Laser Technology in Ports and Terminals

A PEMA Information Paper

This Information Paper is intended to provide a high-level overview of the use of laser technology in the ports and terminals sector. The document describes how laser technology works and how it is used today in port and terminal applications, both manned and automated. The various types of laser system are reviewed in depth, together with a detailed overview of technology deployment in ship-to-shore, yard, horizontal transport and gate operations.

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INTRODUCTION

DOCUMENT PURPOSE

This Information Paper is intended to provide a high-level overview of the use of laser technology in the ports and terminals sector. The document 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 conservancy.

Further Information Papers, Surveys and Recommendations from PEMA and partner organisations can be downloaded free of charge in PDF format at: www.pema.org/publications

1 | BACKGROUND

Time is money: despite the economic downturn of recent years, many ports are today facing congestion problems, some have labour issues, and many are looking at growing competition. The recent and continued rapid increases in ship sizes and call exchanges, both on primary and secondary trades, add a further new dimension. Alongside these challenges is the cold 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 has to 'see' and position itself to a very high degree of accuracy.

So, while the workflow is potentially higher, more consistent and safer than for manned operations, there has to be a (limited) ability to accommodate adjustments. As unmanned operations also do not imply that there are no people on the terminal, there is also a need for safety devices that can recognise and respond to potentially dangerous situations. Both of these areas depend heavily on recognition technology, such as that provided by laser devices or systems.

1.1 CURRENT SITUATION

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

Today, there are well over 30 automated terminals in operation in Asia, Australia, Europe and the Middle East, with further large-scale projects now under development in Europe, Asia and the Americas.

One thing that the vast majority of these terminals have in common is the use of ASCs in the storage area. The approach to horizontal transport is less consistent, however a number of current and planned facilities have partly or fully automated this activity with the use of handling equipment such as AGVs, semi-automatic trucks and driverless shuttle carriers.

New projects on a smaller scale than these are also beginning to use ASCs for the storage area and hinterland operations. What is more, manually operated terminals are also implementing laser technology to improve safety.

2 | DEVELOPMENT AND UTILISATION

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

Laser equipment has benefitted from many years of industrial application in developing resilience against the difficult conditions of the port terminal environment. However, the largest challenges concern not the hardware itself, but the application software – an issue that is now being overcome thanks to the last decade's explosion of computing and programming potential.

Among many other applications, laser technology is now commonly used in ports to:

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

3 | APPLICATION SOLUTIONS AND FEATURES

Laser technology is a key component of fully-automated and semi-automated terminals, assisting in the efficient and safe running of such facilities. Attached is a list of application solutions and features that can be solved with different types of laser technology:

Application solution	Feature	Laser technology			
		1D laser device	2D laser scanner	Multi-layer laser scanner	3D laser scanning system
Stack profiling	Ensuring accurate container stacking		●		●
Vessel profiling	Facilitating spreader positioning over the bay of a ship	●	●		●
Truck positioning	Positioning crane over truck, or enabling automatic container handover between crane and truck		●		●
Trolley positioning	Ensuring accurate trolley position to load	●			
Spreader positioning	Ensuring accurate spreader position to load	●	●		
Container distance detection	Providing accurate distance from spreader or trolley to container	●			
Telescope positioning detection (reach stacker)	Providing accurate distance of reach stacker telescope end	●			
Guidance of E-RTG	Position and guide E-RTG on power bar or other object	●	●		
Boom collision prevention	Ensuring high diagnostic collision prevention between STS crane boom and vessel while operating		●		
Pathway & cross travel collision prevention	Ensuring high diagnostic collision prevention in crane pathway direction (at RTG as well as cross travel collision prevention) while operating		●	●	●
Crane-to-crane collision prevention	Ensuring collision prevention between cranes while operating	●	●		
Stack collision avoidance	Ensuring collision prevention between the handled container and top container row in the stack		●		●
Twin-twenty detection	Ensuring accurate detection of 2x20 ft container or 1x40 ft container before spreader use		●		
Anti-truck lifting	Avoiding trucks being accidentally lifted during container handling because of locked twistlocks		●		
Damage detection	Providing automated damage detection on container		●		●
Driver assistance system (lift truck)	Providing assistance system for lift truck driver. (especially for reach stacker back drive)		●	●	

3.1 SHIP-TO-SHORE CRANE (STS)

3.1.1 TRUCK POSITIONING

The truck has to position the container and trailer centrally under the STS crane trolley, so that the container can be dropped or picked up without any gantry drive, or without leaving the bay. There are two solutions on the market: a 2D laser scanner in each lane or a single 3D laser scanner covering several lanes.

Graphic: 2D laser scanner solution, using one 2D laser to measure the position of the truck in gantry drive direction and another in trolley drive direction

