PEMA

Collision Prevention at Ports & Terminals

A joint initiative with TT Club and ICHCA International

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pema.org

TT

ICHCA INTERNATIONAL

Contents

Background

In a bid to improve safety, reduce injuries and loss of life, equipment damage and minimise costly business disruption at ports and terminals worldwide, **PEMA**, **TT Club**, and **ICHCA International** have pooled resources to create this information paper to promote collision prevention in Ports and Terminals. The results of this research and consultation fall under the auspices of PEMA's Safety & Environment Committee.

All relevant stakeholders have been involved in the development of this project. **PEMA** represents equipment OEM's and technology suppliers, and **TT Club** and **ICHCA International** represent container terminals from the safety perspective.

There is a growing number of non-contact, state-of-the-art technologies for collision prevention that can dramatically improve equipment safety and reduce the risks associated with container handling. However, many of these systems are not currently included in national or international standards. This paper proposes that such technologies should be installed on new and existing equipment.

This paper gives an overview of the solutions and technology that can be used to prevent collisions in the ports and terminals. The focus of the paper is on non-contact solutions. Mechanical solutions such as fences (access control) or protection cages, are additional solutions that can be considered when appropriate.

The document gives a comprehensive overview of the known solutions available in the market, but does not claim knowledge of all the solutions that may be used in the market. In many instances it can be the case that other solutions are derivatives of the solutions mentioned here.

This information provided herein does not have any legislative status. It must be considered in the context of compliance with relevant local, national and international regulatory regimes on the safe design, manufacture, specification and operation of the various equipment types. The adoption of equipment technologies that result in risk reduction and enhance safety, is the primary focus of this document, and must be implemented in conjunction with the terminal's specific robust operational safety processes.

NOTE:

Collision prevention should be a general requirement for all equipment types. In all cases, obstacles should be monitored/detected in the direction of travel for the full range of travel of the equipment and its attachments.

A controlled stop should be a general requirement for all large equipment types. It is a basic safety requirement on such equipment and should be clearly labelled.

Collision prevention technologies are only one layer of a broader range of measures that should be employed in terminal safety design. Such measures should include but not limited to the segregation of operational areas, equipment and personnel, traffic flow marking, concrete and other barriers, signage and of course information, instruction and training.

Disclaimer

The collision prevention at Ports and Terminals content has been jointly developed by **PEMA**, **TT Club**, and **ICHCA Internationa**l, based on information available at the time of publication. It does not constitute professional advice, nor is it an exhaustive summary of the information available on the subject matter to which it refers.

The overview of the technologies used in the individual applications identifies the technologies considered most appropriate for each use case. However, this does not imply that alternative technologies cannot be used. The examples presented in this paper are provided for illustrative purposes only and do not constitute an endorsement of any manufacturer, supplier, technology provider, or proprietary solution .

This document should always be read and used in conjunction with the relevant national and international legislation, as well as any applicable regulations, standards, and codes of practice. Every effort is made to ensure the accuracy of the information but neither **PEMA**, **TT Club**, **ICHCA International**, nor any of their members are responsible for any loss, damage, costs or expenses incurred (whether in negligence or not) arising from reliance on or interpretation of the information.

Edition

This is the second edition of this paper. Since the first release of IP17 in 2015, the development of the technologies and the solutions have continued, such that the participating organisations have decided to issue a revision IP17A to reflect these developments.

1. Introduction

The Collision Prevention at Ports and Terminals paper has been jointly developed by PEMA, TT Club and ICHCA International.

1.1 About PEMA

Port Equipment Manufacturers Association (PEMA) was established in 2004 to provide a forum and a public voice for the global port equipment and technology sectors, reflecting their critical role in enabling safe, secure, sustainable, and productive ports, thereby supporting world maritime trade.

Chief among the aims of the Association is to foster good relations within the world port equipment and technology community, by providing a forum for the exchange of views on trends in design, manufacture and operation of port equipment and technology.

PEMA also promotes and supports the global role of port equipment and technology by raising awareness among customers, the media, and other stakeholders; forging relationships with other port industry associations and bodies; and contributing to best-practice initiatives and information.

PEMA's growing membership represents a cross-section of port equipment OEMs, suppliers of components including brakes, cable reels, controls, drive systems, tyres and more, providers of software, systems and other advanced technologies, and expert consultants in the field of port equipment and technology.
pema.org

1.2 About TT Club

TT Club is the established market-leading independent provider of mutual insurance and related risk management services to the international transport and logistics industry. Its mission is to make the industry safer, more secure and more sustainable. Established in 1968, TT Club currently services more than 1400 Members – container owners, operators, ports, terminals and logistics companies, working across maritime, road, rail and air. The Club is renowned for its high-quality service, in-depth industry knowledge and enduring Member loyalty. Its average annual customer retention rate is consistently over 90%, with some Members having chosen to insure with the Club for over 50 years.
ttclub.com

1.3 About ICHCA International

ICHCA International is the only global association dedicated to the promotion of safety and efficiency in the handling and movement of goods by all modes and throughout the supply chain.

Originally established in 1952 and incorporated in 2002, the Association operates through a series of Local, National and Regional Chapters, Panels, Working Groups and Correspondence Groups and represents the cargo handling world at various international organizations, including the International Maritime Organization (IMO), United Nations Conference on Trade and Development (UNCTAD), International Labour Organization (ILO) and the International Organization for Standardization (ISO).

ICHCA International members include ports, terminals, transport companies and other groups associated with cargo handling and coordination. Members of its Panels represent a substantial cross-section of senior experts and professionals from all sectors of the cargo transport industry globally. Members benefit from consulting services and informative publications covering technical matters, best-practice advice, and cargo-handling news.
ichca.com

2. Requirements

Container terminals are inherently associated with safety risks, such as vehicles, heavy equipment, and people all operating in close proximity. However, given that terminals are broadly similar and typically perform similar tasks, it is possible to model different cases of collisions for various equipment types and methods of operation.

2.1 Collision Cases

The collision cases can be divided into 3 categories.

1. Equipment to people
2. Equipment to equipment, including harming people following the collision
3. Equipment to fixed obstacles

Collisions can have different levels of severity and consequences. The consequences can be:

1. Injuries
2. Death
3. Damage (costs for repair and/or replacement)
4. Loss of production time
5. Consequential costs, e.g. due to the delayed departure of the ships
6. Confidence of shipping lines in the port
7. Employees' feelings of insecurity and trust in the employer

2.2 Equipment Types

Collisions are caused by moving equipment. The equipment usually operating in container ports are STS cranes, yard cranes (RTG, RMG, ASC), AGVs, mobile harbour cranes, trucks, cars, straddle carriers, reach stackers, empty container handlers, forklifts, trains (when transfer to rail), etc.

3. Specific Equipment Solutions

The solutions are divided into different types of collision cases for the different equipment types.

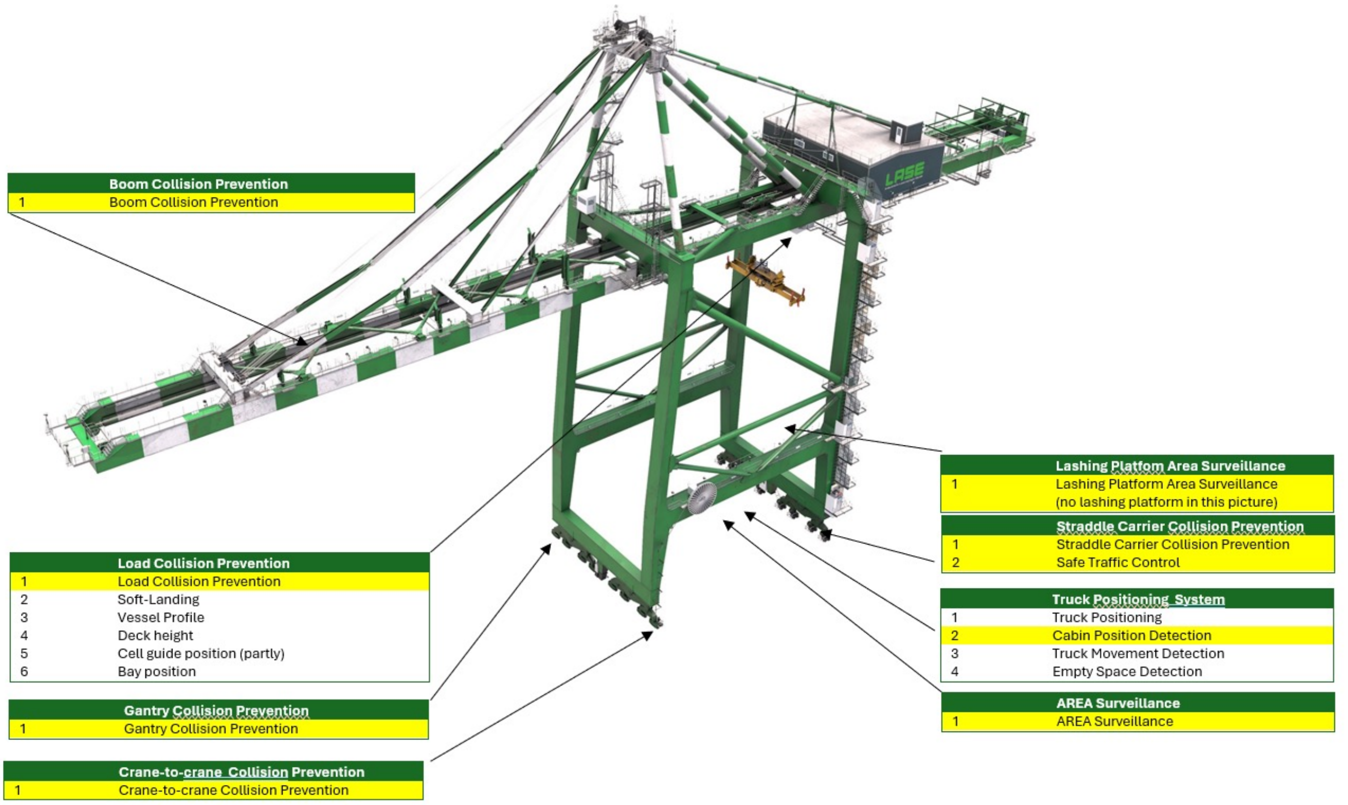
3.1 Ship-to-Shore (STS) Crane Collision Prevention

The table provides an overview of several collision cases that can occur with STS cranes. Different technologies can be used to prevent collisions.

