PEMA

Laser Technology in Ports and Terminals

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Contents

1. Introduction

Document Purpose

This information paper is intended to provide a high-level overview of the use of laser technology in Container ports and Intermodal terminals. This document IP08A is an update of paper IP08 published in January 2015 and describes how laser technology works and how it is used today in port and terminal applications.

About This Document

This document is one of a series of information papers developed by the Technology Committee (TC) of the Port Equipment Manufacturers Association (PEMA). The series is designed to inform those involved in port and terminal operations about the design and application of software, hardware, systems and other advanced technologies to help increase operational efficiency, improve safety and security, and drive environmental conservation.

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2. Background

Laser technology is a key enabler for safer, efficient, and accurate container handling. These criteria are relevant for manual, semi-automatic and automatic operation. The sensors and solutions measure the position of the machines, the container, the vehicle, the vessel and the people. Lasers are the eyes of the operation, either as a driver assistance system for manually driven machines or by providing the position of the objects or subjects for automated machines.

Time is money: Many ports are today facing congestion problems, some have labour issues, and many are experiencing growing competition. The recent and ongoing rapid increase in ship sizes and call exchanges, both on primary and secondary trades, add a further dimension. Alongside these challenges is the fact that container handling remains one of the most dangerous operations in industry.

The introduction of robotic or remotely controlled handling equipment is a growing response to all these pressures, enabling greater reliability, reduced operating costs and a new way of addressing perennial safety concerns. However, the introduction of unmanned handling means that equipment must 'see' and position itself to a very high degree of accuracy.

Automated operation means that productivity is potentially higher, more consistent, and safer than for a manned operation, however there must be a (limited) ability to accommodate adjustments. Unmanned operation does not imply that people are not on the terminal, therefore there is a requirement for safety devices that can recognise and respond to potentially dangerous situations. Both requirements depend heavily on recognition technology, such as that provided by laser devices and/or systems.

2.1 Current Situation

The level of automation in container terminals has increased considerably in recent years. Well-known and established automation projects such as ECT (Rotterdam) and HHLA CTA (Hamburg) have illustrated why laser technology is so significant for this kind of operation. These terminals use automated guided vehicles (AGVs) for horizontal container transport and automated stacking cranes (ASCs) for stacking operations.

Today, there are well over 40 fully automated terminals in operation, the largest in Asia, followed by the Middle East, Australia, Europe, and the Americas, with further large-scale projects under development all over the globe.

One thing that most of these terminals have in common is the use of ASCs, ARMGs or A-RTGs in the storage area. The approach to horizontal transport is less consistent, however several existing and planned facilities have either partly or fully automated this activity with the use of handling equipment such as AGVs, semi-automatic trucks and driverless shuttle carriers.

New projects of a smaller scale are using automation to some degree including automated cranes for the storage area and hinterland operations and other functions.

Manually operated terminals also use laser technology to improve safety by providing assistance functions which allow the crane operator to work more efficiently.

All types of collision protection systems are typical in such an application. The laser-based systems monitor the area where the machine is operating and detect objects/subjects that are either in the operational area of the machine itself or of the load being handled.

3. Development and Utilisation

Laser technology was initially deployed in the early 1990s, coinciding with the first major automation initiatives in the container terminal industry. In the intervening period, the growing port industry's focus on automated and safer handling solutions has fostered a productive collaboration between terminal operators and the manufacturers of laser technology and solutions. This has played a significant part in enabling considerable and rapid improvement in the overall performance of the systems.

Laser equipment has benefitted from many years of industrial application when developing resilience against the difficult weather and operational conditions that exist in the port terminal environment. However, the greatest challenges concern not only the hardware itself but the associated application software. This issue is now being overcome thanks to the last decade's explosion of computing and programming development in many other applications.

Laser technology is now commonly used in ports to:

- Measure the position of the container handling equipment
- Determine the location of the container, trucks, trailer, AGV or straddle carrier
- Create a stack or bay profile in the yard or on the ship
- Position trolley and spreader
- Provide machine collision prevention, load collision avoidance and many other functions

4. Application Solutions and Functions

Laser technology is a key component for manual, semi-automated and fully automated terminals, assisting in the efficient and safe operation of such facilities. Table 1 below lists the application solutions and functions that can be solved with the different types of laser technology. In the following chapters the solutions and features are described. They are separated into individual solutions by crane or vehicle type, but some of the solutions and features can generally be used for any kind of machines.

Application Solution	Equipment	Functions	Laser Technology			
			1D - Laser	2D - Laser	3D - Laser	3D - Laser (2D-Laser + Movement)
Gantry Collision Prevention Pathway & Cross Travel Collision Prevention	RTG, RMG, STS	▪ Collision prevention in crane pathway direction (Includes RTG cross travel collision prevention)		●	●	●
Crane-to-Crane Collision Prevention	RTG, RMG, STS	▪ Collision prevention between cranes	●	●	●	
Truck Positioning	RTG, RMG, STS	▪ Positioning of the chassis or container on the centre -line of the crane ▪ Measures position of the chassis and container in gantry and trolley axes ▪ Map the top surface of container or chassis		●	●	●
Cabin Position	RTG, RMG, STS	▪ Measures the position of the truck cabin to avoid container being dropped on the cabin		●	●	
Container Distance Detection	RTG, RMG, STS	▪ Distance between spreader and top of container	●			
Area Surveillance	RTG, RMG, STS	▪ Detection of objects or persons in the working zone of the crane			●	
Spreader Positioning	RTG, RMG, STS	▪ Measures the load/spreader height	●			
Truck/Chassis Lift Prevention System	RTG, RMG, STS	▪ Prevents trucks being accidentally lifted during container handling because of locked twist locks		●	●	
Twistlock Position Detection	RTG, RMG, STS	▪ Facilitates automatic handover of the container to trucks and wagons				●
Twin-Twenty Detection	RTG, RMG, STS	▪ Ensures accurate detection of 2x20 ft container or 1x40 ft container before spreader is engaged	●	●		●

Application Solution	Equipment	Functions	Laser Technology			
			1D - Laser	2D - Laser	3D - Laser	3D - Laser (2D-Laser + Movement)
Vessel Profiling / Load Collision Prevention	STS	▪ Collision prevention ▪ Soft-landing ▪ Semi-automation with the optimal path of the load when traveling over the vessel ▪ Spreader position and tracking ▪ Deck height measurement ▪ Catwalk height ▪ Position of the containers ▪ Vessel misalignment (difference between the STS crane centre to the centre of the bay) ▪ Cell-guide detection	●	●	●	●
Boom Collision Prevention	STS	▪ Collision prevention between STS crane boom and vessel		●	●	
Straddle Carrier Positioning	STS	▪ Guide the straddle carrier to the centre-line of the STS crane		●		
Stack Profiling / Load Collision Prevention	RTG, RMG	▪ Verifies accurate container stacking ▪ Prevents collisions between the load and the container in the yard ▪ Optimised trajectory of the load traveling over the yard	●	●	●	●
Automatic Stacking in the Yard	RTG, RMG	▪ Measures the position of the container in the yard for pick and drop	●	●		●
Automatic Wagon and Truck handling	RTG, RMG	▪ Automatic pick and drop container from and to wagon and trucks (trailer, chassis)				●
Unpinned Cone Detection	STS, RTG, RMG	▪ Identify unremoved twistlock pins underneath the container		●		
Guidance of E-RTG	E-RTG	▪ Position and guide E-RTG on electrical power barr equivalent.	●	●		
Telescope Positioning Detection	Reach Stacker	▪ Provides accurate distance of reach stacker telescopic arm.	●			
Collision Prevention Horizontal Transport Vehicle	Reach-Stacker, Empty Box Handler, AGV, Straddle or Shuttle Carrier, Auto-Truck	▪ Pathway obstacle detection to avoid collisions between the vehicle (AGV, Shuttle Carrier, Lift-Truck, empty container handler) and obstacles		●	●	

4.1 General Crane Solutions

The general crane solutions are the solutions that can be used on any kind of machine.

4.1.1 Crane-to-Crane Collision Prevention

To prevent the cranes from colliding with each other, distance sensors, 2D or 3D sensors can be used. The sensor is orientated in the direction of travel and can detect the structure of the adjacent crane(s). By measuring the distance between the cranes, the speed of the cranes can be reduced to a safe level and to a stop if cranes are too close to each other. Typically, this function is combined with the function Pathway & Cross Travel Collision Prevention.

When using a 2D-Laser a horizontal scan plane is created at a height of approx. 1.5m. If there are obstacles in this two-dimensional field, the crane motion can be controlled such that a collision is avoided.

When using 3D sensors, a 3D surveillance cube with different zones will be generated. This means that obstacles lying on the ground or projecting anywhere into the surveillance cube will be detected, and collisions are prevented.

In the case of RTG cross travel motion both variants can be utilised for this purpose.

The systems described can also be used for crane-to-crane collision prevention.

