete automatic track guidance system (for this project, our partner is General Electric).
Since RTGs in container stacks always travel along predefined straight lines, the GPS (or the transponder positioning system for other projects) output the current deviation of the crane position from the reference line. This is done automatically for an almost indefinite number of stacks within one terminal. Following the sensor fusion, which generates a position back-up of the odometric position through the absolute position sensor, the value of the deviation is transferred to the vehicle control, usually a PLC, via customized interfaces. Then the vehicle control assesses the vehicle dynamics and generates the control variable for the steering actuators.

7.5 Service Vehicles

It is not only possible to automate heavy load vehicles, but the automation of service vehicles, e. g. for the inspection of container trains, is also very useful. At relatively low speeds, transponder positioning systems are suitable, however, for higher velocities (e. g. 80 km/h) a guide wire system offers more stability.

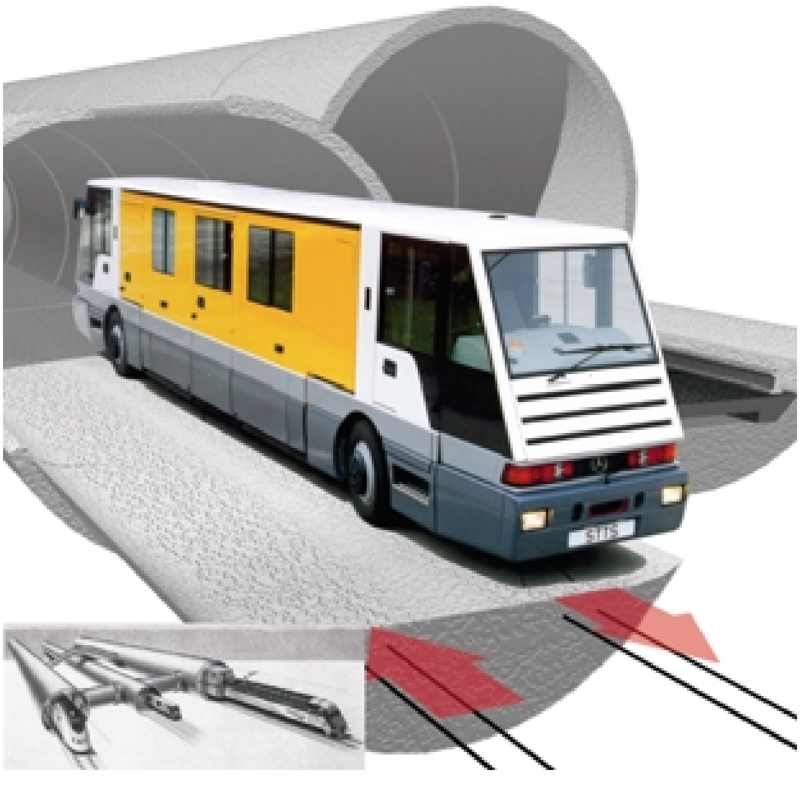


Figure 10 Track Guided Service Vehicle at the Eurotunnel (F – GB)

7.6 Multi-Trailer Systems and Bulk Cargo Transporters

It is planned to set the first project, which will include a total of three Mercedes trucks, type Actros) with four trailers each (4 x 40 t), into operation during the second half of 2000. The terminal tractor will automatically hitch and unhitch the trailers. This AGT will always tow a loaded set of trailers I from point A to point B; there it will autonomously unhitch the set I and hitch an other already waiting set of trailers II in order to tow it from B to A. At this point it will again exchange trailers and repeat the routine with the already loaded set of trailers III etc.

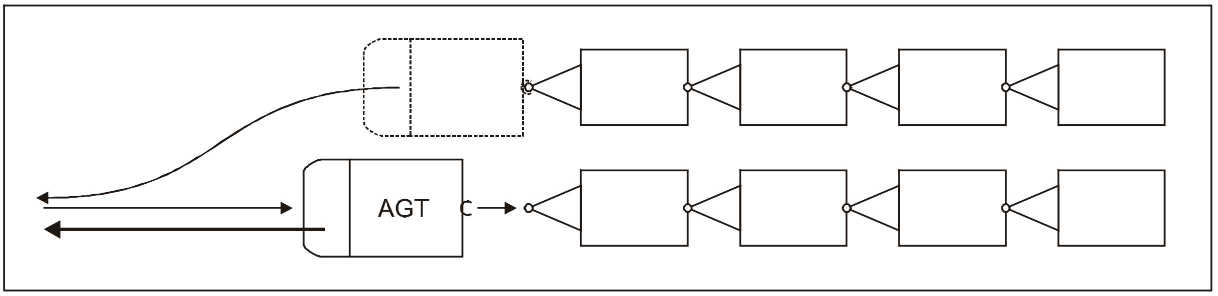


Figure 11 Terminal tractor during automatic shunting and hitching (multi-trailer system)