The table is followed by chapters describing individual collision cases, the applicable prevention technology and explains how these technologies are used in the respective application.

Equipment – STS									
No	**Case**	**Application solution**	**Technology**						
			1D - Laser	2D - Laser	3D-Laser (Multilayer)	3D-TOF camera	Radar	Camera	Light Barrier
1	Collision between cranes	Crane-to-crane Collision Prevention	●	●	●	●	●		
2	Collision with People, Vehicle, Objects on the gantry travel pathway	Gantry Collision Prevention		●	●	●	●	●	
3	Collision between boom and vessel	Boom Collision Prevention		●	●				
4	Lowering container on truck driver cabin	Truck Cabin Collision Prevention		●	●			●	
5	Lowering container on people within the crane portal	Area Surveillance			●	●		●	
6	Collision between Spreader and people on the lashing platform	Access control lashing platform							●
7	Collision between the spreader and container and structures on the vessel	Load Collision Prevention		●	●				
8	Collision between Load and Straddle Carrier	Straddle Carrier Collision Prevention		●	●	●			

Fig 1: Solutions on STS cranes



3.1.1 Crane-to-Crane Collision Prevention

3.1.1.1 Laser Technology

To prevent the STS cranes on the same tracks from colliding, several sensor types 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 brought to a stop if the cranes are too close to each other.

Fig 2: 1D- Laser measurement, radar and 2D-Laser on the boom (with combined functionality)

3.1.2 Gantry Collision Prevention

To prevent the crane from colliding with obstacles along its travel path, various sensor types can be used. The sensors are oriented in the direction of travel and detect the obstacles in the travel path. The distance between the crane and the obstacle is measured and the speed of the crane can be reduced as it approaches the obstacle. The system usually has a number of detection zones for warning and alarm. The size of the zones can be adapted to the crane speed.

3.1.2.1 2D-Laser

When using a 2DLaser, a horizontal scan plane is created at a height of approx. 1.5m. Usually with a slightly tilted angle, such that the scan plane will touch the ground at the maximum braking distance of the crane (approx. 15 meters in front of the crane leg). If there are obstacles in this two-dimensional field, the crane speed can be controlled to prevent collisions.

Fig 3: 2D-Laser mounted on the crane

3.1.2.2 3D-Laser

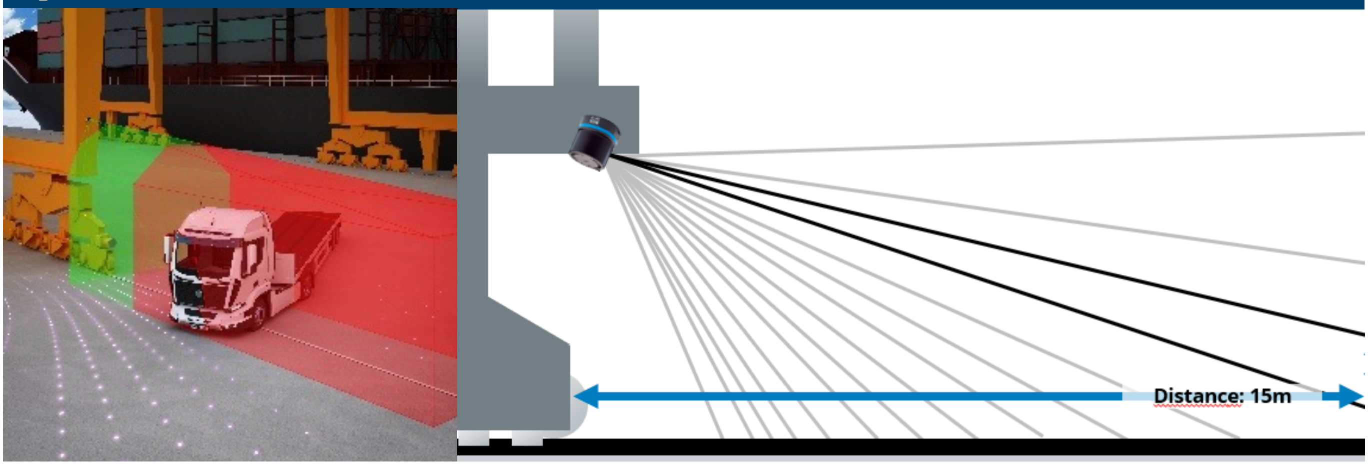
When using 3D-Laser sensors (multilayer), a 3D surveillance cube with different zones will be generated. This means that obstacles lying on the ground or projecting anywhere in the 3D surveillance cube will be detected, and collisions can be prevented.

3.1.2.3 3D-TOF

3D-TOF sensors identify and classify the objects. Sensors with AI can also detect people when only part of the body or an unusual body shape, e.g., a person lying on the ground, is visible. Another option might be to use reflector tracking when wearing safety vests or when using vehicles with reflectors.

Fig 5: 3D-TOF looking down on the travel path

Fig 4: 3D-Surveillance area in front of the crane



3.1.2.4 Radar

Radar sensors with different beam characteristics, such as size, shape and distance can be used and offer excellent results when precipitation, dust, fog and dirt conditions exist. These sensors can simultaneously detect several objects and offer intelligent target selection based on distance and signal strength. This functionality allows not only the detection of objects but also the detection of their direction of movement and speed.

Fig 6: Radar measurement from crane-to-crane and pathway

3.1.2.5 Camera

Cameras integrated AI functionality recognise objects within the pathway.

Fig 7: Camera with surveillance area in red

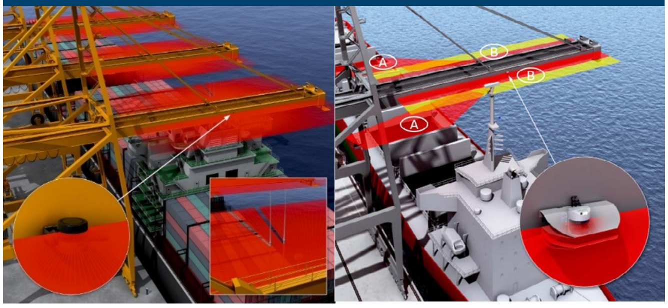
3.1.3 Boom Collision Prevention

To prevent collisions between the crane boom and the vessel superstructure, 2D/3D-Laser scanners are installed on the boom structure to create horizontal 2D or 3D surveillance fields / cubes adjacent to or under the boom. If the bridge or other structures on the vessel are detected within the surveillance fields/cubes during gantry motion or during boom lowering, a warning and, finally, an alarm signal are generated. The control system will then stop the relevant crane motion.

3.1.3.1 2D-Laser

The 2D-Laser solution is based on one or two 2D-Laser(s) installed at the boom tip or midway along the boom. The lasers may also be installed on the fixed seaside leg structures of the crane facing the waterside. The 2D-Laser(s) generate(s) a horizontal field of view under the boom with the corresponding 2D - surveillance fields.

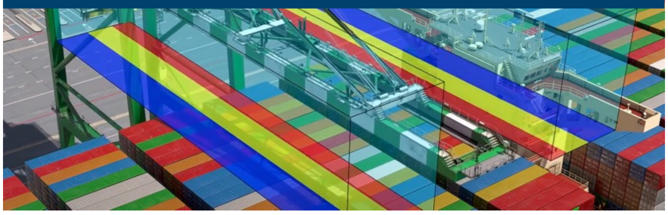
Fig 8: Boom collision prevention principle (with horizontal scan planes)



3.1.3.2 3D-Laser

The 3D-Laser solution is based on one or two 3D-Lasers mounted at the boom tip or midway along the boom. The lasers may also be installed on the fixed seaside leg structure of the crane, facing the waterside. The 3D-Laser(s) generate(s) a 3D-surveillance area on both sides of the boom. When objects are detected in the boom's path, the crane's motion can be slowed or stopped.

Fig 9: Boom collision prevention principle with 3D-Surveillance zones



3.1.4 Truck Cabin Collision Prevention

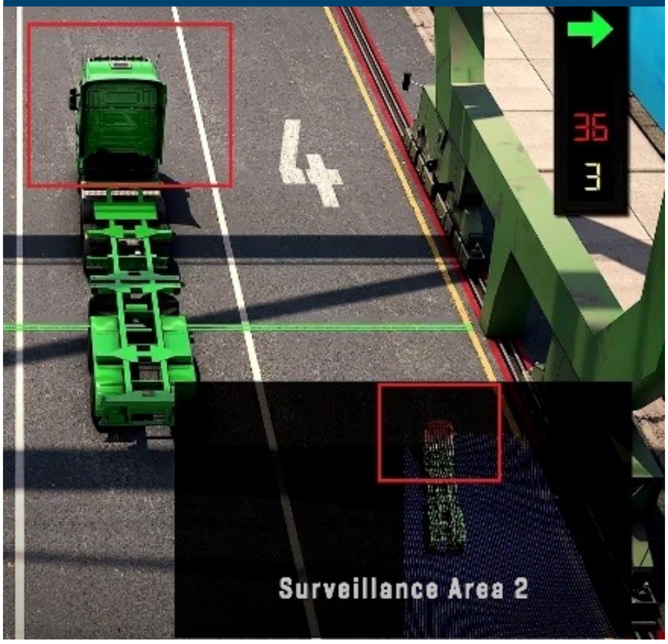
When the container is being placed on a truck within the portal or in the back reach area, the measurement system recognises/measures the position of the truck cabin and compares it with the position and length of the load. When lowering the load overlaps the position of the Truck Cabin, the measurement system will trigger an alarm, and the lowering motion will be stopped by the crane control system.