Fig 1: 1D- Laser measure from crane-to-crane

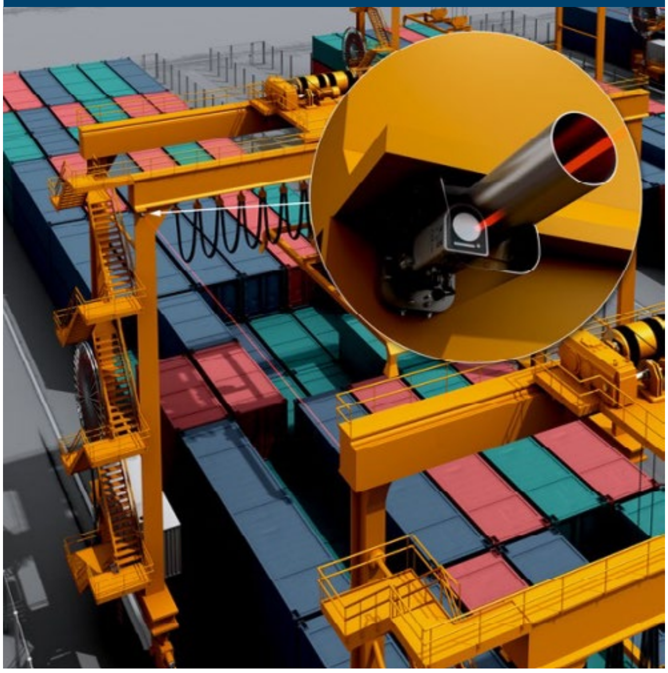


Fig 2: 3D-Surveillance area in front of the crane

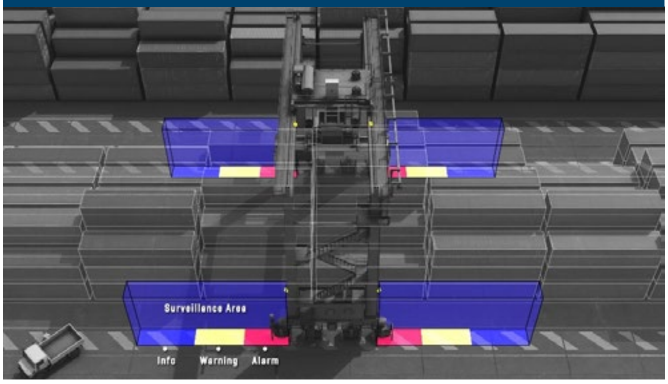
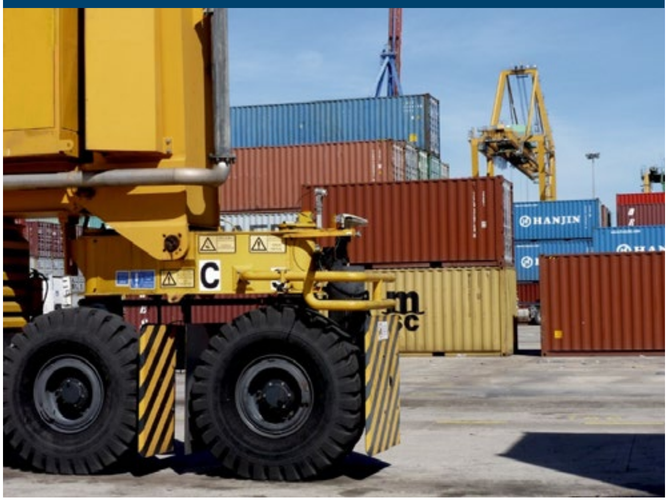


Fig 3: 2D-Laser mounted on the crane



4.1.2 Gantry Collision Prevention, Pathway and Cross Travel Collision Prevention

To prevent the crane from colliding with obstacles in the travel path or during cross travel, 2D or 3D-Lasers can be used. The sensor is orientated in the direction of travel and can detect obstacles that are in the travel path. When the distance between the crane and the obstacle is measured the speed of the crane can be reduced to zero as it approaches the obstacle. The system has a number of detection zones for, warning and alarm. These zones can be adapted to the crane speed.

4.1.3 Truck Cabin Position

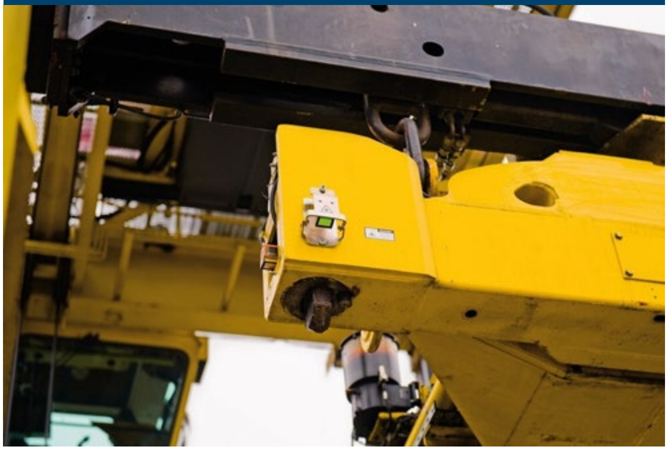
To prevent a container colliding with the truck cabin, the measurement systems measure the position of the cabin. Knowing the position of the load on the crane relative to the cabin can prevent collisions. Distance sensors, 2D or 3D sensors can be used for this function.

This function is usually an integral part of the Truck Lifting Prevention or Truck Positioning Systems.

4.1.4 Spreader to Container Distance

Measuring the distance between the spreader and the top of the container allows the implementation of a soft-landing function. Measurements are carried out using either trolley-based measurement systems (SPSS, AYC) or by installing a laser device on the spreader. Both solutions measure the distance to the objects below.

Fig 4: 1D-Laser on the spreader



4.1.5 Area Surveillance

With the advent of crane automation and the fact that objects and obstacles may be in the work area, it is necessary to monitor the work area to prevent accidents. The 3D-Laser can generate a 3D image of the area in real time.

The sensors are mounted on the portal beams and look down on the truck lane(s). The sensors generate a 3D image of the operation area. The system distinguishes between the allowed vehicle (truck, trailer, container) and objects which might be around the vehicle. When objects are detected, the system triggers an alarm and crane movement is stopped.

Fig 5: 3D-Point Cloud and an actual picture of the area (subject beside the truck in red circle)

4.1.6 Unpinned Cone Detection

To prevent containers with unremoved PINs (interbox connectors) being transferred to the stacking area, the measurement system detects these PINs and triggers an alarm. The system consists of 2 x 2D-Lasers located on the endcarriage of an STS/RTG/RMG or on the lashing platform of an STS crane which build a horizontal scan plane. When the container is hoisted up from the vehicle or lashing platform, the measurement system in conjunction with the hoist movement generates a three-dimensional image of the container. When a PIN sticks out of the structure at the corner of the container the system will recognise it and trigger an alarm.

Fig 6: 3D-Point Cloud of the bottom of a container with interbox-connector

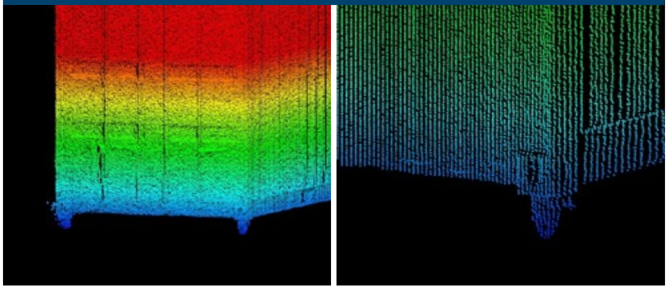
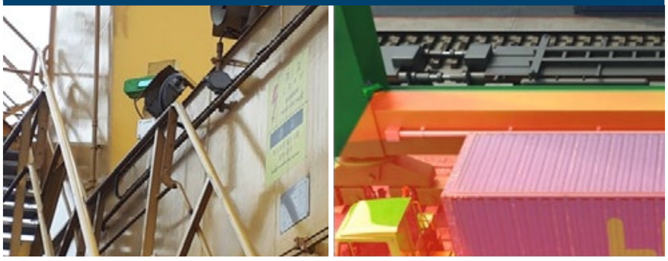


Fig 7: Mounting Positions of the 2D-Laser Red horizontal light curtain (right picture)



4.1.7 Spreader Position

Utilising 2D or 3D distance sensors the spreader position relative to the trolley can be measured. With the distance laser pointing downwards from the trolley onto the headblock/spreader the height of the hoist can be measured. This function may also be used l to compensate for hoist rope elongation for improved accuracy of the hoist height measurement. With the 2D and 3D sensor the position of the load (spreader, headblock) can be measured both in height and trolley axis orientation.

4.1.8 Truck Lifting Prevention

To prevent the trucks (chassis) from being lifted by the crane, the measurement system checks whether the chassis is lifted off the ground when the container is hoisted. Different systems on the market have different approaches to detecting this lifting scenario.

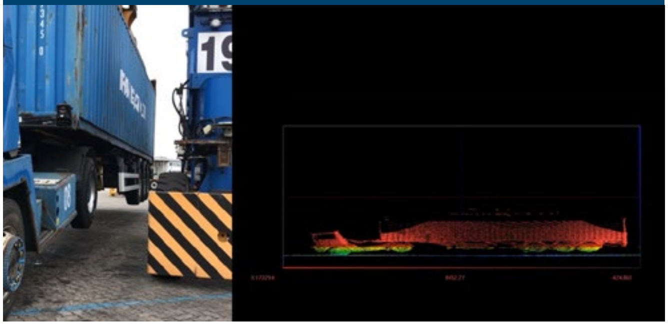
The distance sensor solution consists of a series of 1D-Laser sensors mounted along the gantry beam at a height above the top of the chassis, orientated horizontally towards the truck lane. The same function can be achieved with a horizontally oriented 2D-Laser or 3D-Laser.

The greater the number of dimensions detected by the system, the more information and different functions that can be generated for the final lift detection.

2D and 3D systems can also check/measure the position of the truck and the cabin.

Fig 8: 3D-Scanlines on the side of the vehicle

Fig 9: Actual picture and 3D-Point Cloud of the lifted truck



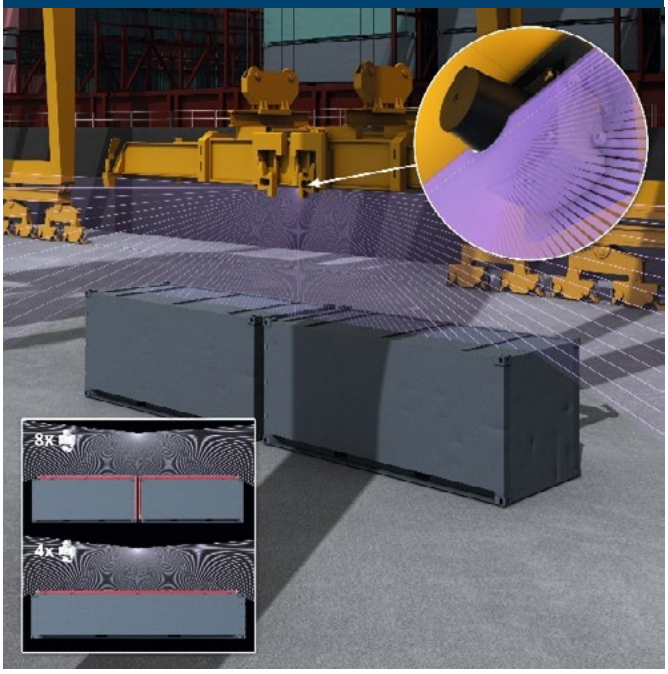
4.1.9 Twin Twenty Detection

To avoid the spreader in 40ft mode incorrectly picking two 20ft containers, the Twin-Twenty detection system will either detect the gap between the containers or identify the corner casting recesses.