3.1.1.1 2D laser scanner solution

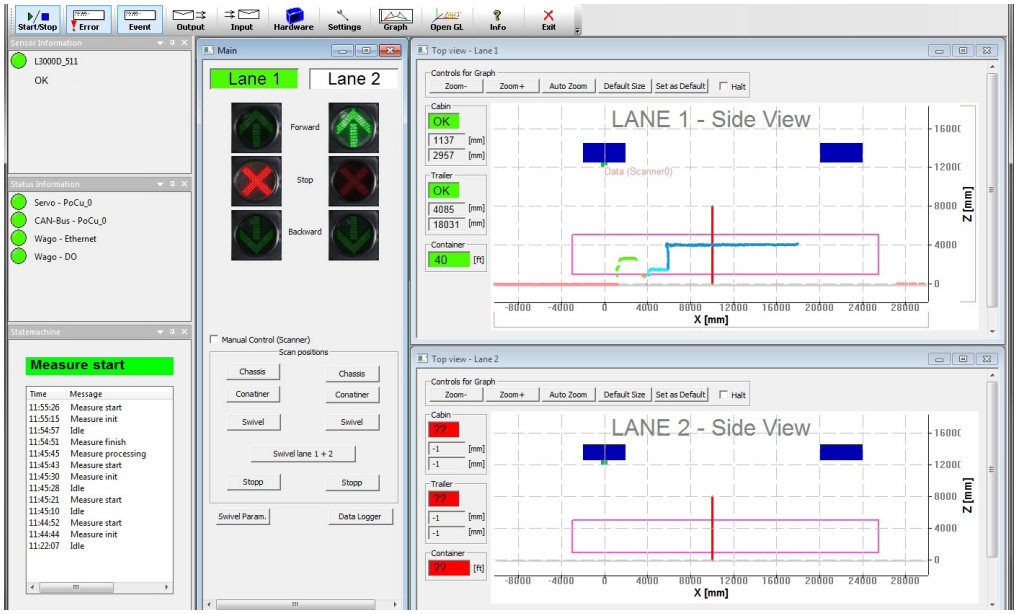
In each lane a 2D laser scanner is placed on the STS crane portal beam and the scan plane is set vertically along the lane. By extracting distinctive spots like the front and back edge of the trailer and the driver's cabin from the 2D profile, the exact position can be determined.

The same holds true for the ship loading process. In this case the containers on the trailers are measured, and the front and rear edges of the container are calculated from the 2D profile.

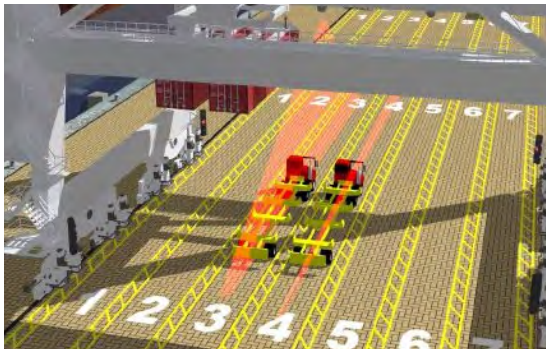
3.1.1.2 3D laser scanner solution

In this solution one or more 3D laser scanners are mounted on the STS crane portal beam. As well as determining the container's position in relation to the gantry drive, it is also possible to measure the container in relation to the trolley orientation. The 3D laser scanner solution also has the ability to identify non-aligned vehicles. As a result, the trolley and spreader rotation can be pre-positioned to ensure a faster handling process than with the 2D system.

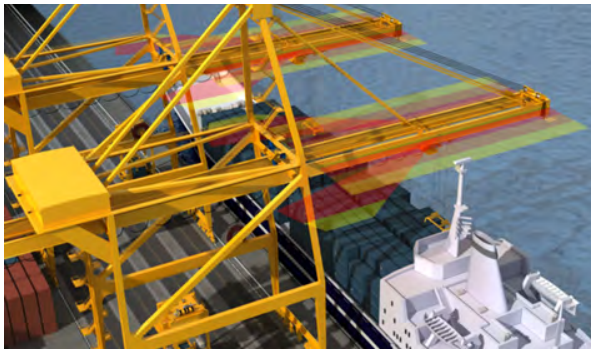
Using 3D laser scanners also improves performance during double hoist or double spreader handling operations, because the relative position of the container/trailer can be measured so that the spreaders can be pre-positioned.



Graphic: Typical software mask of a laser application, with result, status, error and event information, for both 2D and 3D visualisation of the raw data



Graphic: 3D laser scanner solution with parallel positioning of the trucks



Graphic: Boom collision prevention and crane-to-crane collision prevention

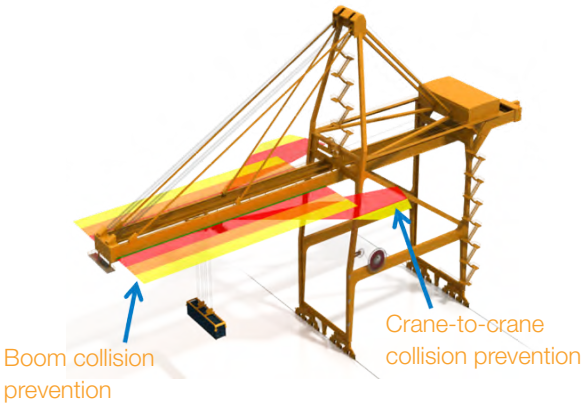
3.1.2 AGV POSITION DETERMINATION

The AGV is guided via GPS, transponders and/or other measuring methods for container handling to/from STS cranes. To verify the relative position between the AGV and the STS crane, 3D laser scanners are mounted to the STS crane.

After the AGV reaches the target position, the 3D laser scanner 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 container, will be determined in its gantry and trolley drive direction and also in its rotation around the vertical axis. The trolley and spreader can then be positioned by the crane control.

3.1.3 BOOM COLLISION PREVENTION

To avoid collisions between the crane boom and vessel superstructure, 2D laser scanners can be installed in such a way that horizontal surveillance fields are created under the boom. If any structures are detected within the surveillance fields during the crane's gantry drive, a warning message with alarm signal or, in emergency cases, an automatic stop will be generated. The laser scanner provides a quantity of parallel available field sets such that, with the same scanner, next-to-boom collision prevention as well crane-to-crane collision prevention can be provided. Current sophisticated solutions, in combination with the 2D laser scanner, provide high diagnostic coverage of the laser scanner functions and scanning field position at any time.