Usually, this function is a sub-function of a truck positioning system.

3.1.4.1 2D or 3D Laser Sensors

With 2D or 3D lasers, profiles of the truck's sides and top, the load, the truck cabin, and its position can be generated.

Fig 10: Cabin position detection visible in the 3D-point cloud



3.1.5 Area Surveillance

The operational area under the crane is prone to collisions/accidents. Staff on the ground check/ remove and insert twistlocks from/to the container and the load (container) is deposited or picked up by the crane.

The measurement systems observe the area, detect when the load is entering the area, and whether personnel are in the operations area.

3.1.5.1 3D-Laser

The 3D Laser sensors generate a real-time 3D image of the operations area.

The sensors are mounted on the portal beams and look down on the truck lane(s). The system distinguishes between the allowed vehicle (truck, trailer, container) and objects that may be in the vehicle's vicinity. When objects are detected, the system triggers an alarm and prevents crane operations in the area.

3.1.5.2 3D Stereo Camera

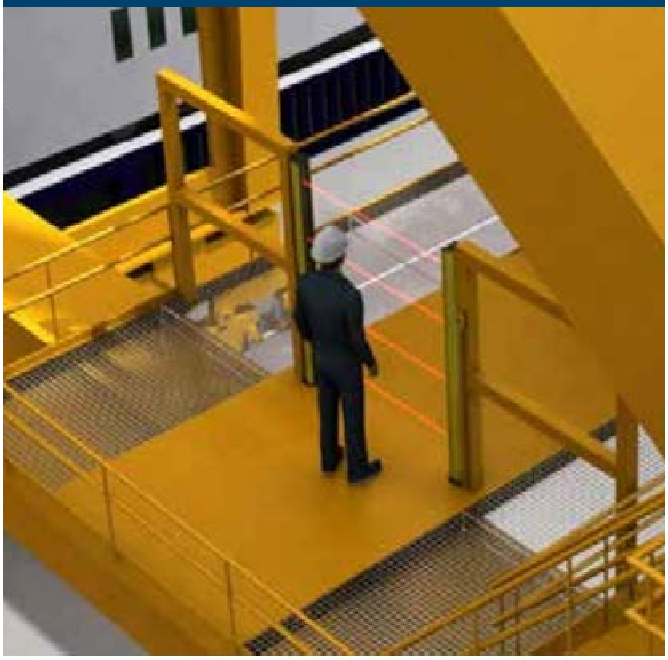
3D Stereo cameras mounted on both sides of the portal beam monitor the operation area under the crane. With individual cube field settings, the cameras monitor these areas and detect objects and people. According to the operation processes, the camera provides alarm information to either slow down or stop the movement.

Fig 11: Surveillance area

3.1.6 Access Control Lashing Platform

The lashing platform provides a traffic-free pinning area on the crane with reduced risks of serious injury and fatalities. To reduce the risk posed by floating loads, a safe access guarding system for the platform is necessary. Firstly, the lashing platform must be fenced, (hard guarded), to prevent personnel from entering the platform from any position. Secondly, an access guard mechanism with a restart interlock and a manual reset function should be installed. A sophisticated and efficient solution in this case is an “optical safety door” for the lashing operative, based on a safety light curtain installed. When the operative passes through the “optical safety door” the hoisting/lowering of the container will automatically stop and the lasher can operate safely. After placing or removing the twistlocks, the lasher steps back behind the access door (safety light curtains), and confirms that the platform area is clear by pushing the reset button which is located outside of the dangerous area to restart the container hoisting/lowering motion.

Fig 12: Lasher stands in front of the lashing platform in front of the light barrier



3.1.7 Load Collision Prevention

The load collision prevention system is a sub-function of the vessel profiling system. The vessel profiling system is primarily used for collision prevention between the moving spreader/load and the container stacks and/or the structures on the vessel.

The function of vessel profiling systems usually supports the following functions:

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 travelling over the vessel
5. Spreader position and tracking
6. Deck height
7. Catwalk height
8. Positions of the container on the vessel and landside
9. Vessel misalignment (difference between the STS crane centre to the centre of the bay)
10. Cell-guide detection
11. Twin – Twenty – Detection

Most of the solutions are based on installations of the sensor system 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.

3.1.7.1 1D-Laser

One or two 1D – Lasers create a profile of the container stacks by combining the laser measurement data with the position of the trolley.

Fig 13: 1D – Laser scanner vessel profile

3.1.7.2 2D-Laser and 3D-Laser

By combining the sensor's measurement data with the trolley position, a 2D profile of the vessel's operation area can be generated. The greatest functionality is achieved by using 3D-Lasers or a combination of 2D-Lasers. In addition to collision prevention, the systems can support semi-automatic crane operation.

Fig 14: 2D.- Profile generated by a 2D-Laser measuring cross travel over the vessel

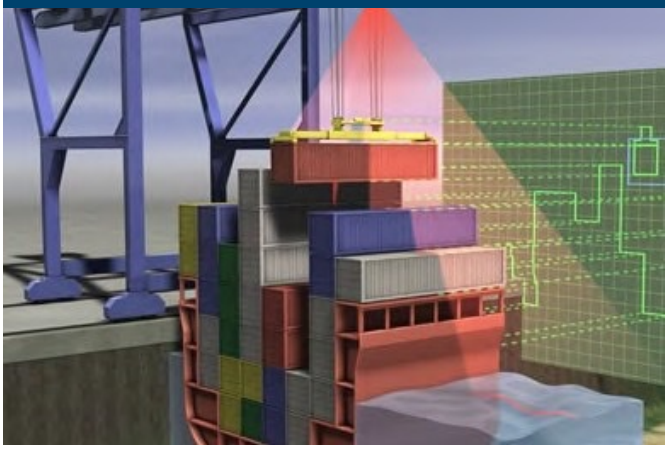
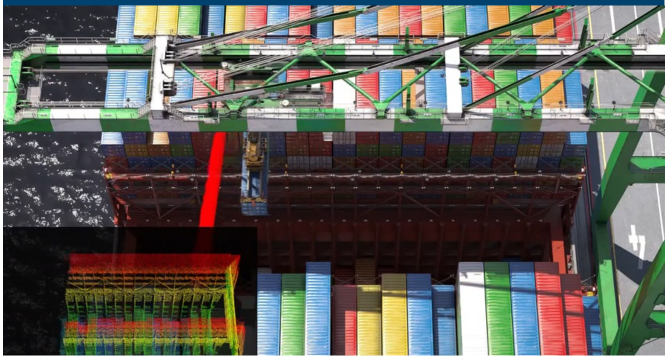


Fig 15: Creating by a second 2D-Laser with scan planes along the vessel a 3D-profile of vessel or by using 3D-Laser (trolley based or fix installed on the boom)



3.1.8 Straddle Carrier Load Collision Prevention

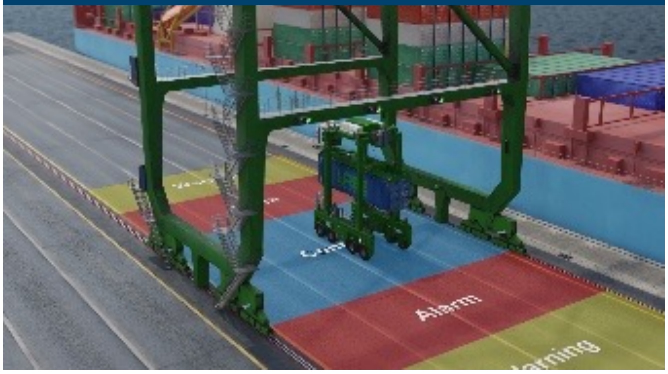
The Load (Spreader) of the STS crane and the Straddle Carrier operate in the same operation area underneath the crane within the portal or in the backreach. A measurement system monitors whether there is a Straddle Carrier under the crane and in which lane. Should this scenario be detected then this lane and the two adjacent lanes are blocked for STS operation.

Conversely, when the load/spreader is detected in a lane in the operation area the Straddle Carrier cannot enter. The operation lane and the two adjacent lanes are prohibited for entry by the straddle Carrier. The Straddler Carrier driver gets a signal indicating which lane he can enter by traffic lights on the outside of the portal girder or at the main columns of the crane (in the case of the backreach).

3.1.8.1 2D-Laser

The 2D-Laser installed on the sill beam observes the area within the portal and checks whether the load or a Straddler Carrier is in the area. The Straddler Carrier driver gets a signal via a traffic light indicating if he is allowed to enter the portal area. Conversely, when a straddle carrier is in the portal, the crane will be prevented from moving the load in the area where the Straddle Carrier is positioned.

Fig 16: Operational area in different zones separated



3.1.8.2 3D-TOF

To prevent a spreader/container from colliding with a container with a straddle carrier located under the crane, 3D-TOF sensors can be used for area surveillance. Due to the size of the area, two systems must be installed with overlapping detection zones.