This function is partially included in the functionality of a container position measurement system, where the container stack is scanned as a whole. In this case the sensors are on the trolley or the crane structure. *(see chapter for automatic stacking 4.3.3)*

Twin Twenty detection can also be solved by 1D-Laser or 2D-Laser units mounted at the spreader which detect the gap between two twenty-foot containers. Care must be taken to protect the sensor against excessive mechanical load (shocks and vibration), e.g., by using shock absorbers and/or soft-landing solutions.

Fig 10: 2D- Laser on the spreader



4.2 Ship-to-Shore Crane Solutions

4.2.1 Vessel Profiling and Load Collision Prevention

Vessel profiling can be utilised for different functions. Primarily it is used for collision prevention between the moving spreader/load and the container stacks and/or the structures on the vessel. All laser options are applicable for this application, depending on the individual solution requirements. Simple solutions, with some operational limitations, are based on a distance sensor installed on the trolley. By combining the sensor's measurement data with the trolley position, a 2D profile of the vessel's operation area can be generated. The highest level of functionality is achieved by using 3D-Lasers or a combination of 2D-Lasers. Most advanced current automation solutions allow semi-automatic movement of the load with the support of the measurement system.

The functions of the measurement system support the following objectives:

1. Collision Prevention
2. Auto drop-off and pickup on the quay
3. Soft-landing
4. Semi-automation with the optimal path of the load when traveling over the vessel
5. Spreader position and tracking
6. Deck height
7. Catwalk height
8. Positions of the container on vessel and landside
9. Vessel misalignment (difference between the STS crane centre to the centre of the bay)
10. Cell-guide detection

All solutions are based on installations on the trolley, however additional information from scanners installed on the boom can be used to enhance the system. By combining the laser sensor data with the trolley position, 2D profiles and/or 3D profiles are generated.

Fig 11: Vessel profiling principle

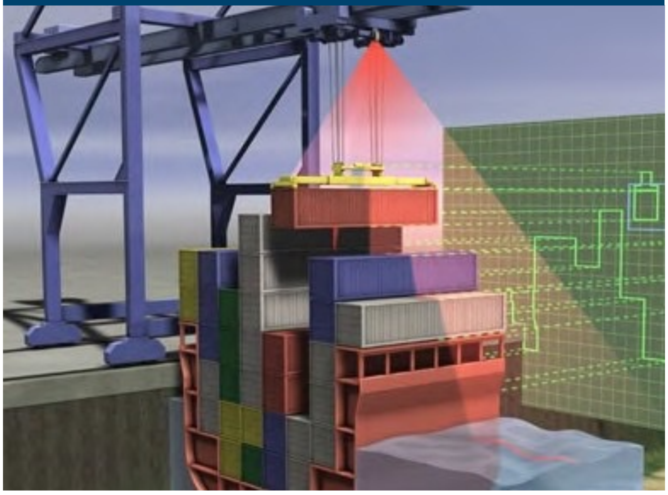
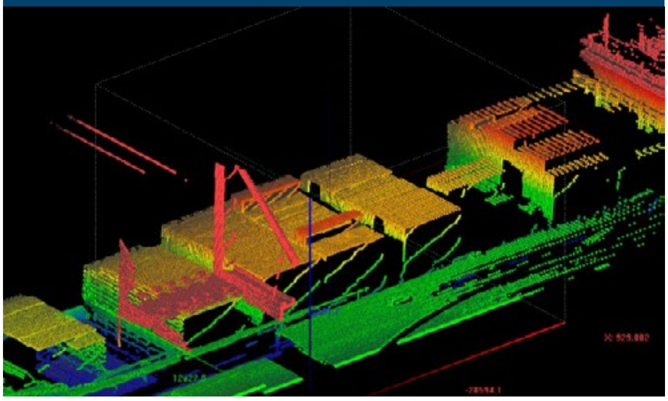


Fig 12: 3D Point cloud of vessel



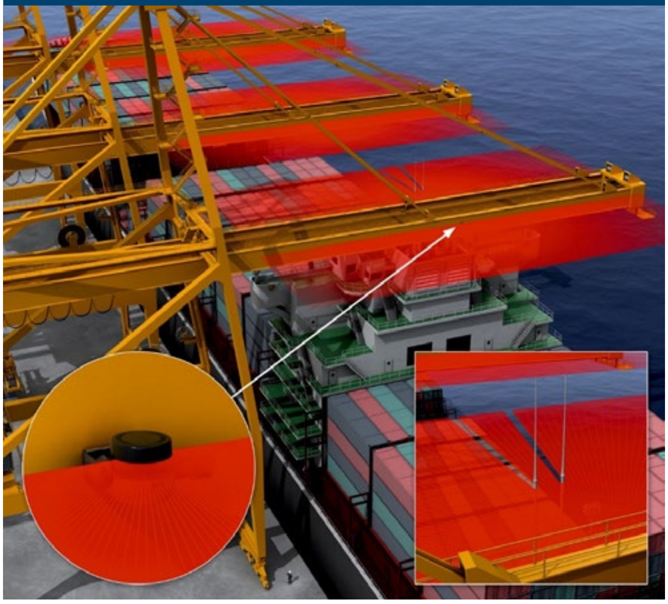
4.2.2 Boom Collision Prevention

To prevent collisions between the crane boom and vessel superstructure, scanners are installed on the boom structure to create horizontal 2D or 3D surveillance fields/cubes under the boom. If the bridge or other structures on the vessel are detected within the surveillance fields/cubes during the crane's gantry motion, a warning message with alarm signal or, in emergency cases, an automatic stop will be initiated.

2D-Laser Solution

The 2D-Laser solution is based on either 1 or 2 2D-Laser(s) installed at the boom tip or in the middle of the boom. Installation can also be on the fixed seaside leg structures of the crane facing the waterside. The 2D-Laser(s) generates a horizontal field of view underneath the boom with the corresponding surveillance fields.

Fig 13: Boom collision prevention principle (with horizontal scan planes)



3D-Laser Solution

The 3D-Laser solution is based on 1 or 2 3D-Lasers installed at the boom tip or in the middle of the boom. Installation can also be on the fixed seaside leg structure of the crane facing the waterside. The 3D-Laser(s) generates a 3D-surveillance area on both sides of the boom. When objects are detected in the path of the boom the crane can be stopped.

4.2.3 Truck Positioning

The truck must position the container and trailer centrally under the STS crane, such that the container can be dropped or picked up without any gantry motion. i.e. The STS remains in the ships bay. There are three solutions on the market for this function: 2D-Lasers for each lane or 3D-Lasers (two variations) covering several lanes. When using 3D-Lasers it is possible to position two trucks at the same time for double hoist or dual cycle operation.

2D-Laser Solution

A 2D-Laser is placed on the STS crane portal beam for each monitored lane and the scan plane is orientated along the lane direction. By extracting distinctive reference points such as the front and rear edges of the trailer and the truck’s cabin from the 2D profile, the exact position can be determined for the empty trailers/chassis.

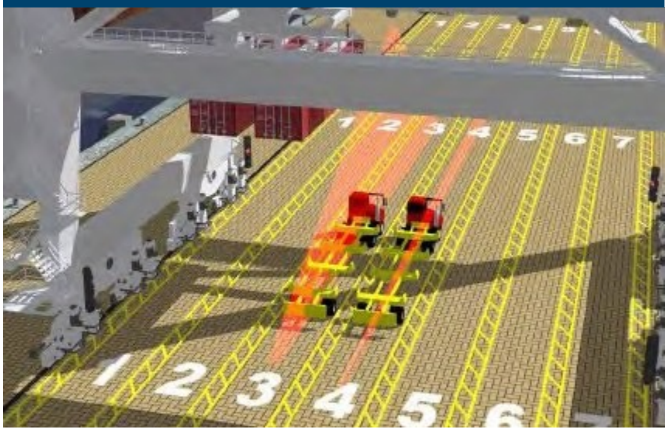
The same principle applies to the ship loading process. In this case the container(s) on the trailers are measured. The front and rear edges of the container are calculated from the 2D profile.

3D-Laser (2D-Laser + Movement) Sensor Solution

With this solution one or more 3D-Laser (2D-Laser + Movement) sensors are mounted on the STS crane portal beam. Since this is a 3D system, the position of and also the rotation of the chassis and/or the container on the chassis is determined.

The use of 3D sensors also optimises performance during double hoist or double spreader handling operations, as the relative position of the adjacent container/trailer can be measured such that the spreaders can be pre-positioned.

Fig 14: Truck Positioning principle 3D-Laser (2D-Laser + Movement)



3D-Laser Solution

3D-Lasers will be installed in similar locations on the crane portal beam as for the 3D-Laser (2D-Laser + Movement) solution. The multilayer sensor generates a complete 3D point cloud of the working area on the ground. All lanes can be monitored in real time. It is possible to position two trucks at the same time. Additionally, the position and rotation of the chassis/vehicle in the trolley direction axis can be measured to facilitate automated landing.

Fig 15: Truck positioning principle 3D-Laser

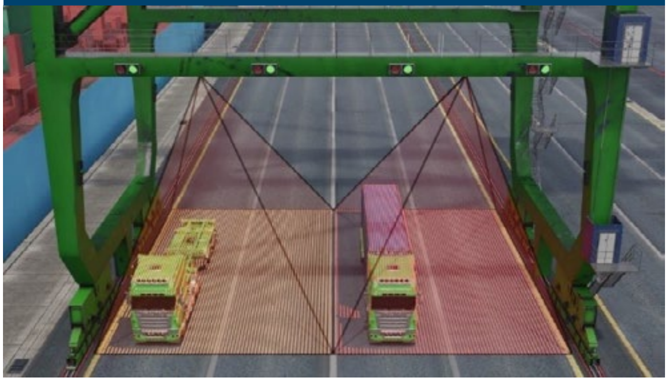


Fig 16: Truck positioning actual picture and 3D-Point Cloud

4.2.4 Straddle Carrier Positioning

The straddle carrier (SC) must be positioned centrally under the STS crane when depositing the container in order to prevent the crane from having to change its gantry position. A straddle carrier positioning system works with a 2D-Laser installed on the waterside and/or landside gantry endcarriage/beam of the STS crane at a height of approx. 6m. The straddle carrier is fitted with reflector strips on the outside of each of its 4 legs also at 6m height. When a straddle carrier enters within the STS portal or the back reach area, the laser system detects the reflective strips on the legs and measures the position of the SC. Digital displays or traffic lights installed on the crane legs at the height of the SC cabin provide the operator with feedback on the SC position relative to the centre line of the crane.