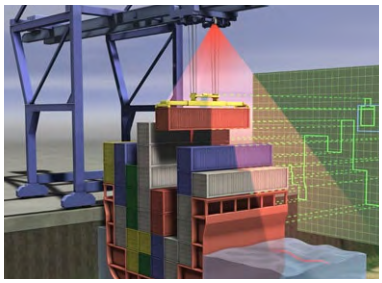


Graphic: Surveillance field with different zones

3.1.4 VESSEL PROFILING

For a collision-free spreader drive over the bay on the ship, a single dimension (1D) laser distance meter or 2D laser scanner can be installed on the trolley. The trolley position combined with the laser distance values, gives a 2D profile of the bay.

Comparing the actual position of the spreader with the profiling data prevents collision. Additionally a 'soft landing' for the spreader can be achieved based on stack height information, giving a suitable hoist speed when near landing position.



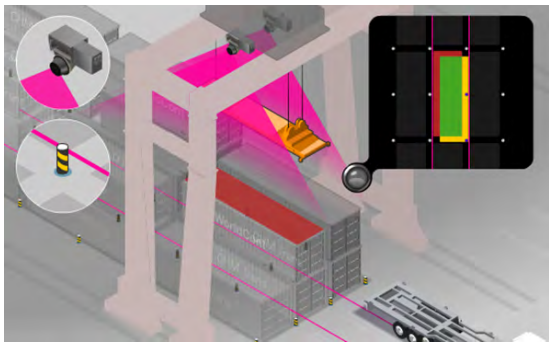
Graphic: Vessel profiling for collision prevention and soft landing

3.2 AUTOMATED STACKING CRANE (ASC)

Precise measurement of container position in the stack is a prerequisite for automated yard crane operations.

3.2.1 ACCURATE STACKING IN THE YARD

Containers are usually stacked in bays with a gap of approx. 400mm. However, tolerances are tight and it is critical to avoid one container extending into an adjacent stack and to ensure that corner castings of the stacked container overlap. Anomalies caused by ground subsidence or rail tracks complicate matters further.



Graphic: Two 3D laser scanners (red scan planes) measure the position of the container for automatic operation

3.2.1.1 2D laser scanner solution

By using 2D laser scanners installed on the trolley, the position of a container in the stack can be measured. Pairs of 2D laser scanners can measure the 20ft, 40ft and 45ft slots from the gantry drive's perspective. A further 2D laser scanner measures the container's positions from the trolley drive's perspective.

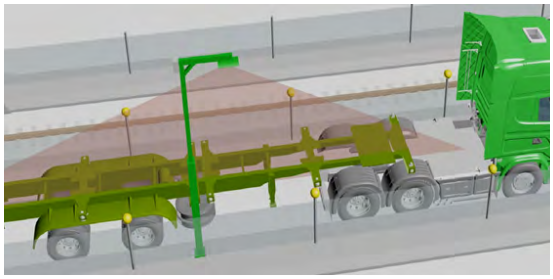
3.2.1.2 3D laser scanner solution

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

3.2.2 AUTOMATIC CONTAINER HANDOVER BETWEEN ASC AND ROAD TRAILER

Based on the previous description of 3D measuring technology for accurate container stacking, it is also possible to automatically drop containers onto a road truck chassis.

Due to the fine scan resolution and small laser spots, even the twistlocks can be detected. The position of the trailer is detected by laser scanners on the crane or through additional laser scanners positioned next to the truck lanes.

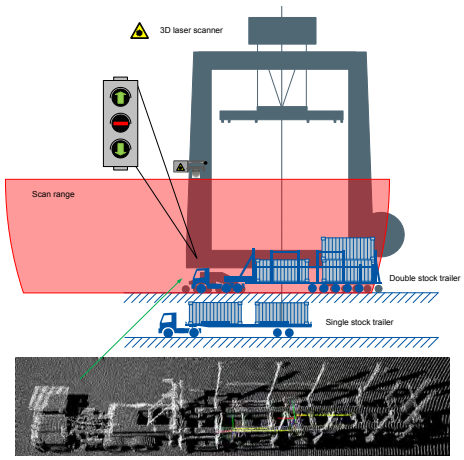


Graphic: Twistlock position measurement by a 3D laser scanner for automatic drop on road trailer

3.2.3 AUTOMATIC CONTAINER HANDOVER BETWEEN ASC AND TERMINAL TRAILER

Terminal trailers remain the workhorse for the internal transport of containers. The drive for better truck fleet utilisation and handling productivity has also spurred the development of multi-box systems, built for transporting 2x40ft or 4x20ft containers without the need for interlocks between the containers. For the positioning and measuring of these trailers, 3D laser scanners are already in use.

The position of empty trailers, and/or selected containers for off-loading, is detected by a 3D laser scanner located in the ASC transfer lane. Additionally, the laser scanner is able to detect the cabin location after the trailer has been positioned. This cabin location is used as an 'assistant system' to prevent damaging the truck cabin, or injuring the driver, during the handover procedure.



Graphic: Positioning and load position measurement on multi-box trailer by a 3D laser scanner (red scan plane)

3.3 RUBBER TYRED GANTRY CRANE (RTG)

The rubber tyred gantry crane (RTG) is one of the most widely used types of equipment in yard operations. Like other equipment types, the RTG presents various operational, asset utilisation and safety challenges that laser technology can help to address.

Graphic: RTG gantry collision prevention by 2D laser scanner with a warning and alarm surveillance fields

3.3.1 GANTRY COLLISION PREVENTION

In order to reduce risk and provide interruption-free operation processes at all times, as well as to enable a high level of efficiency in this application, four 2D lasers mounted on the RTG crane can scan the surrounding area during the drive.

The 2D scanner can evaluate multiple fields at the same time. This functionality can be combined with a sophisticated system enabling the highest level of diagnostic coverage, including pre-configured fields for warning, deceleration and stop.

The system can also be adapted to specific user requirements. Evaluation features include the blanking of objects, reference contours etc. Fields can change dynamically, depending on the status of the inputs.