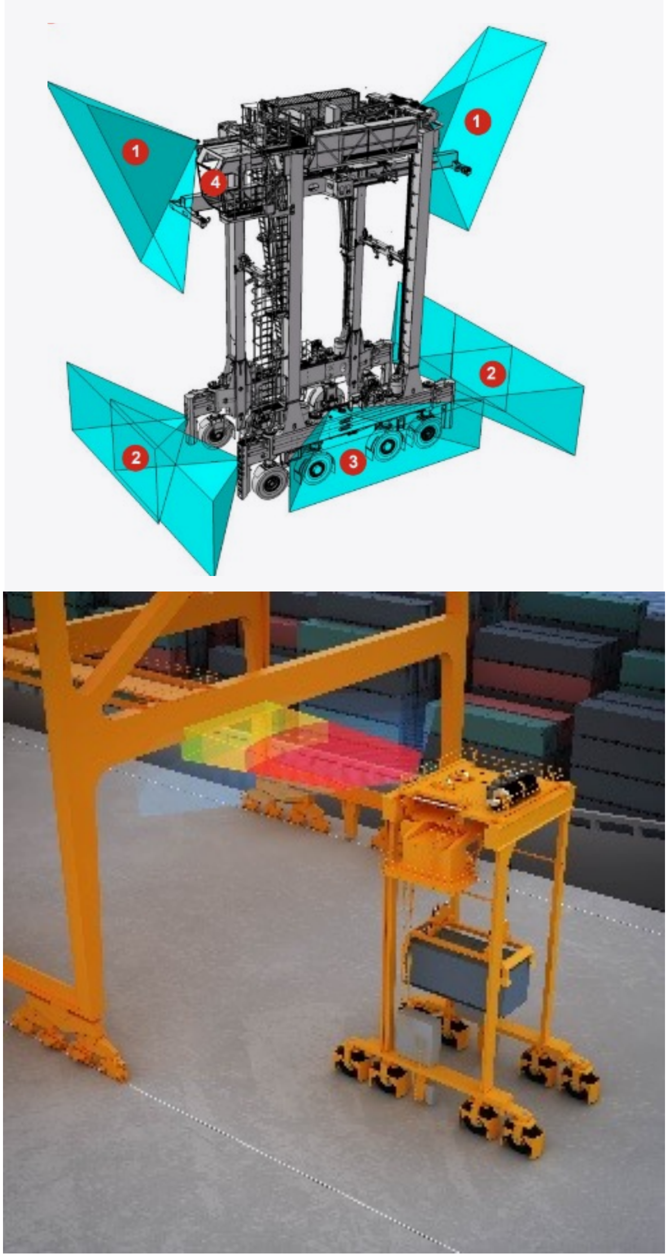
Fig 17: 2 x 3D-TOF (black boxes in the middle)

3.1.9 Straddle Carrier to STS Crane Collision Protection

When using different Straddle Carriers with varying heights and a mix of STS cranes with different Portal beam heights, it is necessary to protect the higher SC so that they do not collide with the STS crane portal beam if they drive to the wrong STS crane.

This collision scenario is addressed by Lasers or Radar Sensors mounted on top of the Straddle Carrier structure, vertically scanning the area in front of the machine in the direction of movement. This over-height detection provides a signal to the SC driver in any case of an object, such as an STS portal beam structure, that is in the collision path with the top of the Straddle Carrier.

Fig 18: Multifunctional approach, scanner 1 used for portal beam collision prevention



3.2 Stacking Cranes Collision Prevention

The stacking cranes are defined as:

1. Rubber Tired Gantry Cranes (RTG)
2. Rail Mounted Gantry Cranes
   (RMG, ARMG, ASC, CRMG, CARMG)

They generally operate in seaports, but can also be used in the hinterland in intermodal terminals.

The table provides an overview of several collision scenarios that can occur with Stacking Cranes. Different technologies can be used to prevent collisions. The table is followed by chapters describing the individual collision scenarios, the applicable prevention technology and explains how these technologies are used i n the respective application.

Equipment – RTG, RMG										
No	**Case**	**Application solution**	**Technology**							
			1D - Laser	2D - Laser	3D-Laser (Multilayer or Solid State)	3D-TOF	Radar	Camera	Light Barrier	Personal tracking (Tag)
1	Collision between cranes	Crane-to-crane Collision Prevention	●	●	●	●	●			●
2	Collide with People, Vehicle, Objects on the gantry travel pathway	Gantry Collision Prevention		●	●	●	●	●		●
3	Lowering container on truck cabin	Truck Cabin Collision Prevention		●	●	●		●		●
4	Lowering container on people in the crane portal	Area Surveillance			●					●
5	Collision between the spreader and container in the Yard	Load Collision Prevention		●	●					
6	Collision between Load and Straddle Carrier or Trucks	Transfer Zone Collision Prevention		●	●					

Fig 19: Solutions on RMGs

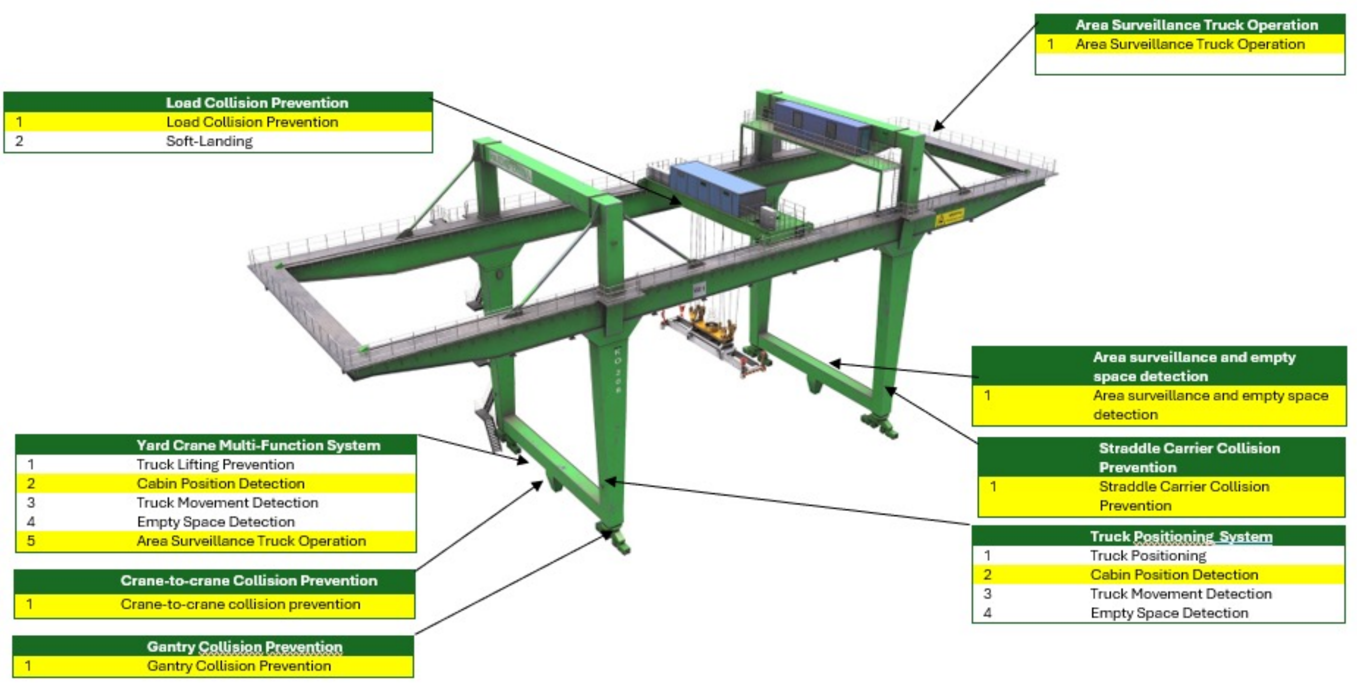
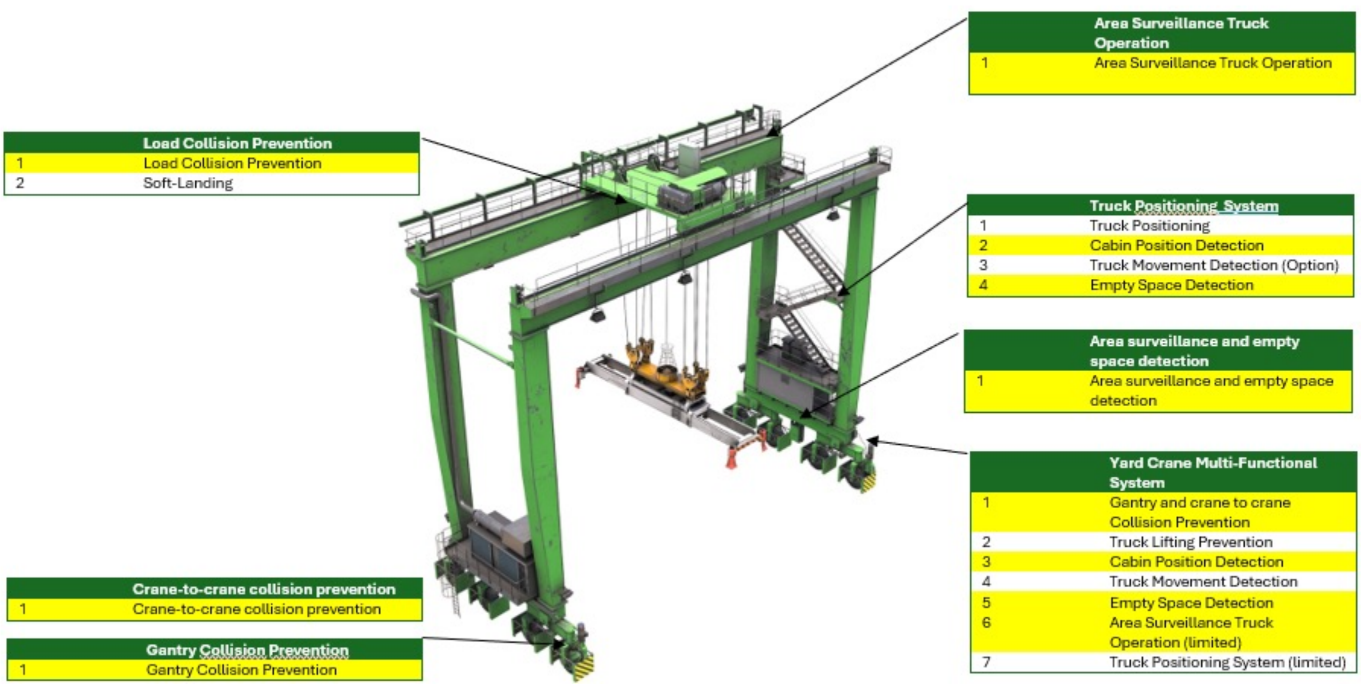


Fig 20: Solutions on RTGs



3.2.1 Crane-to-Crane Collision Prevention

To prevent Stacking cranes from colliding with each other, distance sensors 1D, 2D or 3D sensors can be used. The sensors are orientated in the direction of travel and can detect the structure of the adjacent crane(s). By measuring and monitoring the distance between the cranes, the speed of the cranes can be reduced to a safe level and brought to a controlled stop if the cranes are too close to each other.