4.2.5 AGV Position Verification

AGV's are guided via GPS, transponders and/or other measuring methods for container handling to/from the STS cranes and the yard. To verify the relative position between the AGV and the STS crane, 3D-Laser (2D-Laser + Movement) are mounted on the STS crane.

After the AGV reaches the target position, the 3D-Laser (2D-Laser + Movement) measures the position of the AGV and/or the position of the container on the AGV. As a result, the position of the AGV relative to the crane spreader will be verified against the crane's gantry and trolley position and also its rotation around the vertical axis. The trolley and spreader can then be positioned by the crane control system.

Fig 17: AGV 3D-Point Cloud top view

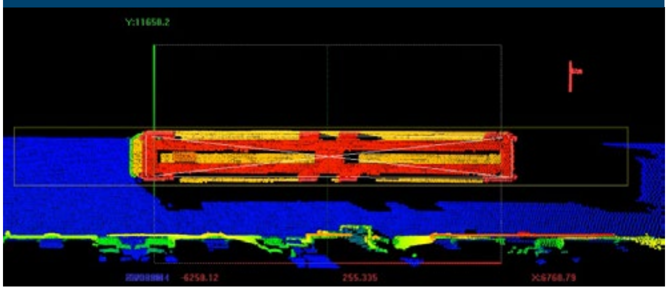
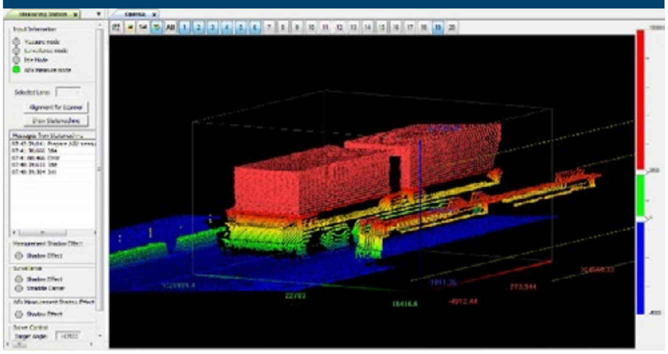


Fig 18: AGV 3D-Point Cloud perspective view (2 x 20´Container)



4.3 RTGs or RMGs Solutions

Rubber-tired gantry cranes (RTG) and rail-mounted gantry cranes (RMG/ARMG) are the most widely used equipment types for yard and rail operations. As with other types of equipment, RTG's and RMG's present a number of challenges in terms of operation, equipment utilisation and safety that can be solved using laser technology.

These cranes can be operated manually with Laser measurement systems being used as *driver assistance systems* or for automated operation. In the automated application additional requirements of the laser systems include identifying and moving container positions in the stack and/or transferring a container to/from the horizontal transport vehicle i.e. (truck, AGV).

4.3.1 Stack Profiling and Load Collision Prevention

In order to optimise the yard performance, systems using all types of laser sensors are employed. The type of system selected depends on the type of machine. In the case of RTGs, the trolley with the spreader/container always enters the bay coming from the truck lane and vice versa.

For RTGs a 2D-Laser system may be sufficient, if collision prevention only with containers in the operational bay is to be provided by the system. Container stack profiling is also possible with distance sensors mounted at the trolley (looking downwards onto the container stack).

RTGs and RMG's can also drive horizontally along the yard stack and therefore load collisions are also possible in the gantry movement axis. In this case if collisions with containers in adjacent bays are to be prevented, then 3D sensors must be utilised.

Fig 19: 1D-Laser solutions for stack profiling

Fig 20: 3D-Laser solutions for stack profiling

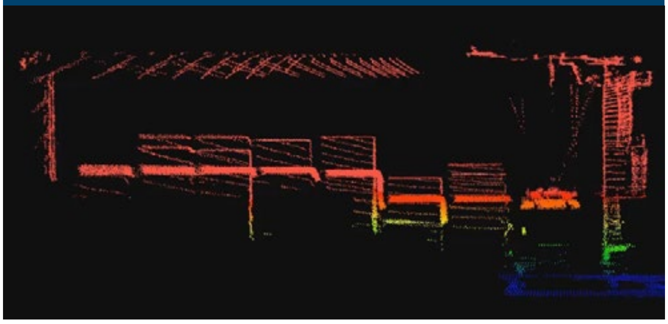


Fig 21: Possible occurrence of a collision, therefore surveillance cube around the load is red and the crane has stopped moving

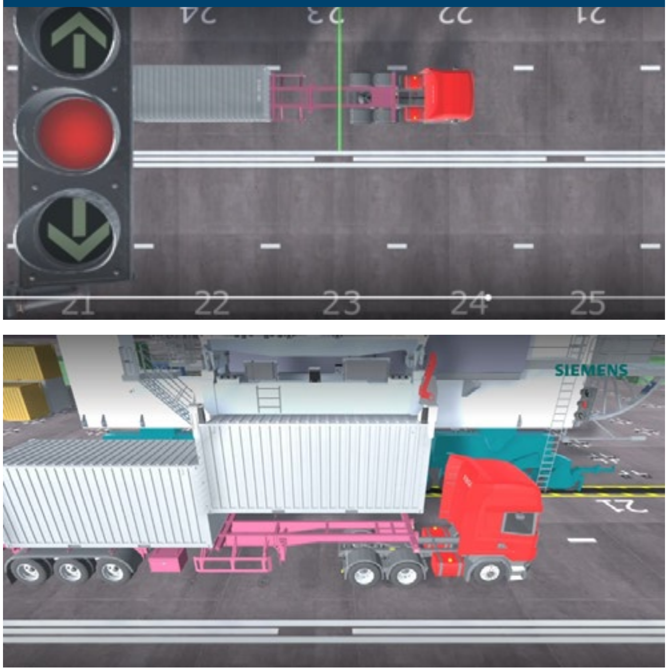
4.3.2 Truck Positioning

In this application a 2D-Laser, a 3D (2D-Laser + Movement) or a 3D-Laser is installed on the crane structure above/beside the truck lane, which scans the truck lane and determines the position of the trailer and the container on the trailer. The truck driver receives feedback on the position of the truck relative to the crane centre line through a digital display or traffic light indicator.

By using the 3D (2D-Laser + Movement) or 3D-Laser both the location and orientation of the truck and the load can be determined and sent to the crane control system. The crane can use this data for further processing (e.g., supervised pick and place of the container in the truck lane.)

In the case of external trucks, the positioning system can also detect the location of the locking pins on the road chassis for accurate landing.

Fig 22: Truck positioning in visualisation



4.3.3 Automatic Stacking

In the case of automated cranes, the containers must be accurately stacked in the yard. Anomalies caused by ground subsidence or uneven rail tracks necessitate the requirement for measurement and verification of container positions. Solutions available are based on either 1D-Laser, 2D-Laser or 3D-Laser (2D-Laser + Movement) technology.

1D-Laser Solution

This solution utilises a set of 4 or 6 1D-Lasers mounted on the spreader edges looking directly downwards. When picking up a container all 1D-Laser have the same signal status whereby they detect nothing within 2m. This is the indication, that the spreader is centred directly above the container.

2D-Laser Solution

Using 2D-Lasers installed on the trolley, the position of a container in the stack can be measured. Pairs of 2D-Lasers can measure the 20ft, 40ft and 45ft slots from the perspective of the gantry motion direction. A further pair of 2D-Lasers measure the positions of the containers from the perspective of the trolley motion direction.

3D-Laser (2D-Laser + Movement) Solution

By using one or two 3D-Lasers on the trolley, it is possible to measure the corner castings of the container and its outer shape. In this case, the laser sensors can measure all existing container formats (20ft, 40ft and 45ft, including open top or even tank containers) by creating complete 3D container images.

4.3.4 Automated Wagon and Truck Handling

Based on the solutions for automated stacking, some systems are also capable of supporting the automated handover of the container to the transport vehicle (wagon or trailer). In this case the container pick-up scenario is similar to that in the yard. However, when depositing a container on a vehicle the positions of the locking PINs must be measured in order to generate the exact landing position. For terminal chassis the structure of the chassis (i.e., guides on the sides) can serve as orientation aids to determine the landing position.

Fig 23: Image with scan-plane of 2 x 3D-Laser to measure the wagon position

4.3.5 Automatic Truck Handling (ASC Transfer Zones)

The previous section 4.3.4 detailed the accurate container stacking and automatic wagon and truck handling, however it is also possible to place containers automatically onto a road truck chassis with ground-based systems.

The position of empty trailers, and/or containers for off-loading, is detected by a 3D (2D-Laser + Movement) sensor located in the ASC transfer lane. Additionally, the laser can detect the vehicle cabin location after the trailer has been positioned in the lane.

Fig 24: 3D-Laser on a pole beside the lane

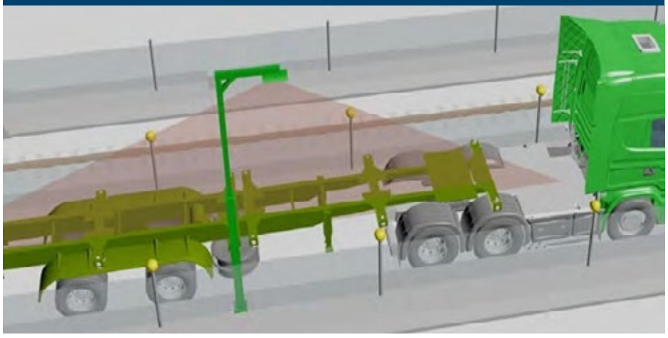
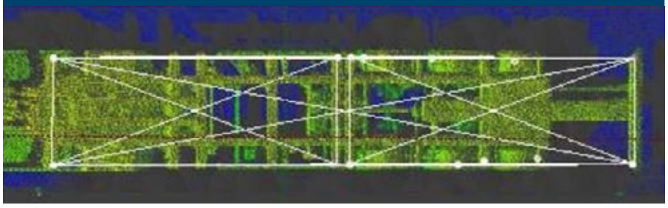


Fig 25: 3D-Laser point cloud, with measurement results drawn into the image



4.3.6 Guidance of E-RTG

Laser sensors may also be used to control the gantry alignment of E-RTG’s. The distance and position between the electrical conductor bars and the E-RTG structure must be measured to ensure a correct and continuous relative position between the partners. With a 1D or 2D-Laser sensor mounted on the side of the gantry frame - facing the conductor bars – the relative positions are measured. The laser generated signal representing the measured distance between Gantry and Conductor bar is utilised in the E-RTG Gantry steering/drive control system.