The scanner will automatically detect all possible obstacles in the travel pathway, as well as automatically identifying the direction of cross travel. The RTG is able to stop appropriately.

The combination in a sophisticated system features self-testing functions with software installed to constantly check the availability of the laser scanner system regarding all configured field sets and installation position.

For the self-testing functionality, the system controller uses a fixed test target, such as the legs of a crane, and cyclically checks all scanner functions against this specific target. Incorporation of the laser scanner within the self-testing system provides a high degree of diagnostic coverage and system reliability.

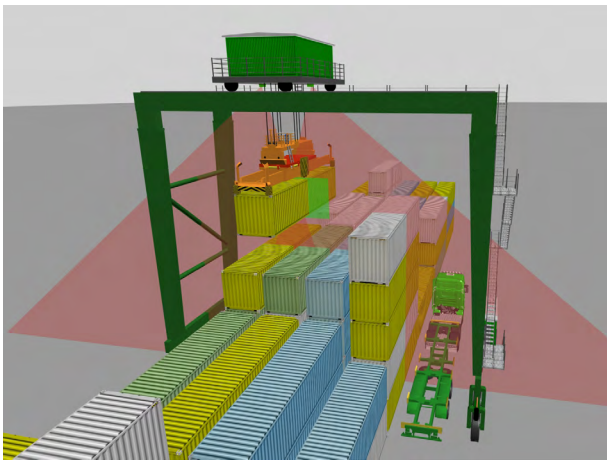
Graphic: 2D laser scanner installed on the RTG

3.3.2 STACK COLLISION PREVENTION

The use of 2D or 3D laser scanners enables stack profiles to be scanned in order to prevent a collision between the loaded spreader and the stacked containers.

If no gantry drive is processed during the trolley drive, 2D container profiling might be sufficient inside the bay.

In the case of gantry drive or of containers extending into the space from adjacent bays, a post-pickup container profile has to be implemented by a 3D laser scanner to optimise the path and to avoid collision.

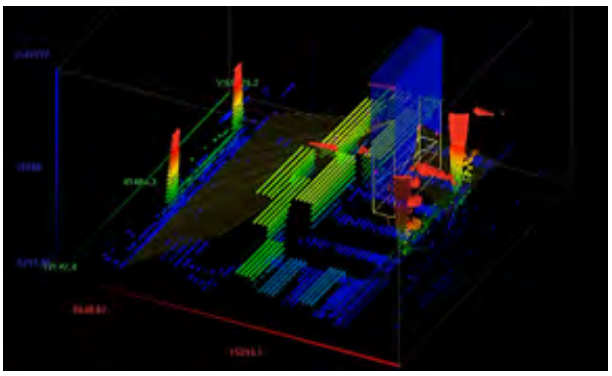


Graphic: 2D laser scanner for stack collision prevention

Graphic: Possible collision appearance, therefore surveillance cube is red and crane has stopped the move

3.3.3 TRUCK POSITIONING

In this application, a 2D laser scanner, installed on a leg of the RTG, scans the truck lane and determines the position of the trailer. The RTG driver receives feedback about the relative position of the truck to the RTG through a traffic light indicator. This system is also applicable to cantilever ASCs.



Graphic: 3D raw data profile measured by a 3D laser scanner, with surveillance cube around the load

3.4 STRADDLE CARRIER (SC), AUTOMATED GUIDED VEHICLE (AGV) AND AUTOMATIC TRUCK (AT)

Collision prevention solutions for the straddle carrier (SC) have a similar set up to the RTG application. Four laser scanners are mounted on the chassis to scan the area around the SC. If an object moves into the monitored area, an alarm is given and the automatic controller stops the operation.

As an extra precaution, a 2D laser scanner can be mounted to the front and back of the AGV to help prevent collisions between AGVs or to prevent the AGV running into items like surrounding fences.

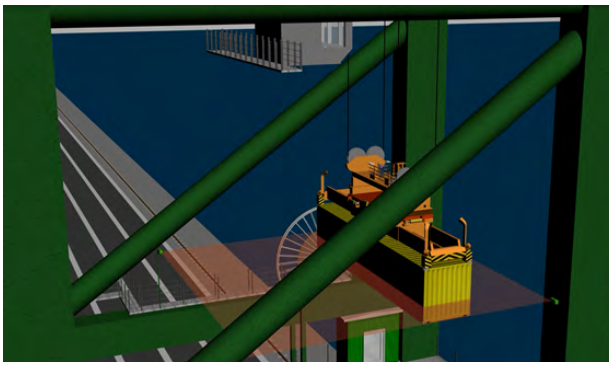
In case of automated guided SCs, four multi-layer laser scanners can also be installed. This type of scanner provides more information about the surrounding area and movements over rough ground.

Graphic: Straddle carrier with 2D laser scanner

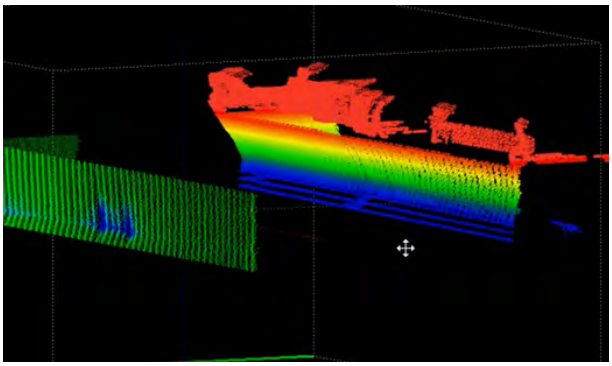
3.5 CONTAINER DAMAGE INSPECTION

As containers enter the terminal, they have to be checked for damage. By means of two 2D laser scanners, which create a light curtain, and one further 2D laser scanner for the measurement of the vehicle position, a 3D container profile can be generated. This will automatically detect dents, general deformations or holes in the container.