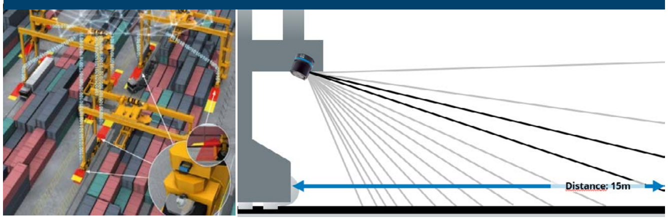
In fully automated terminals, the primary means of crane-to-crane anti-collision is by use of a position-based system identifying each crane's position on the rails. Using this data, the equipment control system (ECS) controls the relative position and movement of the cranes on the rail to avoid collisions.

The solution utilised is the same or similar to that used on STS cranes.

Fig 21: 1D- Laser measurement or radar at bogie level, 1D-Laser on the portal girder

When using a 2D-Laser, a horizontal scan plane is created at a height of approx. 1.5m. When an adjacent crane comes too near, the crane speed can be reduced and stopped so that a collision is prevented. Similar functionality applies to the 3D-Laser solution.

Fig 22: 2D – and 3D-Laser scanner (crane to crane and gantry collision prevention)



When 2D- and 3D-Sensors are installed, they are usually also utilised for the general gantry collision prevention function below.

3.2.2 Gantry Collision Prevention

To prevent the crane from colliding with obstacles in the travel path or during cross travel, 2D or 3D Sensors can be used. The sensors are oriented/looking in the direction of travel and can detect obstacles in the travel path. The distance between the crane and the obstacle is measured, and when within the detection range, the speed of the crane can be reduced to zero as it approaches the obstacle. The systems usually have a number of detection zones for warning and alarm. These zones can be optimised for the crane speed.

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 speed can be controlled such that a collision is prevented.

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 in the 3D - surveillance cube will be detected, and collisions will be prevented.

The solution is the same or similar for STS cranes.

Fig 23: 2D-Surveillance area in front of the crane

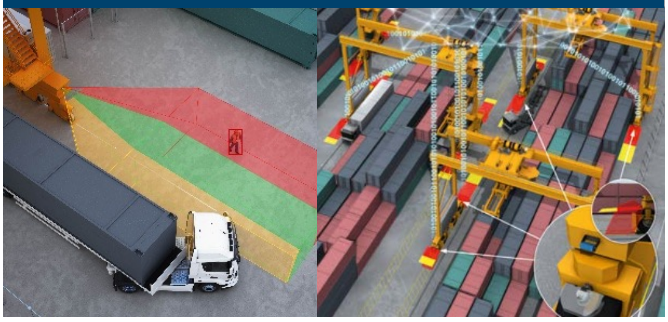
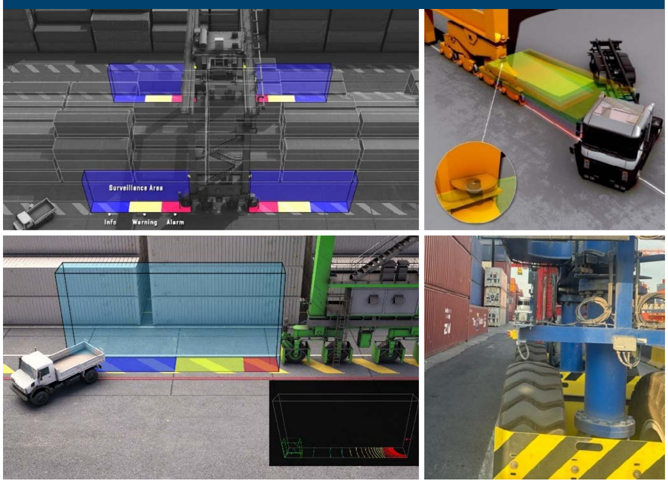


Fig 24: 3D – Laser scanner / surveillance fields



3.2.2.1 3D-TOF Sensors

3D-TOF sensors identify and classify the detected objects. Sensors with AI can detect people even when only a part of the body or an unusual shape of the body is visible, e.g. a person lying on the ground. An alternative option for personnel detection might be to utilise reflector tracking using safety vests or vehicles with reflectors.

Fig 25: 3D-TOF looking down on the travel path

3.2.2.2 Radar Sensors

Radar sensors with different characteristics, such as beam size, shape and distance can be used and offer excellent results with the presence of precipitation, dust, fog and dirt. They can simultaneously detect multiple objects and provide intelligent target selection based on distance, signal strength. With this functionality, they not only detect objects but also determine their direction of movement and speed.

Fig 26: Radar measurement from crane-to-crane and pathway

3.2.3 Truck Cabin Collision Prevention

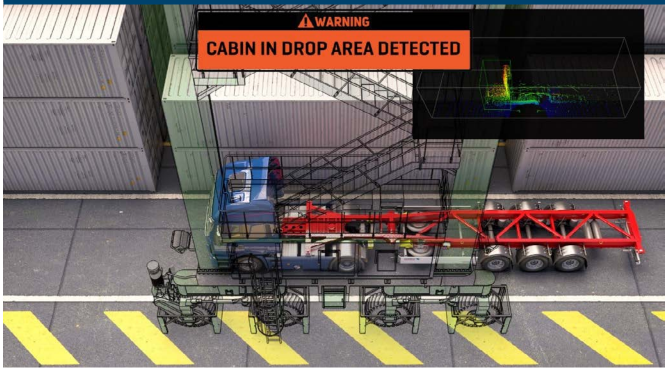
When a container is placed on a truck within the portal or in the cantilever area, the measurement system recognises/measures the position of the truck cabin and compares that with the position and length of the load. When the load overlaps (in the vertical axis) with the position of the Truck Cabin, the measurement system will raise an alarm and the operation of the trolley and hoist in the truck lane is prevented by the crane control system.

Usually, this function is a sub-function of a Truck Positioning System.

3.2.3.1 2D- or 3D-Laser

With the 2D or 3D profiles of the side or the top of the truck, the truck cabin and its position can be recognised. When the cabin is detected in the container transfer zone, the operation of the crane hoist motion in this area is prohibited by the crane control system.

Fig 27: Detection of the driver's cabin (green square) in a prohibited position



3.2.4 Area Surveillance

When people are in the transfer area around the truck and in the transfer zone the sensor system will detect the people, and the operation of the crane shall be blocked.

The system can be used in conjunction with either manual (as driver assistance) or automated crane operation.

3.2.4.1 3D-Laser Scanner

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

Fig 28: 3D-Point Cloud and real picture of the area (subject beside the truck in red circle)

3.2.4.2 Area Surveillance and Empty Space Detection

Before placing a container on a chassis, the measurement system will recognise/measure whether there are people on the chassis or around it.

With a 3D-Laser scanner, the area above the chassis platform and around the chassis will be monitored during the container drop placement process. In the case when a person enters the area or is on the chassis platform, the system will raise an alarm, and the crane control system will stop the crane motion.

Usually, such a system is combined with and included in systems for Truck Lifting Prevention.

Fig 29: Person beside the truck on the side to the yard

3.2.5 Load Collision Prevention

The load collision prevention is a sub-function of a Stack Profiling System. The stack profiling system is primarily used to prevent collisions between the moving spreader/load and the container stacks.