4.4 Horizontal Transport Vehicle Solutions

4.4.1 Straddle Carrier

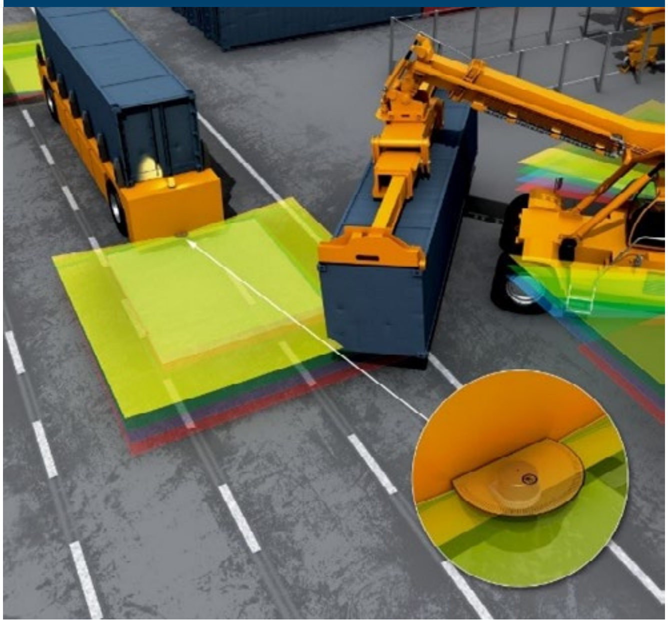
Collision prevention solutions for the straddle carrier (SC) have a similar arrangement as applied on RTG/RMG and STS applications. Four lasers are mounted on the SC gantry legs near ground level which scan the area around the SC. When the SC is moving and an object enters the monitored area, an alarm is triggered, and the control system slows/stops the machine.

4.4.2 AGV or Automatic Truck

A laser sensor mounted on the front and back of the AGV or truck prevents collisions between the machine and other vehicles or surrounding fences or structures.

Fig 26: AGV collision prevention with 2 x 2D-Laser scanning to both sides

Fig 27: Collision case with reach stacker



4.5 Multifunctional Solutions

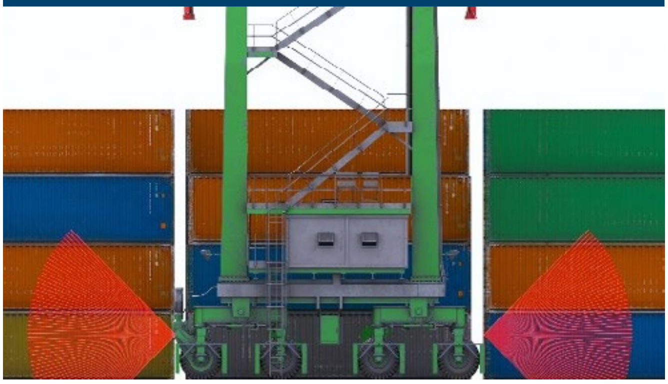
Depending on the selection of sensors type (1D to 3D) and using the correct mounting position and scanner orientation it is possible to realise more functionality within a one scanner setup. The key factor here is that the more dimensions the sensor can measure the more functionalities that can be covered.

The selection of the right sensor must take into consideration resolution, accuracy and process dynamics.

For example, having 2 x 3D-Lasers mounted on the gantry extremities above the wheels on an RTG, Gantry Collision Prevention and Truck Lifting Prevention can be covered with the same hardware. Additionally, the vehicle cabin position will be measured, and the truck can be accurately positioned.

Fig 28: 3D-Laser view into the truck lane for Truck Lifting Prevention

Fig 29: 3D-Laser view into gantry drive direction for Gantry Collision Prevention



4.6 Digital Twin/Simulation

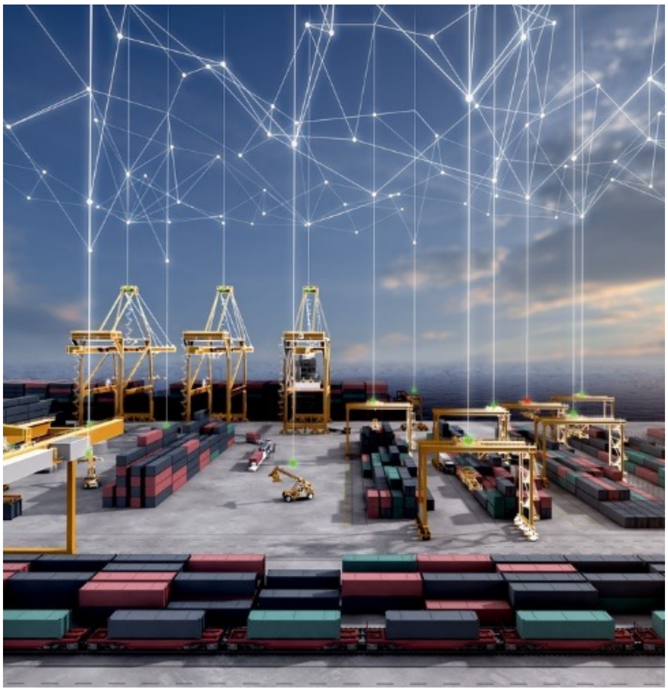
The growth in demand for digital twins and simulation is pushing laser sensor technology into the virtual world. The ability to set up a digital twin with the accuracy of the real world requires the virtualisation of the laser sensors, in conjunction with both the machines' mechanical and control systems. As laser technology becomes more integral to the higher-level function solutions, including lasers in digital twins and simulation platforms becomes equally important. With the digital twin/simulation technology it is possible to identify the optimum mounting positions of the sensors. Using the Digital Twin system enhancements can be proven virtually to minimise impact on the cranes when in operation. Interfaces can be validated, exception case scenarios can be analysed, and solutions modelled more quickly than when testing cranes in the field.

4.7 Condition Monitoring

Gigabits of data are generated in a modern port on an hourly basis. The utilisation of this data can generate major benefits such as optimising service schedules and improving processes.

Digital services such as Condition Monitoring are based on service and process data. Service data enables the sustainable optimisation of service activities, such as need-based maintenance. The continuous monitoring and analysing of process data empowers data-based optimisation and decision-making. As an example, crane travel distances or vehicle speeds can be improved incrementally using such data.

Fig 30: Interconnectivity of data



5. Technology and Laser Choices

Lasers use the time-of-flight (ToF) measurement method as the basis of its technology. It is useful to understand the functional principles and criteria of ToF in order to choose the correct sensor for the application. The first part of this chapter addresses how ToF works in various laser types.

Fig 31: 1D-Laser measurement principle time-of-flight

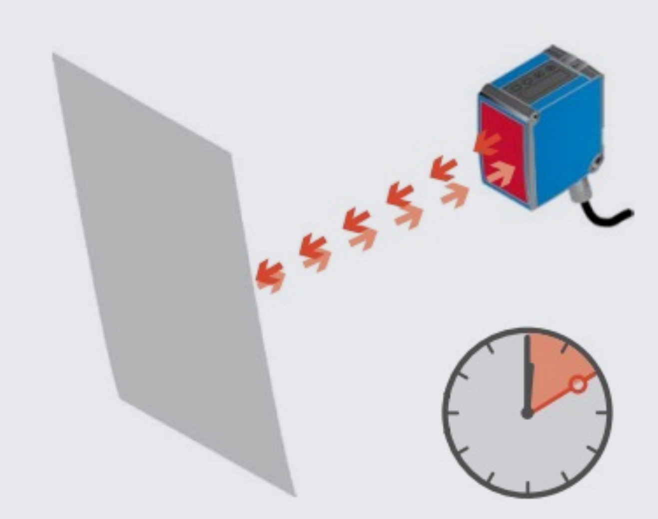


Fig 32: 2D-Laser measurement principle time-of-flight

5.1 Types of Sensors

There are different types of sensors from a number of suppliers available on the market. The market continues to change and evolve as sensor suppliers enter and consolidations take place. The choice of a technology and sensor supplier is critical to the performance and serviceability of the integrated system and the associated solutions.

The first selection decision is how many dimensions the laser should measure. Then other individual parameters must be selected.

5.1.1 1D-Laser

Generally, distance sensor devices consist of the following components:

- Laser diode
- Receiver
- Optics
- Processor with high resolution clock

In operation, the distance sensor sends a laser pulse or a sequence of laser pulses towards the object/ target to be detected. The target can either be a natural object or a retroreflective reflector. The laser light that is reflected by the target is detected by the distance sensor. Using the speed of light as reference, the distance between the sensor and the target is calculated. For enhanced measurement reliability, statistical methods can be used that evaluate a sequence of echoes.

The operating frequency of a distance sensor is up to 20,000 measurements/second. By averaging several measurements, an accuracy of up to +/-2 mm can be achieved.

Depending on the specific application, the measurement range for laser systems in port and terminal applications can range from mm, cm up to 1.5 km.

5.1.2 2D-Laser

The core of a 2D-Laser is the same as the 1D-Laser. However, the 2D-Laser sensor also has a rotating mirror, glass prism, or transmitter -receiver-module. The values from the deflection unit, which combine distance and angle of deflection, can be used together with the other data to create a 2D picture. Depending on the type of sensor used, the deflection unit rotates at 5–150 Hz. This means that the update rate of the 2D profile is between 200 ms and approximately 7 ms.

For the 2D-Laser, the laser distance measurement performance is similar to that of the 1D-Laser. In addition, the angular increments between the laser shots are important. The narrower the laser spots are, the more accurately the edges of an object can be measured.