The 3D laser profile can be stored with an image to protect the terminal operator in case of any dispute over damaged containers or cargo. Damage inspection can take place at the gate, on the ship-to-shore crane or on rail.

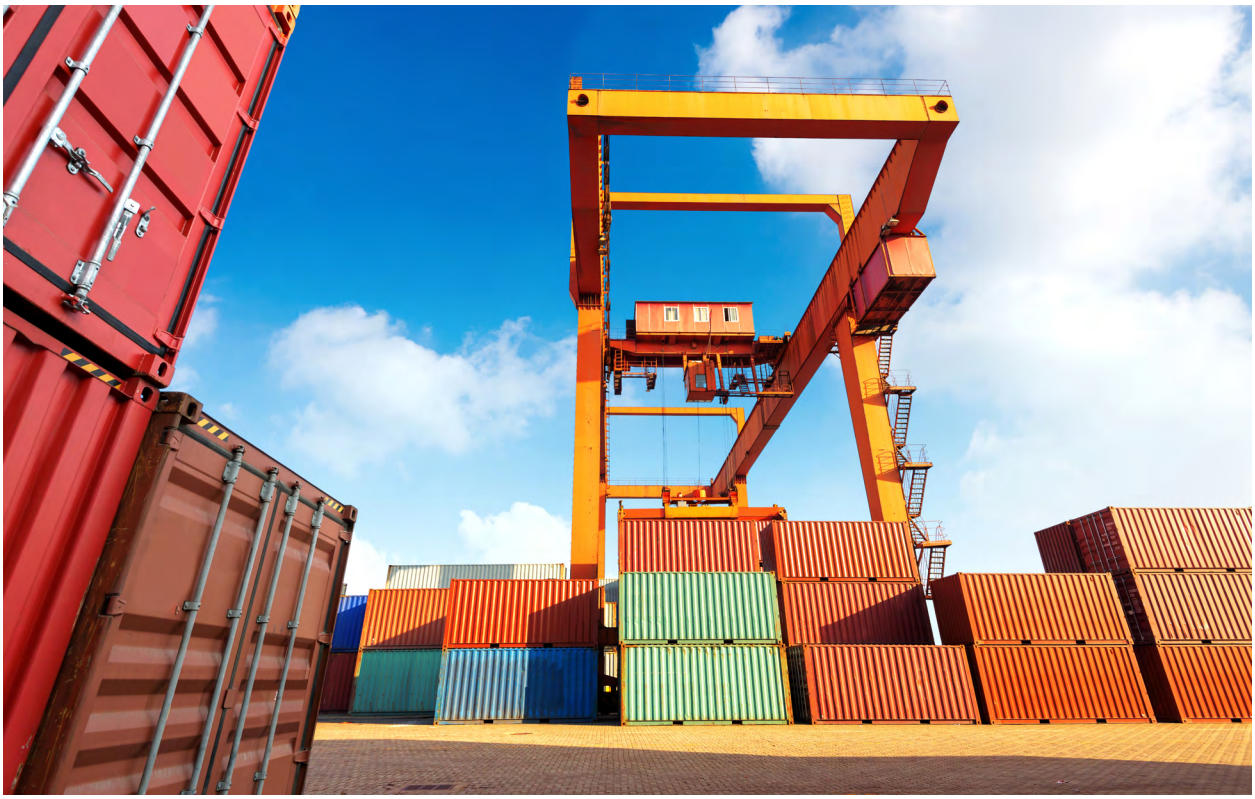


Graphic: Container damage inspection with two 2D scanners, building a horizontal light curtain (red plane)



Graphic: Raw data from one 2D laser scanner, turned during the lowering process. Final result with significant damage in the center of the container (coloured in blue)

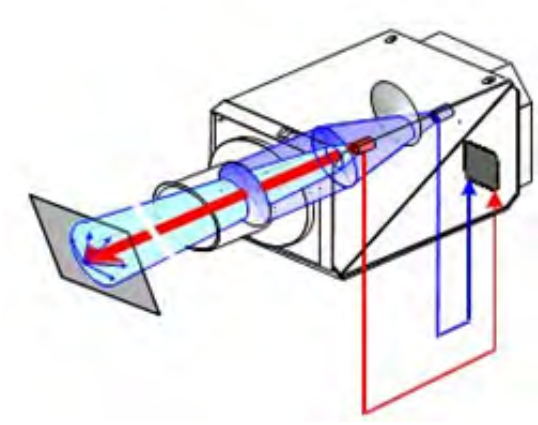
Graphic: Truck profiling with the scan plane generated by two 2D laser scanners



4 | TECHNOLOGY AND LASER CHOICES

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

Graphic: 2D laser scanner - time of flight principal



Graphic: 1D distance measurement system

4.1 TYPES OF LASER

There are different types of laser. Each has its place and cost/benefits, depending on what is needed in any particular application.

4.1.1 SINGLE DIMENSION (1D) DISTANCE MEASUREMENT

Generally, single dimension (1D) laser meters consist of the following components:

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

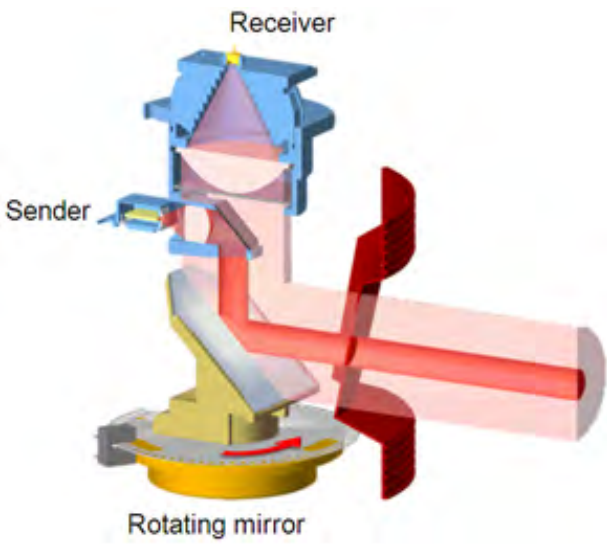
In operation, the laser diode sends a laser impulse while the clock starts counting time. When the laser beam hits the target (either a natural surface or a reflector), some of the light will be reflected back. This stops the clock and the time taken at this point is used to calculate the distance between sensor and object.