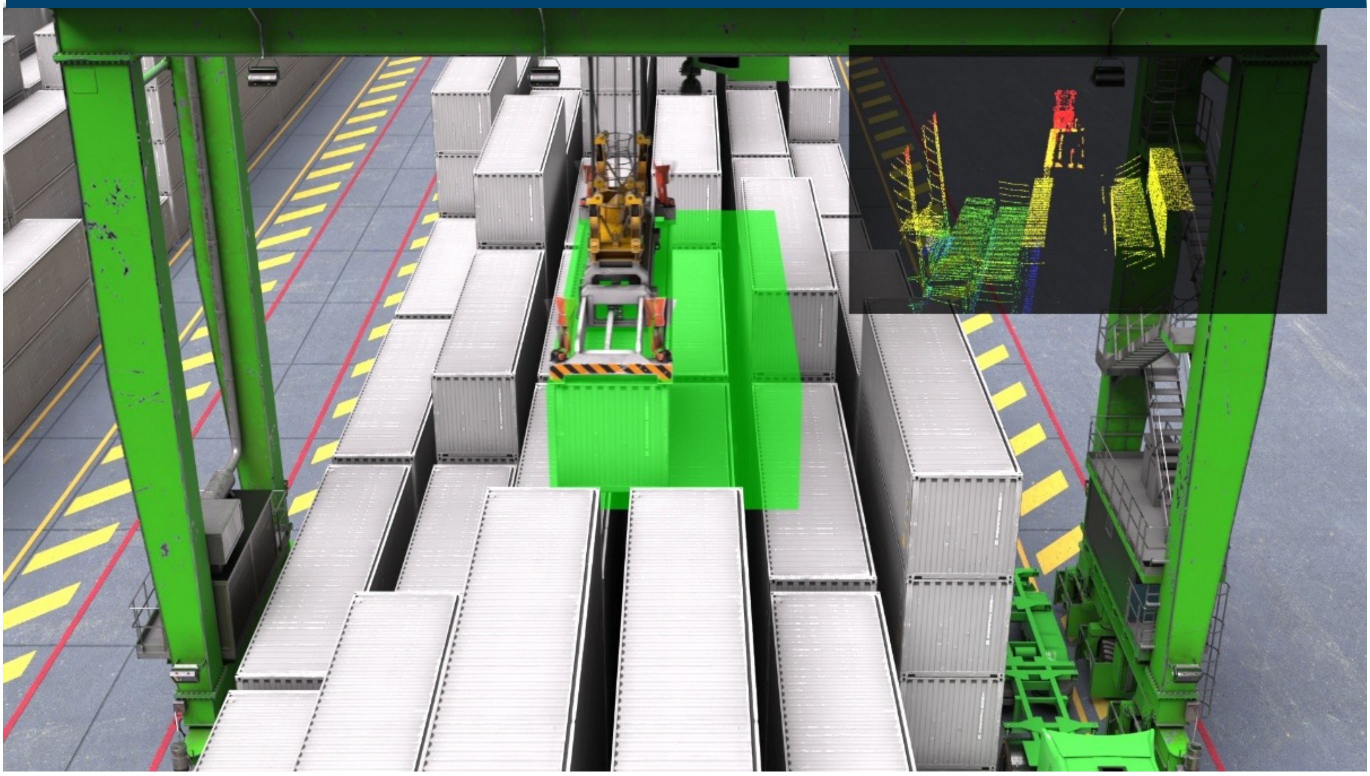
2D-Laser and 3D-Laser installed on the crane trolley are options applicable for this application, depending on the individual solution requirements. The highest level of functionality is achieved using 3D-Lasers or a combination of 2D-Lasers. Most advanced current automation solutions allow full- and semi-automatic movement of the load with the support of the measurement system.

Stack profiling systems usually include the following functions:

1. Collision Prevention in the operations bay
2. Collision Prevention with container in the adjacent bays (with 3D-Laser)
3. Soft-landing
4. Semi-automation with the optimal path of the load when travelling over the stack
5. Spreader position and tracking

The Load Collision Prevention System creates an image of the entire stacking area during travelling over the yard. The load and trolley position will be measured by the laser and position sensors during this process. The system then creates a surveillance field (2D) or surveillance cube (3D) around the load. By knowing the position of the load, having measured and having stored the yard profile, then using the speed and direction of motion of the load the system calculates the size of the surveillance fields or cubes. When the surveillance field/cube around the load intersects with the stack profile, then the speed of the moving load will be reduced and ultimately stopped by the crane control system.

Fig 30: 3D-Point cloud and the surveillance cube (in green) around the load during trolley travelling to the truck lane



3.2.6 Transfer Zone Collision Prevention

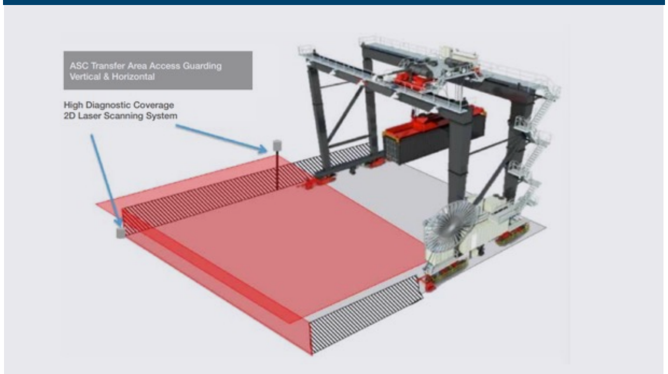
Transfer areas are designated zones at the end of a stacking area in the case of ASC Operation with end-fed zones or in the case of Cantilever RMGs transfer areas outside the crane leg structure. Depending on the type of horizontal transport vehicles employed, different collision-prevention options are available.

3.2.6.1 Transfer Zone – Straddle Carrier Operation

The Straddle Carrier drops/picks up the container in the transfer zone. When the Straddle Carrier operates in the transfer zone the ASC is either not allowed to enter the area or, in a multiple-lane scenario, to enter only the lanes not occupied by the Straddle Carrier.

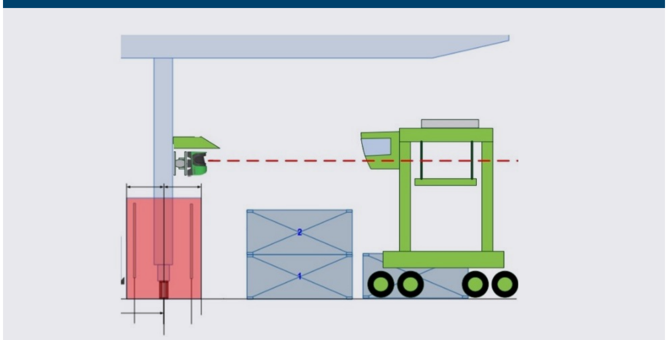
To identify if a Straddle Carrier is inside the Transfer zone a 2D-Laser scanner installed on a pole monitors the area with a horizontal scan plane.

Fig 31: Horizontal observation field over the transfer lanes and vertical laser in the entry to the transfer area



The same concept is applicable for the Cantilever areas of an RMG. In this case a 2D-Laser scanner is installed on the crane structure monitoring the cantilever area. When a straddle carrier is in the area, the crane trolley cannot enter.

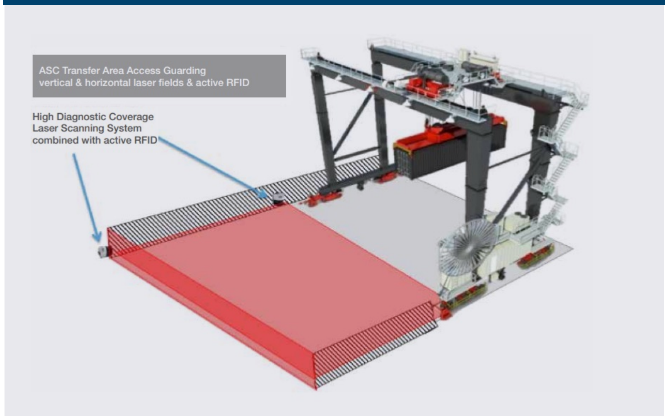
Fig 32: Scanner checks the area above the stacked container for the presence of a straddle carrier in the transfer zone



3.2.6.2 Transfer Zone – Truck Operation

Similar to the solution for the Straddle Carrier, the area in the transfer zone can be monitored for the presence of Trucks. Using one or several 2D-Laser scanners the area will be monitored by creating horizontal scan planes, When a vehicle is in the transfer zone, the operation is allowed only when people are not in the vicinity of the truck.

Fig 33: Horizontal observation field over the transfer lanes and vertical laser in the entry to the transfer area



3.3 Mobile Harbour Crane Collision Prevention

The table provides an overview of several collision scenarios that can occur with Mobile Harbour cranes. Different technologies can be used to prevent collisions. The table is followed by chapters describing the individual collision scenarios the applicable technology, and explains how these technologies are used in the respective application.

3.3.1 Load Collision Avoidance

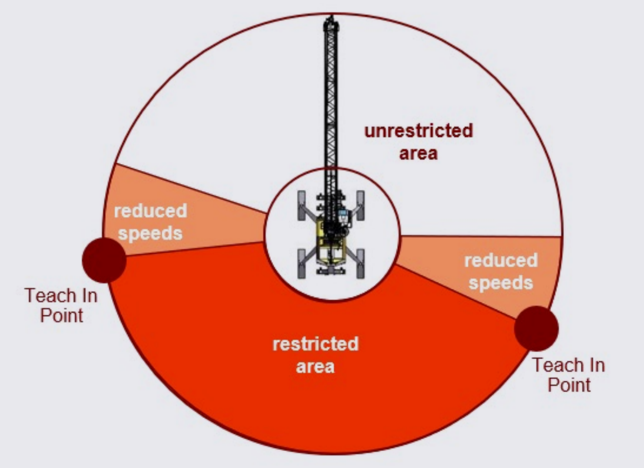
The avoidance of collisions between loads attached to the MHC crane ropes and static obstacles can be achieved utilising a dedicated assistance system.

The assistance system obtains the absolute position data of the slewing and luffing motions from incremental sensors, which are designed with redundancy.

Existing static obstacles are identified by the assistance system in a "Teach-In mode" before the operation commences, and a restricted area is defined. The continuously recorded position data of the crane boom is compared with the defined restricted area.

Before reaching the restricted area, the boom speed of both the slew and luffing motions is initially reduced and then stopped. This prevents the load from entering the restricted area and thus avoids a collision with static obstacles.