Fig 33: Inner architecture of the 2D-Laser

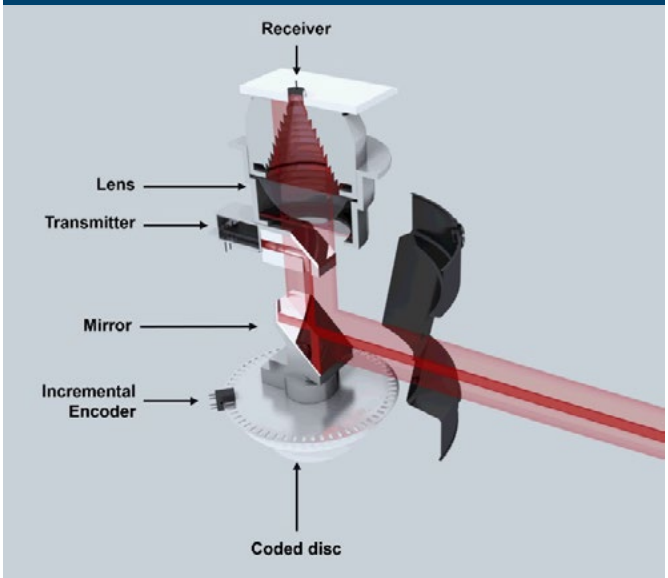
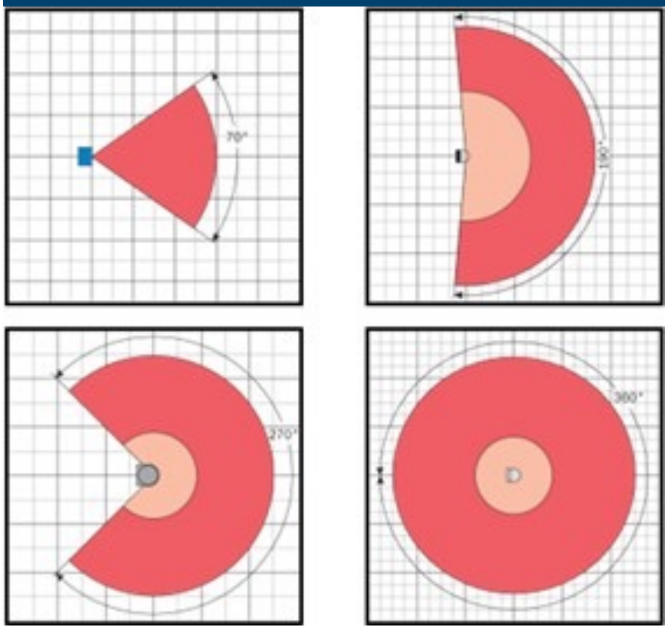


Fig 34: Scan angles 2D-Laser



Typically, the following types are used from 70°, 190°, 270° up to a full 360° angle.

Depending on the scanner type, the measurement distance of a 2D-Laser is in the range from 0.2m – 250m and from 0.2m-120m (on a deep black target with a remission of 10%).

The detection range depends on the reflectivity of the target (remission). A remission of 10% (deep black target) is, for reliability reasons, the value used to describe the detection range.

There are Safety rated 2D-Lasers available in the market for outdoor applications which provide safe functionality up to 4 m.

5.1.4 3D-Laser (2D-Laser + Movement)

The 3D-Laser (2D-Laser + Movement) is based on a 2D-Laser mounted on a swivelling platform with a servomotor that moves (rotates) the platform. The rotation angle of the platform is measured by an encoder integrated in the servomotor, or the encoder may be externally mounted on the rotating platform.

When the 2D-Laser is rotated by the servomotor, the 2D-Laser measurement data is combined with the rotation angle. As result a 3D-Point cloud is created. With this 3D-Laser (2D-Laser + Movement) a very fine resolution point cloud can be generated. The resolution of the swivel axis depends on the swivelling speed. The slower the swivelling speed the better the resolution.

The 2D-Laser in this application has the same performance data as mentioned in chapter 5.1.2 [2D-Laser], the possible angle resolution for the rotation being as low as 0,002°.

These sensors should be used for high accuracy measurement in static object measurement applications.

Fig 35: 2D-Laser on a swivelling platform with servomotor and encoder

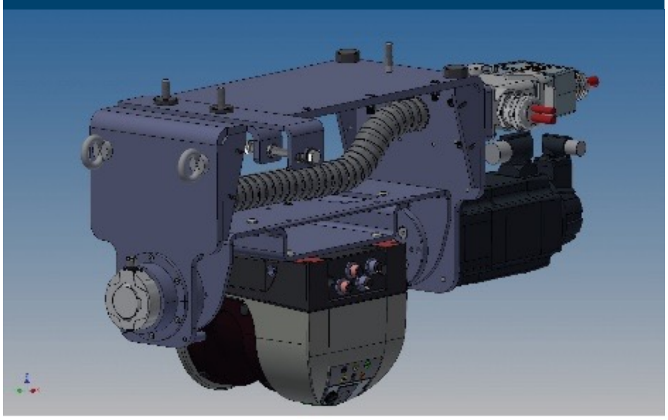


Fig 36: 3D Point Cloud with low point density (left) and high point density (right)

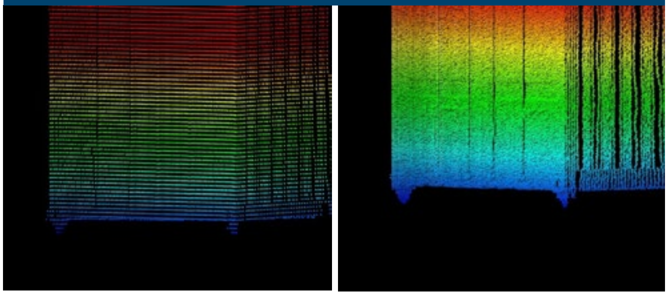
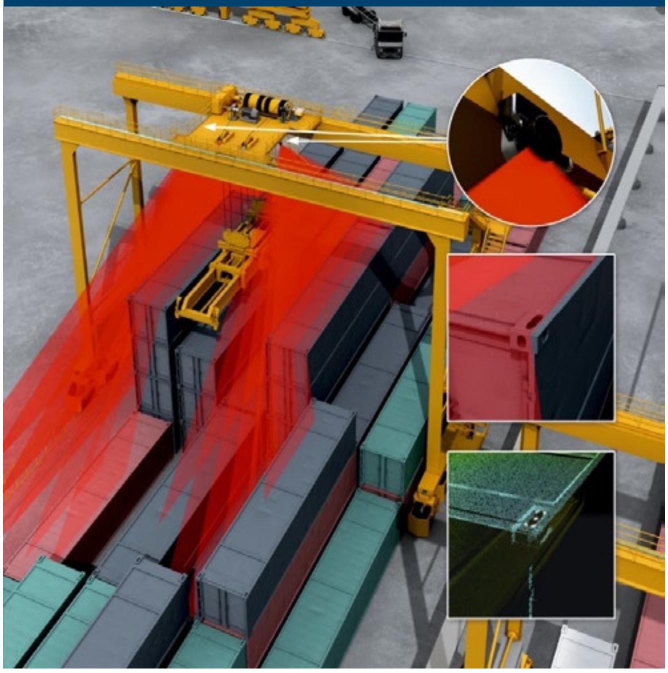


Fig 37: 2D-Laser + Movement for container corner casting detection



5.1.3 3D-Laser

These kinds of sensors are multilayer sensors or 3D-TOF Sensors. The characteristics of these sensors are that they can create a 3D-Point cloud effectively in real time. There are different ways to create this 3D-measurement data as detailed below.

Multilayer-Laser

Unlike a 2D-Laser which creates only one 2D-Scan plane (layer), the Multilayer-Laser sensor, creates multiple scan planes. Typically, a 3D multi-layer laser has between 4 to 128 layers. The performance data for the 3D-Scan data is similar to that of the 2D-Laser. Additionally, the Field of View (FOV) in the vertical axis is important. In this case, typical values are in the range of 12° to 90°.

Depending on the FOV and the number of Laser-Layers the sensor has a defined resolution in the vertical axis.

For example: When using a laser with 64 Layers and a Field of View of 90° then the resolution – i.e. distance between the layers – is 90° / 64 = 1.406°.

Fig 38: 3D-Laser with 90° Field of View (FOW) in vertical axis

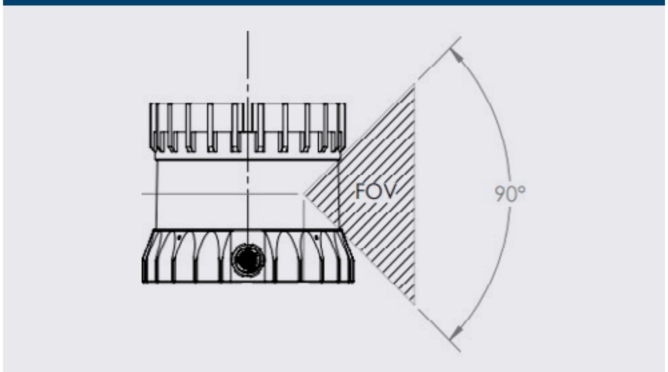


Fig 39: 3D-Laser with 4 - layer

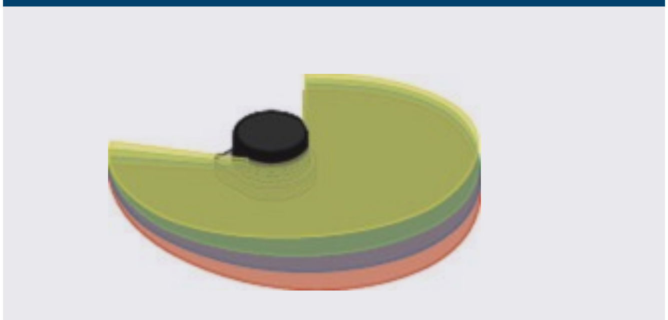


Fig 40: Scanner types

3D-TOF Sensor

A 3D ToF sensor emits infrared light signals within a complete given field of view, which are reflected by all objects in its surroundings. The object distance is either determined via direct measurement of the *time-of-flight*, i.e., the runtime of short emitted light pulses (‘*pulsed 3D ToF*’) or via the phase shift between the emitted and the reflected light of a continuously emitted amplitude modulated light wave (‘*phase-shift-based 3D ToF*’).

All measurement data is available in one laser shot e. Typical scan frequencies are 10 – 50 Hz.