In addition, the use of heavy duty Actros trucks is planned for bulk cargo transportation. The vehicles are loaded by a excavator and then carry their load to a riddle construction. At this point the load is dumped backwards and the AGTs return to the loading point.

A combination of different systems is going to be used for track guiding these vehicles: Transponders, GPS and Guide Wire for certain sections. In addition there will be cameras on the vehicles and along the track, since the control post located approx. two kilometers from the track has to be informed of the situation at any time.

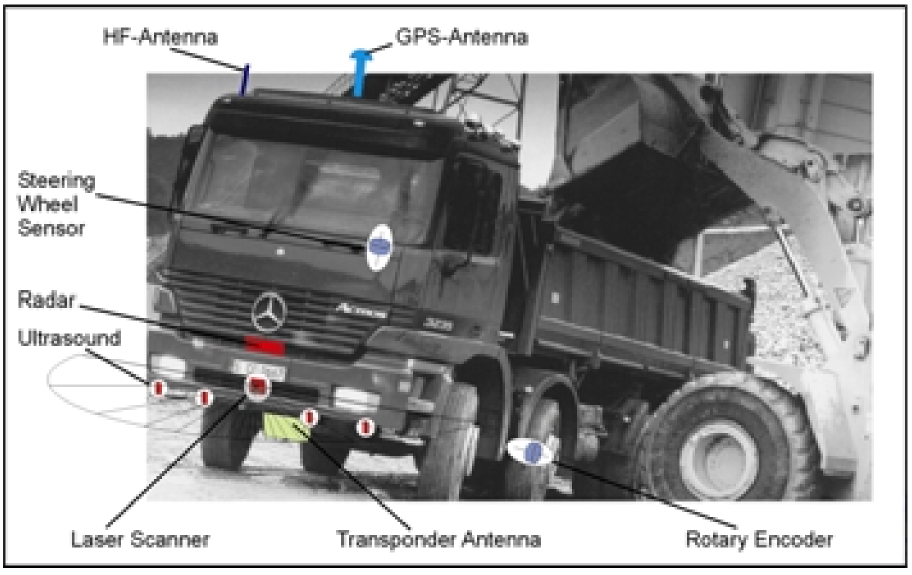


Figure 12 Loading a bulk cargo truck

7.7 Future Systems

It is already possible to have trucks driving in convoy while only the first truck in line has a driver. Instead of a multi-trailer system, this enables creating a multi-truck system. These vehicles have a contactless connection with each other via a so-called “electronic drawbar“ (spacing approx. 4 m). This kind of convoy (called “Load Trains“) requires less personnel, energy and road space than single trucks. These vehicles are therefore well suited for the transport between ports, plants and other large transshipment places.

Figure 13 Convoy of two trucks with electronic drawbar

For most vehicles (AGV, AGT, RMG, RTG, etc.) the task of track guidance has been solved satisfactorily. Even VCs will soon be able to steer and operate automatically. Significant improvements, however, are still to be expected for object and obstacle recognition sensors. Even future terminals will not be ‘unmanned’. Therefore, safe automatic recognition of people is the most important requirement for further success with the automation within and outside port environments.

8 Summary

The new sensor technologies, wireless communication systems, and computers have enabled new concepts of automation, and this enables ports to introduce more and more automated processes, because reliability and cost reduction are the key issues.

9 About the Author

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Hans-Heinrich Götting graduated from the Fachhochschule Hannover (Germany) in 1979 with a degree in Diplomengineering (Dipl.-Ing.), he then took his MSEE at Newark, New Jersey (USA). Having finished university, he entered GÖTTING KG, Lehrte (Germany) and has been heading this company as general manager since 1986.

GÖTTING KG is a world-wide leading engineering company for sensors for track guiding so-called AGVs.

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