Fig 34: Illustration of restricted area and unrestricted area



Equipment – MHC										
No	**Case**	**Application solution**	**Technology**							
			1D - Laser	2D - Laser	3D-Laser (Multilayer or Solid State)	3D-TOF	Radar	Camera	Retro-reflective sensor	Increment sensors and data exchange
1	Collision of load with static obstacles	Load collision avoidance								●
2	Collision between portal and obstacles	Portal collision avoidance		●	●	●	●		●	
3	Collision between boom and obstacles	Boom Collision Prevention			●					

3.3.2 Collision Between HMC Portal and Obstacles

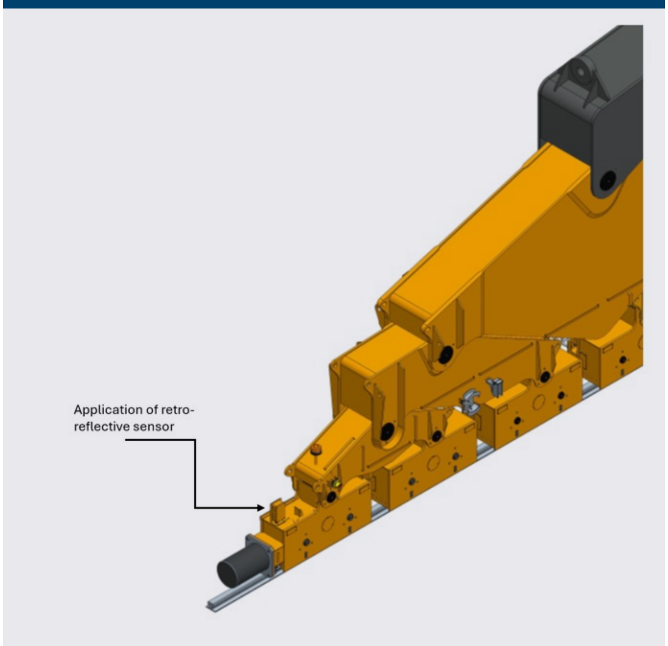
To avoid collisions between HMC cranes mounted on Gantry structures and obstacles, laser or radar-based systems are installed on the crane bogies.

3.3.2.1 Radar

These systems use advanced radar technology to continuously monitor the surroundings and provide early detection of potential obstacles. The sensors can identify both stationary and moving objects and provide reliable detection regardless of weather conditions or time of day. By accurately detecting the position and movement of objects near the crane, these systems can issue timely warnings or initiate braking to avoid collisions. Integrating such radar systems into rail-mounted HMC cranes is an effective measure to improve operational safety and efficiency. However, radar systems have disadvantages in tight environments due to signal reflections and interference.

In addition to radar-based systems, retro-reflective sensors are used on gantry structures to avoid collisions, see *Figure 35*. These sensors operate by emitting a light beam that is reflected by the surface of an obstacle. When the reflected light is detected by the sensor, a signal is sent to the crane's control system, which then takes appropriate measures to prevent a collision.

Fig 35: Radar Sensor on the bogie of the MHC



3.3.2.2 2D-Laser, 3D-Laser and 3D-TOF

The Gantry Collision Prevention solution for STS and stacking cranes can be applied to mobile harbour cranes in a similar way.

When 2D/3D/TOF laser sensors are used, 2D fields or 3D surveillance cubes comprising different zones will be generated. This means that obstacles within these zones/areas will be detected, preventing a collision.

3.3.3 Boom Collision Prevention

The solution consists of one or more multi-layer lasers mounted near to the hinge point of the boom at locations that allow the generation of a Field of View capturing the whole boom, the load and the area around the boom and the load.

The solution creates visual and/or acoustic warnings to the crane driver similar to a car parking assist system or can interface with the MHC control system, such that the control system can slow down or stop crane movements in case of a predicted collision.

Fig 36: Mounting position of the multilayer-laser scanner (in yellow square, left) and 3D-Point cloud generated by the scanner

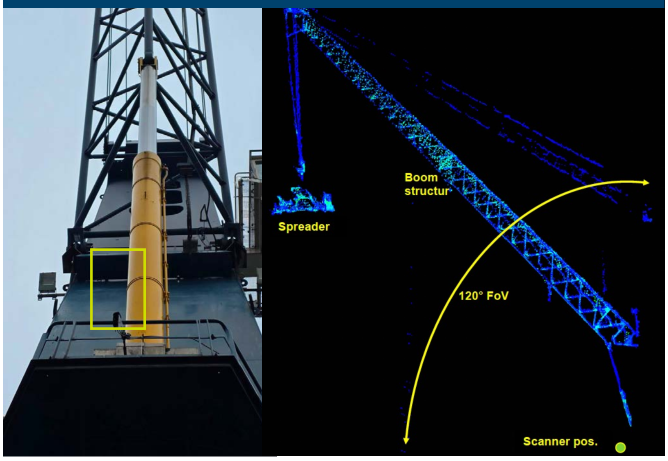


Fig 37: Visualization of the boom and the collision areas

3.4 Horizontal Transport Vehicle Collision Prevention

The table will give an overview of several collision scenarios that can occur on Horizontal transport vehicles such as Reach-Stacker, Empty Box Handler, AGV's, Straddle or Shuttle Carriers, and Auto-Trucks. Different technologies can be used to prevent collisions. The table is followed by chapters describing the individual collision scenarios. The application of the selected technology is explained in the context of the respective application.

3.4.1 Pathway Obstacle Detection

Similar to the functionality of RTG, RMG and STS cranes obstacle detection, the pathway of the horizontal transport vehicle needs to be guarded to prevent collisions with objects, e.g. containers, vehicles or other unwanted obstacles.

3.4.1.1 2D- and 3D-Laser Scanner

The system used consists of multiple 2D or 3D lasers and a safety controller. A laser scanner can be positioned on each wheel bogie to monitor the travel path, covering the bogie's full width. The system provides separate slowdown and stop signals to the machine drive control system.

The Collision Prevention system used on a Straddle Carrier is very similar to that used for Heavy Lift Trucks, Reach Stacker, Empty Container Handler or AGVs.

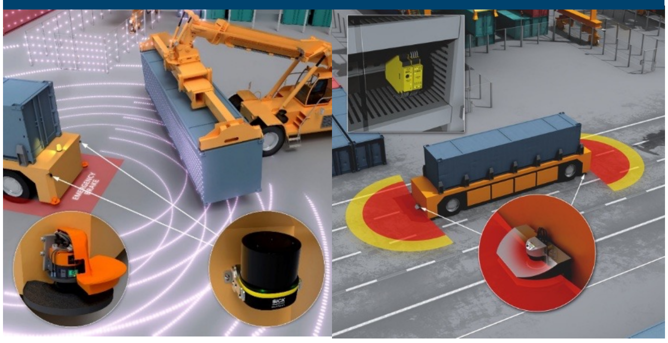
AGVs

The Automated Guided Vehicle (AGV), in its base configuration, can be equipped with Laser sensors with integrated object detection functions to prevent collisions. To enhance reliability, an advanced object detection system based on Laser sensors and a safety controller can be used to prevent collisions between AGVs.

Equipment - Reach-Stacker, Empty Box Handler, AGV, Straddle or Shuttle Carrier, Auto-Truck										
No	**Case**	**Application solution**	**Technology**							
			1D - Laser	2D - Laser	3D-Laser (Multilayer or Solid State)	3D-TOF	Radar	Camera	Light Barrier	Personal tracking (Tag)
1	Pathway obstacle detection	Collision Prevention		●	●	●		●		

Fig 38: Typical installation location on a straddle carrier

Fig 39: Collision prevention system based on 2D- or 3D- Laser



3.4.1.2 3D-TOF Enhanced Straddle Carrier Application

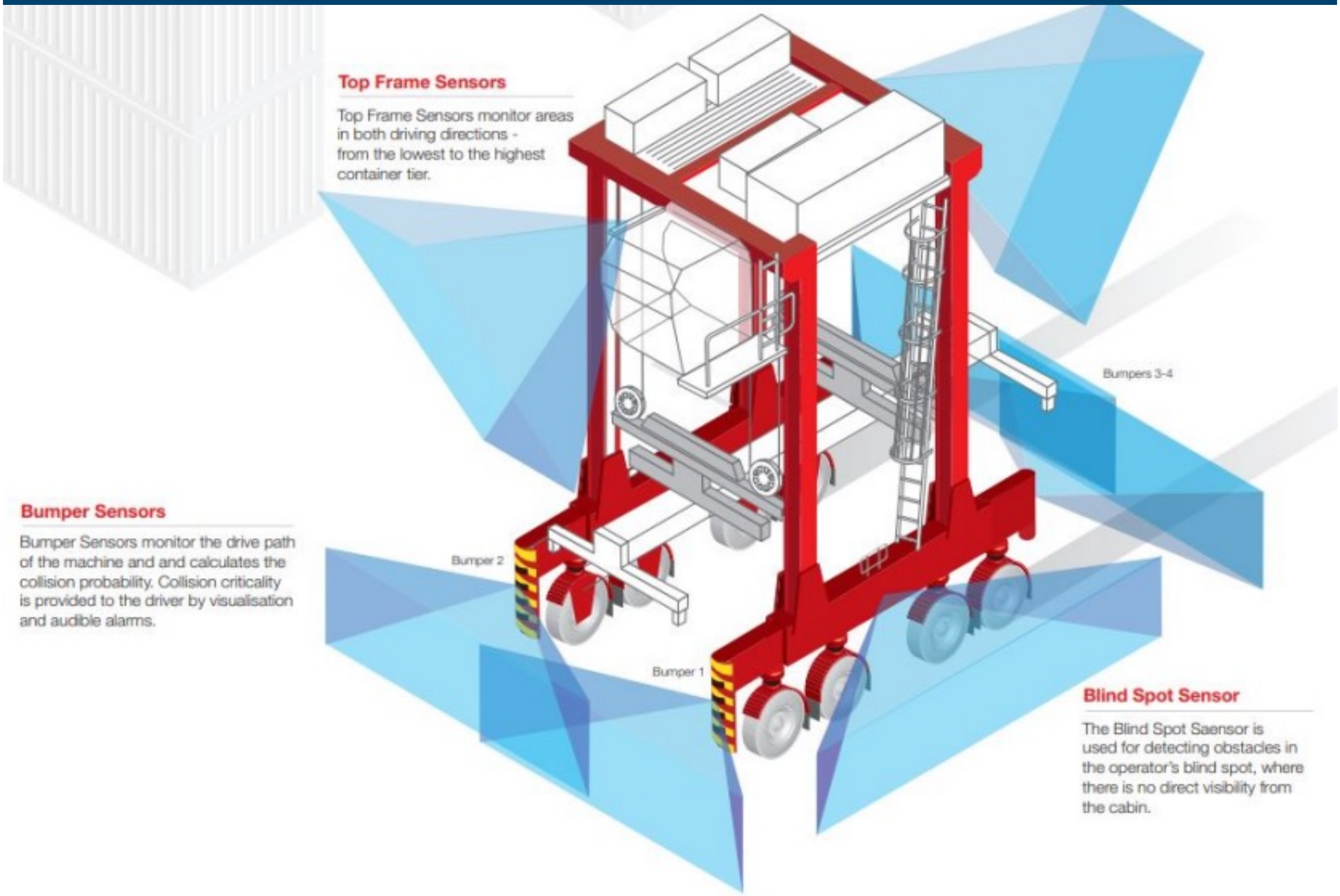
A holistic approach is to use several 3D-TOF Sensors to provide full collision-prevention coverage across different conditions and tasks. In addition to protecting the bogies against collisions, additional top frame sensors monitor areas in both driving directions across the lowest to the highest container tiers. For each tier, the region of interest (ROI) is monitored, and the sensors will provide operational information for each ROI. This information can be processed in the PLC which determines possible collision scenarios with stacked containers and initiates alarms and provide visual information.. The bogie corner sensors monitor the vehicle's drive path and provide object detection information. Objects are tracked, and the time-to-collision / critical information is provided to the machine PLC. Side frame middle sensors are used for detecting obstacles in the blind spot (the blind spot is the direction where the driver does not have direct visibility from the cabin). Via a display in the cabin, the driver gets a Top View, Live View and System info.