Fig 41: TOF Sensors

5.2 Selection of Sensor

The appropriate sensor selection must be made depending on the application. Key selection criteria are as follows:

- Distance
- Divergence (spot size)
- Angular resolution
- Accuracy
- Scan frequency
- Environmental conditions
- System design/concept
- Data processing unit
- Application software
- Network Data Requirements
- Software API

The following are some general tips when selecting the optimum sensor for an application:

- When the position of an object must be determined in the line of the movement of the object, for example the position of a trolley the 1D-Laser can measure the position.
- When an object must be measured in its position in one or two dimensions, but the sensor cannot be mounted in line with the motion axis, then a 2D-Laser can be used (for example, for truck positioning, only the information about the position of the vehicle in Gantry axis might be sufficient).
- 2D-Lasers can also be utilised to create a 3D-Profile, when the sensor is physically moved in one axis – for example when moving with a 2D-Laser mounted on the trolley above the vessel and combining the 2D-Laser data with the trolley position a 3D-Profile of the vessel can be generated.
- For static and high accuracy measurement applications, the 3D-Laser (2D-Laser + Movement) is the most appropriate. With the high resolution of the 2D- swivelling laser a high density point cloud results in very accurate position determination of an object.
- When an object has to be tracked or when the detected subject is required to interpreted for the proper functioning of the handling process, then 3D-Laser are the most appropriate. e.g., Dynamic area surveillance to track objects/subjects around the crane or in the Truck lifting prevention application for the detection of the lifting of the truck with the container.

5.2.1 Distance (range)

The maximum distance between the sensor and the object must be established to meet the application requirements. Typical applications in ports need sensors with a range of at least 30m, and sometimes up to 80m or more.

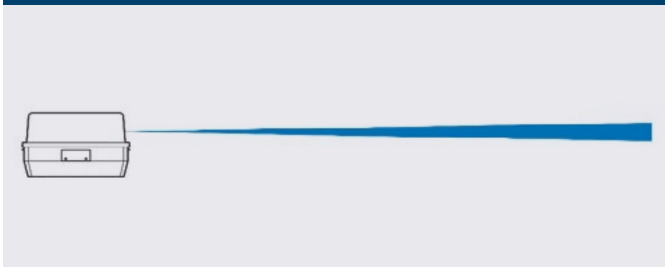
The distance a laser can measure depends on the reflectivity of the target. White is a good reflecting colour, black is a bad reflecting surface. Sensor suppliers quote different distance values in their data sheets, but it should be noted that while most of the applications are on natural surfaces (containers, trailers, etc.), there are occasionally dark surfaces where the reflectivity is reduced to 10% remission or even lower.

5.2.2 Divergence (spot size)

The greater the distance between the sensor and the object, the larger the laser spot. The advantage of a small spot is that small objects can be measured more precisely, for example, twist locks, corner castings or vessel antenna.

The beam divergence is measured in mrad = mm/m. The value describes the increase of Xmm per m distance. Typically values for outdoor scanners range from 0,4 mrad up to 10 mrad.

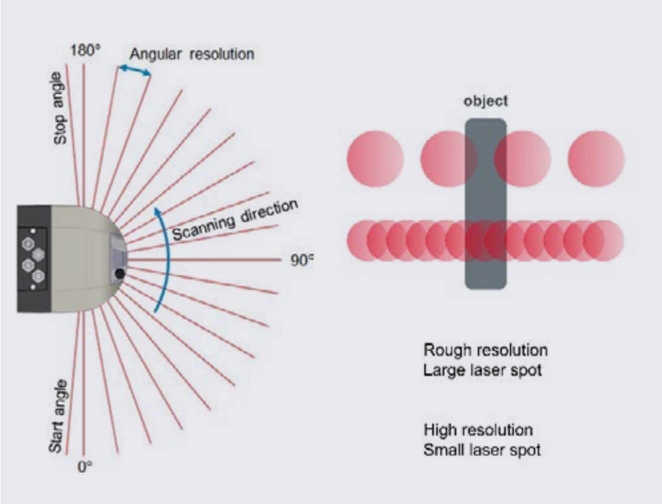
Fig 42: Divergence of laser beam



5.2.3 Angular Resolution

The angular resolution describes the angular steps of the laser deflection unit in the sensor. This can be achieved via rotation or the optical system. Typical angular steps are between 0.0225° to 1° for the 2D-Laser. These steps have an influence on how accurately the shape/position of the objects can be detected. For the 3D-Laser (2D-Laser + Movement) the rotation speed and the scan frequency are fundamental for the resolution. In the case of the 3D-Laser the resolution in the vertical scan axis depends on the angle between the layers.

Fig 43: Scan angle, angle steps and spot size



5.2.4 Accuracy

The accuracy of the sensor can be expressed by the distance accuracy for each laser beam. The distance between the spots, the size of the spot at a certain distance and the scan frequency are very important when determining the position of an object in the 3D-Space.

5.2.5 Scan Frequency

The typical pulse frequency of 1D-Laser is up to 20000 Pulses/second. The 2D-Laser has a scan frequency – i.e. the rotation of the deflection device, of between 5 and 150 Hz. With the 3D-Laser (2D-Laser + Movement) the 2D-Laser can be rotated to a max. angle of 180°/s (typical). The 3D-Laser has a scan frequency of 5 – 50 Hz.

The scan frequency is one of the most important factors to be considered for laser applications as it indicates how often objects can be detected. This becomes important when objects to be detected are in motion as the number of scans must be high enough to track the movement, and the system needs to match the speed of the object in motion with an appropriate frequency.

Every laser type has a certain trade-off between resolution and frequency. At higher scan rates, the angular resolution decreases. If process times are to be shortened, the possible combination of both values, the so-called frequency to resolution ratio, must be considered.

5.2.6 Condition and Diagnostic Features

Sensor data like contamination indication or IMU (inertial measurement unit) can provide important information about the device status. Such information can be accessed as a remote service feature for monitoring, analysing and predicting service and process data. Of particular importance is that a continuous evaluation of sensor contamination is required as a standard integrated feature of a laser device. With this functionality, an immediate indication of the sensor availability is possible, either through direct on-device information (warning/error) or through measured values transmitted for external evaluation.

Software filters are used to mitigate external factors and provide robust scan data even under harsh conditions, e.g. by suppressing disturbances like rain, fog, dust or glaring lights.

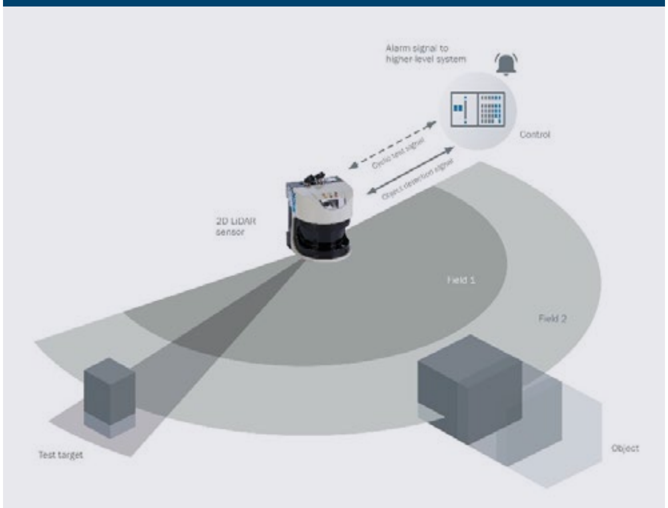
Sensors typically include a self-test function ensuring that the 2D-Laser continuously detects the test target and sends correct switching signals.

If a correct response is not received, the controller is locked and sends a fault signal to the higher-level machine controller. The connecting cables are also cyclically monitored. The high level of diagnostic functionality included in the device assists with obtaining individual safety certifications for machines.

Diagnostic Functions:

- Cable or wire break
- Missing test target
- Short to ground or crosstalk
- Misaligned sensor
- Physically defective switching output

Fig 44: Sensor function and alignment checks over external target



5.2.7 Environmental Conditions

Very harsh environmental conditions prevail in ports and terminals. In order to operate in this industry optical sensors and systems-specific technical solutions capable of dealing with weather conditions like snow, rain, fog, moisture, dust, etc., as well as shocks and vibrations are required.

The robustness is ensured by features included in the sensors themselves, and is also enhanced and ensured with filter and logic functions in the system solutions.

Robustness of Sensor Equipment

It must be ensured that the selected sensor and its accessories are suitable for the proposed application. This specifically should be assessed in the context of mechanical and weather-related influences as highlighted above. Furthermore, the electrical integration, mechanical connections/ fixings, sea air and other special local conditions must be considered.

Multi-Echo Technology

The transmitted beam may encounter various weather conditions such as rain, fog, dust, etc., and other interfering objects. Each of these creates a reflection of the transmitted laser beam (an echo), which is received by the laser.

Disturbing objects include:

- windows / glass
- rain drops
- steam / fog
- snow
- foils
- dust

By filtering out unwanted echoes, multi-echo technology ensures reliable object detection even under unfavourable environmental conditions and other interference sources. The reflected light and echoes are matched by high-speed scanning and thus identified as interfering objects that can be ignored in the software. For example, if the scanner is behind glass, the glass will reflect light back to the receiver as it becomes dirty. As soon as the level of this reflected light exceeds a certain threshold, an echo is generated. This first echo is confirmed by the scanner but can also be ignored depending on the filter setting.