The frequency of a 1D laser is up to 20,000 measurements/second. By averaging several measurements, accuracy can be as high as +/-2 mm.

Depending on the specific application, the measuring range for laser systems in port and terminal applications can go from mm/cm up to 1km.

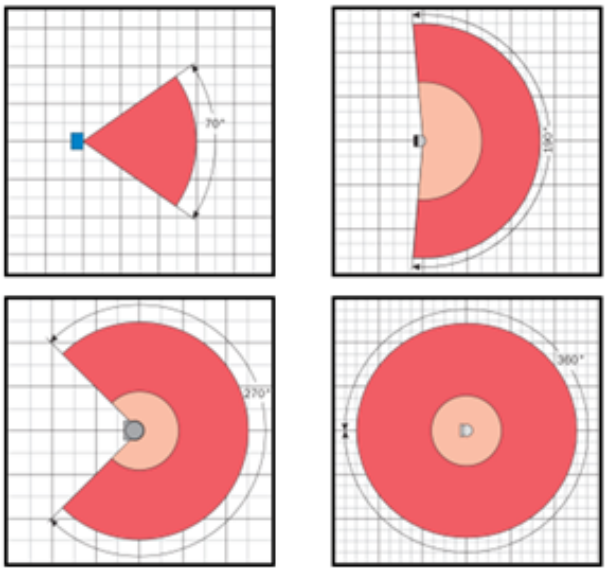
4.1.2 2D LASER SCANNER

The core of a 2D laser scanner is the same as the 1D laser measurement sensor. However, the 2D laser scanner also has a rotating mirror or glass prism. The readings from the deflection unit, which combine distance and angle of deflection, can be used alongside the other data to generate a 2D picture. Depending on the type of sensor used, the deflection unit rotates at 5–100 Hz. That means the actualisation rate of the 2D profile is 200 ms down to 10 ms. Accuracies are similar to the 1D laser measurement sensor.



Graphic: Inner architecture of the 2D laser scanner

The field of view that a 2D laser scanner can verify depends on the laser scanner type. Typically the following types are used from 70°, 190°, and 270° up to a full 360° angle.



Graphic: Scan angle 70°, 190°, 270° and 360°

Depending on the scanner type, the measurement of a 2D laser scanner ranges from 10m-80m (on deep black target with a remission of 10%).

The detection range depends on the target reflectivity (remission).

A remission of 10% (deep black target) is, for safety reasons, the value used to describe the safety detection range. In general there are two operation modes which can be used for a 2D laser scanner:

- Detection with field evaluation cases, which triggers 'simple' switching outputs. For example, this function can be used in collision prevention cases where warning and stopping fields can be freely configured to the individual case
- Ranging, which uses the measurement data of the laser scan to generate a profile of the environment or an object. This type of operation is used in positioning applications or stack profiling for load collision avoidance

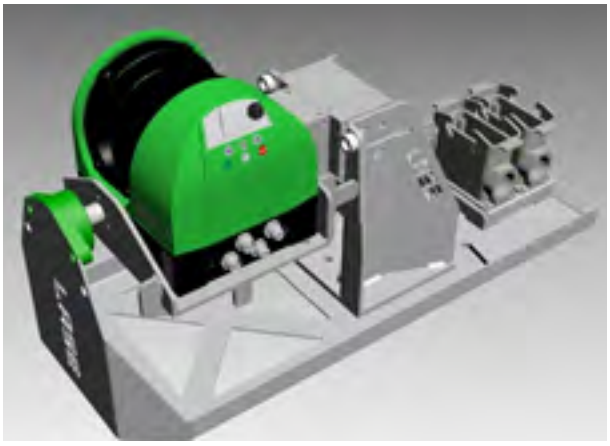
4.1.3 MULTI-LAYER 2D LASER SCANNER

The multi-layer 2D laser scanner has the same principal function as the 2D laser scanner but in layers ('multi-scan planes') which differ in vertical aperture angles.

Graphic: 4 scan planes

4.1.4 3D LASER SCANNING SYSTEM

The 3D laser scanning system works with two different methods to generate a third dimension: either by a rotating 2D laser scanner or through deflection of the laser beam by a second rotating mirror unit.



Graphic: 3D laser scanner

4.2 CHOICE OF SENSOR

Appropriate choices need to be made depending on the application. Key selection criteria include:

- Distance (range)
- Divergence (spot size)
- Angle resolution
- Accuracy

4.2.1 DISTANCE

The maximum distance between the sensor and the object has to be examined. Typical applications in ports need sensors with a range of at least 30m, sometimes up to 80m.

The distance a laser can measure depends on the reflectivity of the target: white is a good reflecting colour, black is bad at reflecting light. 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 by 10%.

4.2.2 DIVERGENCE (SPOT SIZE)

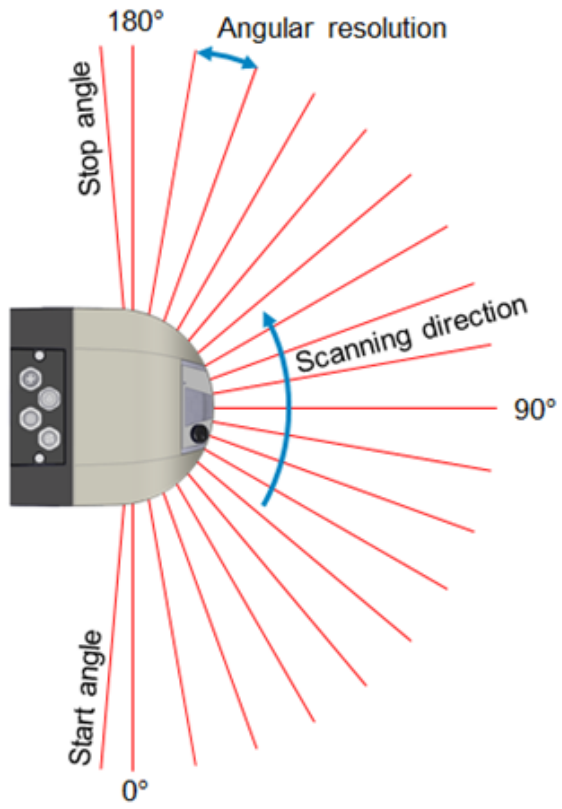
The further the distance between the sensor and the object, the bigger the laser spot size. The advantage of a small spot is that small objects can be measured more precisely, for example, twistlocks, corner castings or vessel antenna.

The beam divergence is measured in mrad = mm/m. The value describes the increase of x mm per m distance. Typically values for outdoor scanners range from 0.7 mrad up to 15 mrad.

Graphic: Divergence of laser beam

4.2.3 ANGLE RESOLUTION

The angle resolution describes the angle steps of the rotating units. Typical angle steps are between 0.0225° to 1° and these steps have an influence on how accurately the shape of the objects can be seen.



Graphic: Scan angle and angle steps

4.2.4 ACCURACY

The accuracy of the sensor can be expressed by the measurement of distance and the accuracy of deflection angles. In 3D applications, the speed of the deflection unit and the rotating angle are very important.

4.3 HARSH ENVIRONMENTAL AREAS AND TECHNICAL SOLUTIONS

The ports and terminals environment is one of very harsh conditions. Operating in this industry therefore requires 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.

4.3.1 MULTI-ECHO TECHNOLOGY

The sender beam may encounter different weather conditions such as rain, fog, dust, etc., and other disturbing 'objects'. Each of these produces a reflection of the sending laser (an echo) which is received by the laser.

Disturbing objects include:

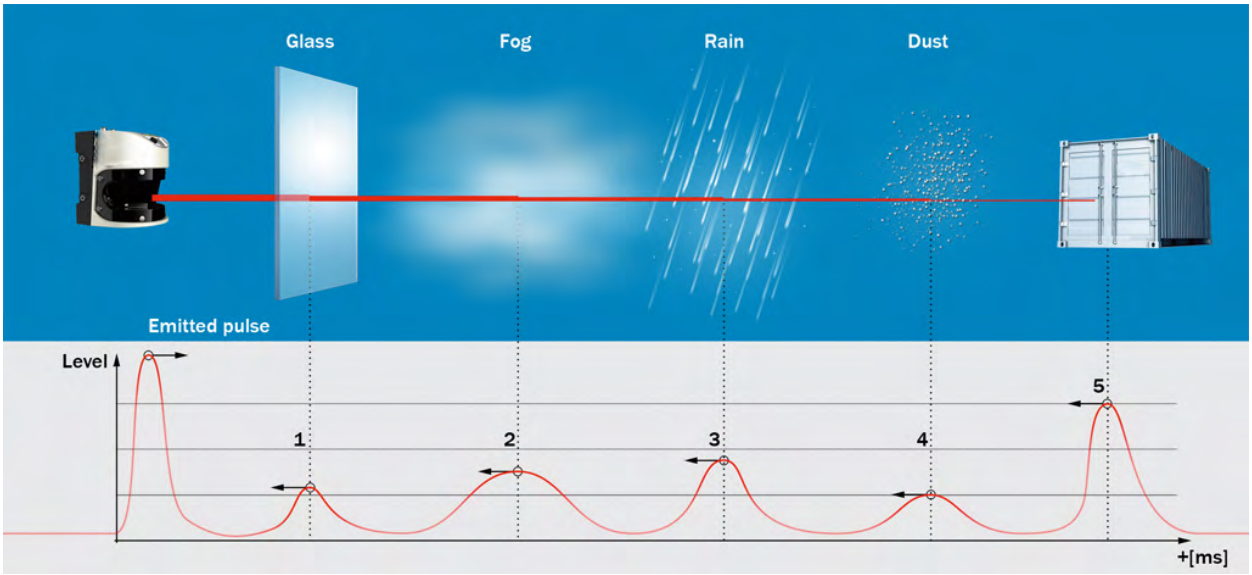
- Windows / glass
- Rain drops
- Steam / fog
- Snow
- Foils
- Dust

By filtering out unwanted echoes, multi-echo technology ensures reliable object detection even under unfavourable environmental conditions and other disturbances.