Fig 45: 5 echo technology

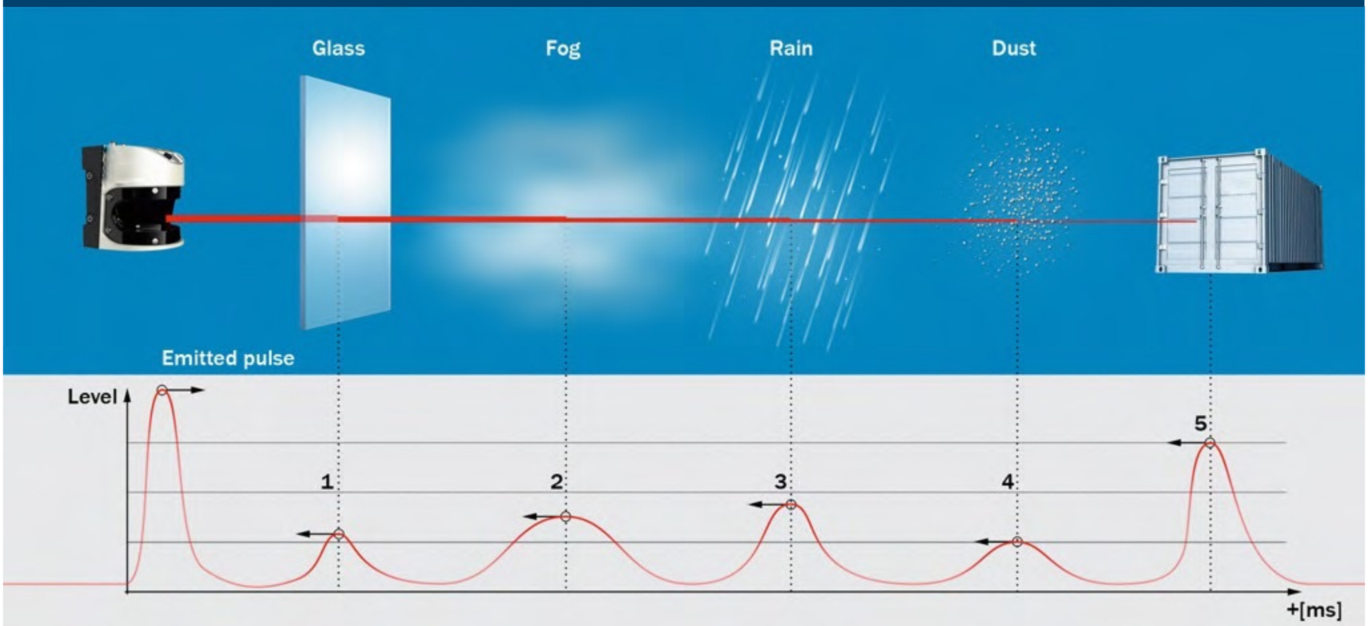
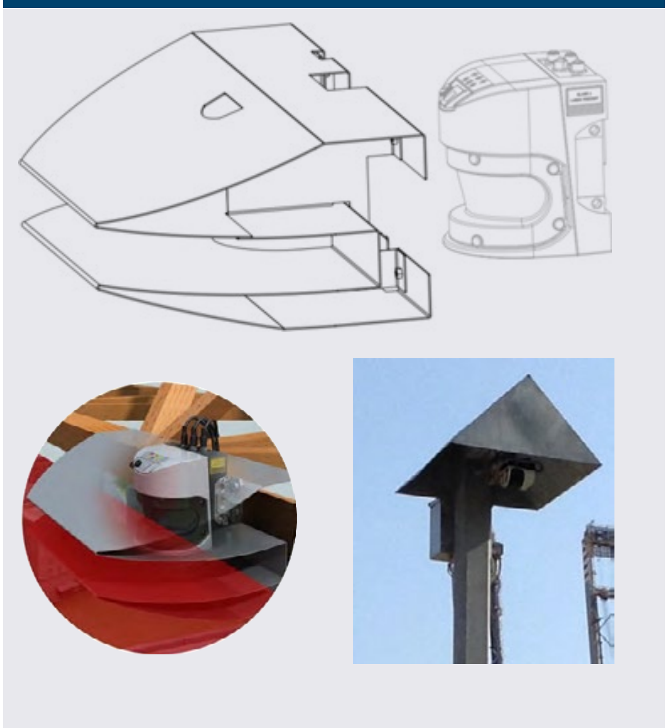


Fig 46: Extreme environmental application

Weather Accessory

The impact from weather conditions such as snow and rain can be minimised by using mechanical solutions, such as the installation of a mounted weather hood, which shields the optical lens from snow and rain. The effect of sunlight, another disturbing factor for optical systems, can also be reduced using a weather hood. In hot climates a weather hood and sunroof can significantly reduce the potential for sunlight to heat the sensor above its permissible operating temperature range. The use of a simple weather hood (and/or sunroof for some climatic areas) is therefore highly recommended.

Fig 47: Extreme environmental application



5.2.9 Data Processing Unit

State-of-the-art distance sensors use highly complex signal processing algorithms for enhanced sensing performance and reliability even under harsh conditions. The distance sensors typically provide distance threshold information (e.g., for anti-collision applications) and/or distance values (e.g., for container stack profiling) to the control systems to which they are connected.

In addition 2D and 3D-Laser solutions can capture high density contours and point clouds which require intelligent data processing. This cannot be done by the PLC control systems of the cranes because the data rates of the scanners are too high, and during commissioning and maintenance it is necessary to verify the received information independently of the PLC. Therefore, an extra controller with the appropriate application-specific software is required.

The data processing unit is a high-performance processing platform for high-speed evaluation of the measurement data of the sensor and for the generation of results. Typically, it is an industrial PC with a Windows operating system.

5.2.10 Application Software

The data processing unit should include all software tools to include the following functions:

- Communication interface to laser sensors
- 2D and 3D visualisation of the measurement data
- Status and event message handling
- Algorithm for object capturing and position determination
- Filtering of data (defining what is of ‘interest’ in the field of view)
- Calibration user set-up and maintenance modules
- Well-designed interface to the crane control PLC system

Conclusion

The port of the future is more and more automated. To support automation, laser devices are the most commonly used sensors that are the eyes of the machines.

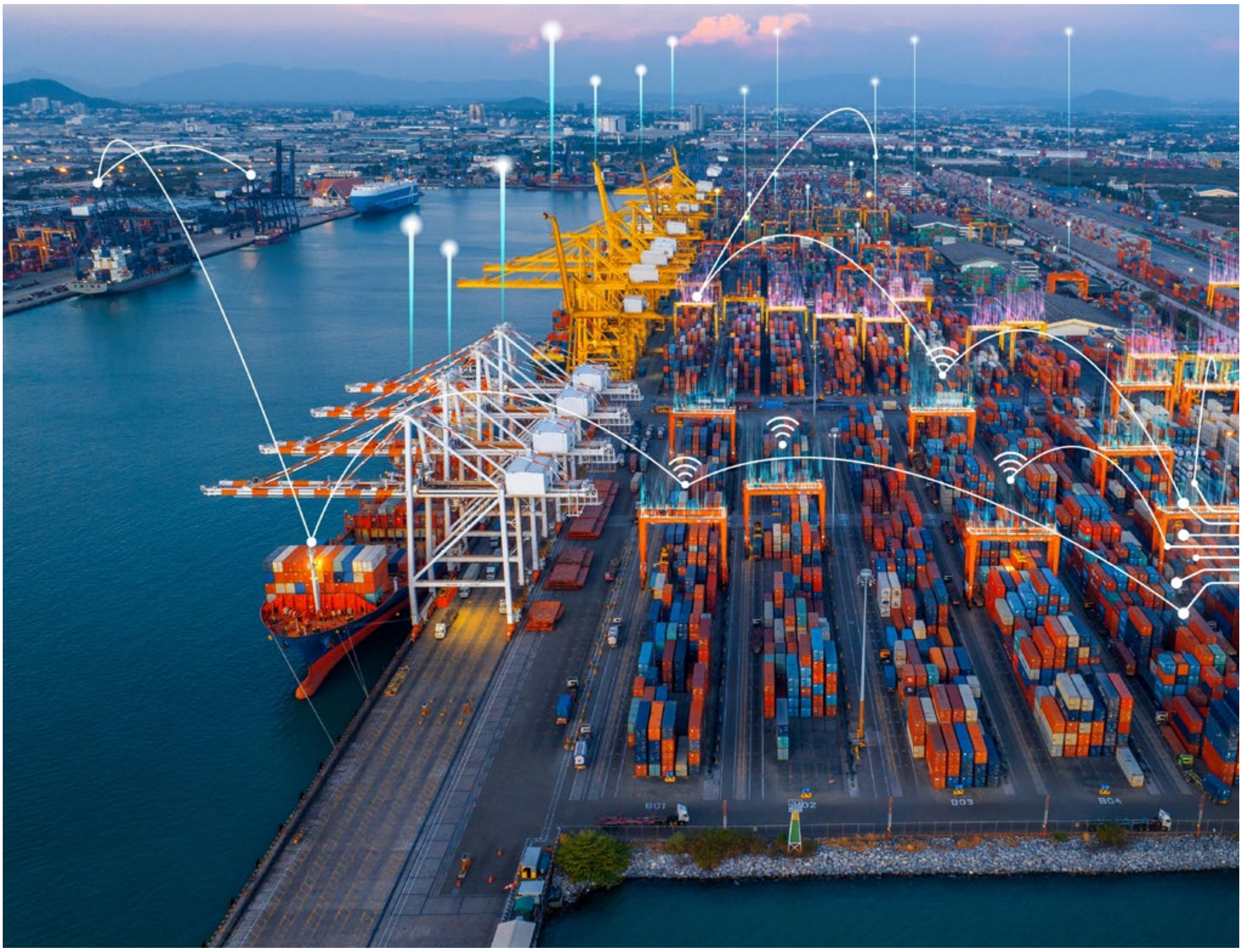
New laser technologies that have emerged from developments in the automotive industry have found their way into the port sector. This is one of the factors why the variety of laser solutions has grown over the years and continues to grow.

The port operators make safer operation a top priority, not only because accidents lead to downtime, but also because a poor safety record can affect relationships with shipping companies and the community beyond the port.

Keeping vulnerable personnel out of the way of yard, quay and gate operations as much as possible would seem to be the way forward, and automation of handling activities is one key way to achieve this.

The port operator must select the right sensor and solution according to his or her needs.

This document hopefully has provided a good overview of the types of sensors and application solutions that are available on the market that are applicable to the port and terminal industry.



About the Authors and PEMA

About the Authors

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About PEMA

Founded in late 2004, PEMA's mission is to provide a forum and public voice for the global port equipment and technology sectors, reflecting their critical role in enabling safe, secure, sustainable and productive ports, and thereby supporting world maritime trade.

Chief among the aims of the Association is to provide a forum for the exchange of views on trends in the design, manufacture and operation of port equipment and technology worldwide.

PEMA also aims to promote and support the global role of the equipment and technology industries, by raising awareness with media, customers and other stakeholders, forging relations with other port industry associations and bodies; and contributing to best practice initiatives.

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- Manufacturers and suppliers of components or attachments for port equipment
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Laser Technology in
Ports and Terminals

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