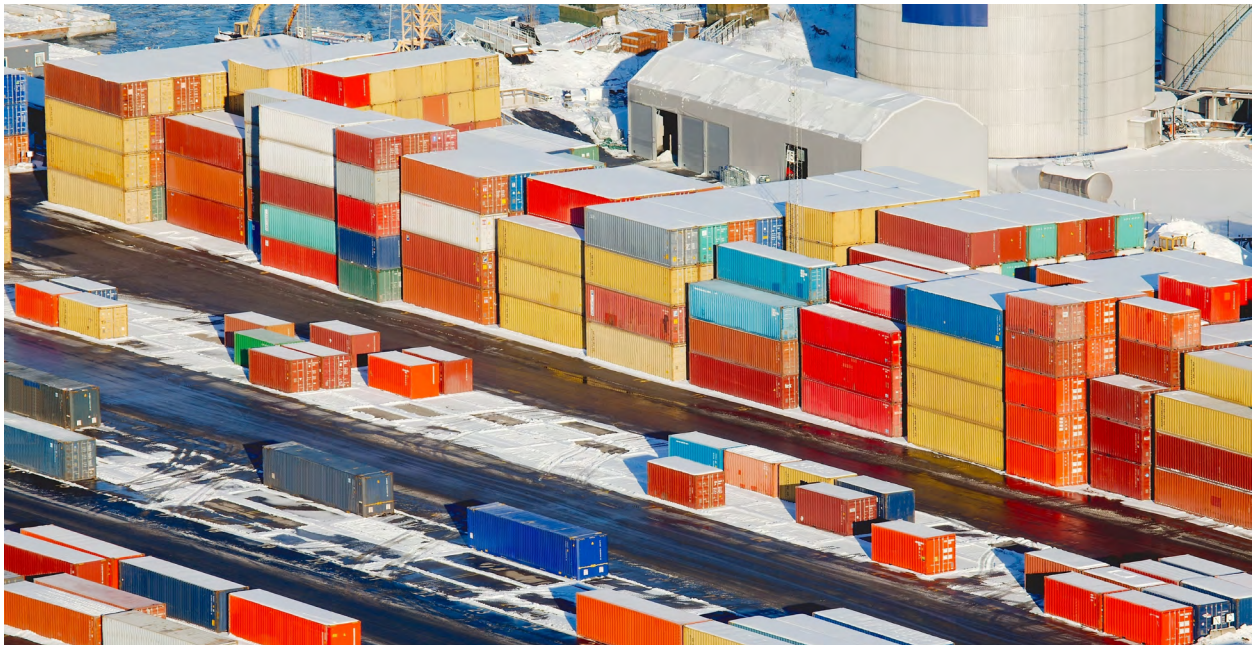
The reflected light and echoes are matched by a high speed sampling and will therefore be identified as disturbing objects that can be ignored in the software.

For example, if the scanner is placed behind glass, as the glass gets dirtier it will start reflecting light back to the receiver.

Once the level of this reflection light is above a certain threshold, an echo will be produced. This first echo will be acknowledged by the scanner, however, depending on the filter settings, this echo can be ignored.

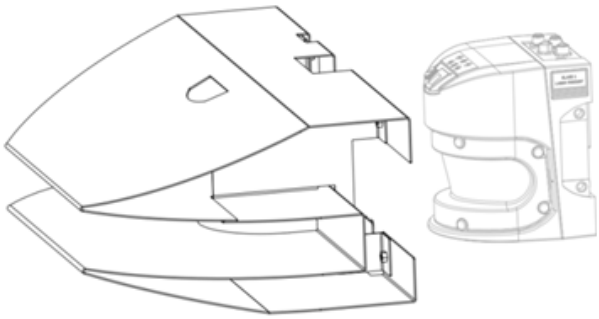


Graphic: 5 echo method



4.3.2 WEATHERHOOD ACCESSORY

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



Graphics: Weatherhood

4.4 SYSTEM CHOICES

The accuracy of the total system can be expressed by its ability to recognize the position of objects in two or three dimensions and its ability to respond appropriately.

For example, one common objective is that a container can be picked up under an STS quay crane without moving the gantry or repositioning the trailer. Therefore, a 2D or 3D laser scans the truck looking down from an installation point above the lane(s).

The scan frequency is one of the most important factors for laser scanners as it expresses how often the objects can be seen. This becomes important when the objects are in motion because the number of scans has to be high enough to track the movement, and any system needs to meet the speed of the object in motion with an appropriate frequency.

Typical scan frequencies for 2D laser scanners are between 5 and 100 Hz. The scan frequency of a 3D laser scanning system is related to the area which is to be covered.

The behaviour of the laser scanner when the spots hit part of the edge of the object and part of the background (the trailer or the ground) is also significant. This means the accuracy of the system is partly dependent on the sophistication of the application software which runs in the processing unit.

4.4.1 DATA PROCESSING UNIT

Apart from applications with 1D laser distance measurement systems and 2D applications, where the laser is used simply for field surveillance operations, all the solutions provided by 2D and 3D laser scanners require intelligent processing of laser scanner data. This cannot be done by the PLC control systems of the cranes, because the data rates of the scanners are too high, and because during commissioning and maintenance it is necessary to verify the received information. Therefore an extra controller with the appropriate application-specific software is required.

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

4.4.2 SOFTWARE OVERVIEW

The data processing module should include all software tools to generate the result:

- Communication interface to the 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
- Interface to a superior PLC system

5 | CONCLUSION

There seems to be little doubt that the port of the future will be more automated. The top four operators list safety as their first priority, not just because accidents cause downtime, but also because a poor safetey record can damage relations with the shipping lines and the community beyond the port's gateway.

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

However, when using laser technology as part of an automation programme, the details are important. For example, the choice of sensor has to be integrated with the total system, and the role of data processing in the whole cannot be underestimated.

Ensuring that this kind of solution can be easily managed by the end user is also vital for its acceptance. As these systems rely on complex data from the lasers it can be difficult to interpret the results. Therefore, the industry must respond by giving users the tools and methods to esily set up and maintain laser scanning systems.

It is also salutary to note that the effort needed to develop these tools and methods can easily exceed the efforts required for pure application development.

ABOUT THE AUTHORS & PEMA

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ABOUT PEMA

Founded in late 2004, the mission of PEMA 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 the media, customers and other stakeholders; forging relations with other port industry associations and bodies; and contributing to best practice initiatives.

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