3.4.1.3 Camera Reach Stacker

The blind zone at the rear of the vehicle is the most sensitive area. By using 3D-cameras, the area can be monitored, and additionally the pictures can be visualised to the Equipment operator on the cabin display.

Fig 41: Reach stacker collision prevention system based on camera technology

Fig 40: Multifunctional approach (pathway and stack collision prevention)



4 Holistic Collision Prevention Solution - RTLS

The holistic approach integrates mobile equipment, fixed infrastructure, and personnel into a unified collision prevention system. Cranes, material handling equipment (MHE), and personnel are equipped with Real-Time Locating Systems (RTLS), also referred to as Position Detection Systems (PDS), enabling continuous tracking throughout the terminal area.

The real-time position data is processed in a digital twin environment, where roles and movement patterns are monitored and analysed. By contextualising proximity, speed, and operational priorities, the system enables automated warnings and interventions to prevent collisions. The tracking configuration is tailored to the specific layout and work-flow of each terminal, ensuring accurate detection and operational relevance.

The key advantage of this approach lies in the full interconnectivity of all critical objects – cranes, MHE, and personnel – within a shared collision prevention framework. This enables mutual detection and coordination across all actors, allowing various collision scenarios to be addressed with a single, unified technology stack:

The system is designed to continuously protect endangered objects from potential harm caused by dangerous objects. Any object equipped with RTLS/PDS hardware is tracked within the system, enabling collision prevention measures. Independent of crane/machine type, the system supports tracking and collision avoidance with MHE and personnel.

Collision prevention is achieved through continuous real-time position tracking of all relevant objects in the operating environment. Cranes, material handling equipment (MHE), and personnel are monitored within a shared spatial model. When the system detects that MHE or personnel are approaching predefined safety zones around a crane, it automatically initiates appropriate responses. These include deceleration, controlled stops, or dynamic adjustment of the crane's movement path, depending on the specific scenario. This ensures safe and coordinated operation in environments with mixed traffic and shared workspaces.

DANGEROUS OBJECT		ENDANGERED OBJECT		
		Crane	MHE	Personnel
CRANE	Crane Leg	X	X	X
	Spreader Container	X	X	X
MHE	MHE	X	X	X

Crane-to-Crane

The system supports crane-to-crane collision prevention across all crane types, including ship-to-shore (STS), rail-mounted gantry (RMG), and rubber-tired gantry (RTG) cranes.

When two cranes move toward each other, and a potential collision is detected, the system automatically intervenes by issuing a slow-down or stop command. This applies to both parallel and perpendicular travel movements.

Another critical scenario occurs when the spreader of one crane moves into the upper working area of a neighbouring crane - such as above the operator's cabin, machinery housing, or other exposed components. In these cases, the system detects the potential hazard of a suspended load travelling over sensitive zones. To mitigate the risk of incidents such as dropped loads, swinging motions, or mechanical failures, the system automatically adjusts the spreader's movement path or hoisting height. This ensures that suspended loads do not pass directly over safety-critical areas, significantly enhancing operational safety during parallel crane movements.

Crane to MHE

Collisions between MHE and crane structures, such as (crane-)legs or moving spreaders, are avoided by triggering appropriate responses. When predefined proximity thresholds are reached, the system initiates actions such as speed reduction or controlled stopping of crane movement.

Following the same logic used in crane-to-crane operations, the system also monitors spreader movements near MHE. If the spreader approaches a zone above operator cabins or exposed components, it automatically adjusts its path or lifting height. This prevents suspended loads from passing over safety-critical areas and reduces the risk of incidents related to load drops or mechanical failures.

Crane to Personnel

The same safety logic is applied to interactions between cranes and personnel. If a person approaches a crane leg or enters the crane's travel path, the system responds immediately by reducing speed or initiating a controlled stop to prevent physical contact.

In addition, the system continuously monitors the spreader's surroundings. If a person is about to enter the predefined safety zone beneath or near the spreader, the system adjusts the spreader's movement path or lifting height in advance. This ensures that suspended loads do not pass over individuals and that personnel are not exposed to overhead hazards.

MHE to Personnel

The system applies the same collision-avoidance logic used in crane operations to all material handling equipment (MHE) described above. When personnel are detected near moving MHE, the system automatically reduces speed or initiates a controlled stop. These actions are triggered based on predefined proximity thresholds and ensure safe interaction between MHE and personnel in shared work areas.

The Real Time Locating System supports structured and rule-based collision prevention across all relevant operating scenarios. By relying on continuous real-time tracking, the system remains effective even in complex environments with visual obstructions or poor visibility.

The RTLS/PDS infrastructure supports scalable, redundant tracking across all equipped assets. It enables continuous monitoring and control of cranes, vehicles, and personnel, forming the basis for real-time collision prevention. Safety functions such as dynamic exclusion zones and a Collision Avoidance System (CAS) are integrated into the system logic. CAS maintains operational continuity by guiding equipment around potential hazards, rather than stopping it entirely.

The system is designed to be flexible and adaptable to a wide range of terminal configurations. It supports predictive maintenance and allows for tailored integration based on specific operational needs. Implementation requires a detailed planning phase and a longer installation period to ensure alignment with terminal work-flows and infrastructure.

System functionality depends on the presence of RTLS/PDS equipment. Only tagged or sensor-equipped assets can be tracked and protected, which ensures data accuracy and system responsiveness. While the initial investment and reliance on the technology provider are significant, they reflect the complexity of a terminal-wide safety solution and support long-term operational availability.

4.1 System Architecture and Functional Setup

To enable position tracking and collision prevention, the system requires specific hardware configuration and functional setup:

Personnel Tracking:

Workers are equipped with tags, either mounted on helmets or carried as standalone units. These tags enable continuous tracking of personnel and supply real-time location data. A virtual exclusion zone is dynamically generated around each tag, allowing the system to maintain safe distances.

Crane Equipment:

Cranes are equipped with antennas for continuous tracking of their absolute position, and sensors to detect nearby objects such as personnel or vehicles. Based on object type and proximity, the system triggers predefined responses.

To ensure safe distances, a virtual exclusion zone is dynamically generated around the crane legs and the spreader. These zones enable timely system reactions - such as speed reduction, path correction, or controlled stopping - to reliably prevent collisions.

Material Handling Equipment (MHE):

MHE is equipped with antennas for continuous determination of their absolute position and sensors to detect nearby objects, such as cranes or personnel. A virtual exclusion zone is dynamically generated around each unit to maintain safe distances and avoid interference with surrounding objects. This enables proactive system responses and supports safe, coordinated operation in shared environments.

Building on the hardware components described above, the integrated RTLS/PDS system enables key safety and automation features that operate across all tracked objects.

Digital Twin and Real-Time Visualisation of Operations:

In addition to physical tracking infrastructure, the system architecture incorporates a digital twin model that provides real-time visualisation of the terminal layout, and all tracked entities.

This environment is subdivided into geofenced zones, enabling predefined system behaviour in context-specific areas. Critical sections, such as loading lanes or maintenance zones, can be assigned special logic layers to enforce stricter safety responses.

All tracked objects are surrounded by dynamic virtual exclusion zones that extend beyond their physical dimensions to account for latency, acceleration, and system tolerances. These zones are adjusted in real time based on operational parameters such as speed, direction, or functional state. For example, exclusion zones for MHE dynamically expand during high-speed travel and contract during idle states. Their dimensions are configured in coordination with terminal operations to achieve a balance between safety and operational efficiency. (See ***Figure 42*** for a sample exclusion zone around MHE.)

In addition to dynamic zones, static exclusion areas can be configured within the digital twin. These are used to define temporarily restricted areas, such as for maintenance work, without requiring physical barriers or additional hardware components.

This layered zoning logic enables real-time, context-sensitive collision prevention across all actor constellations in the terminal.

Each object classified as a dangerous object according to Table 1 is assigned multi-layered exclusion zones (See *Figure 43*). When the virtual exclusion zones of the objects in the yard begin to overlap, the system initiates a controlled response and slows down or stops completely, before entering in the proximity of the hazard. This configuration ensures that entry into critical zones is categorically blocked by the system logic, preventing any risk to personnel or equipment.

Fig 42: Virtual exclusion zone around MHE

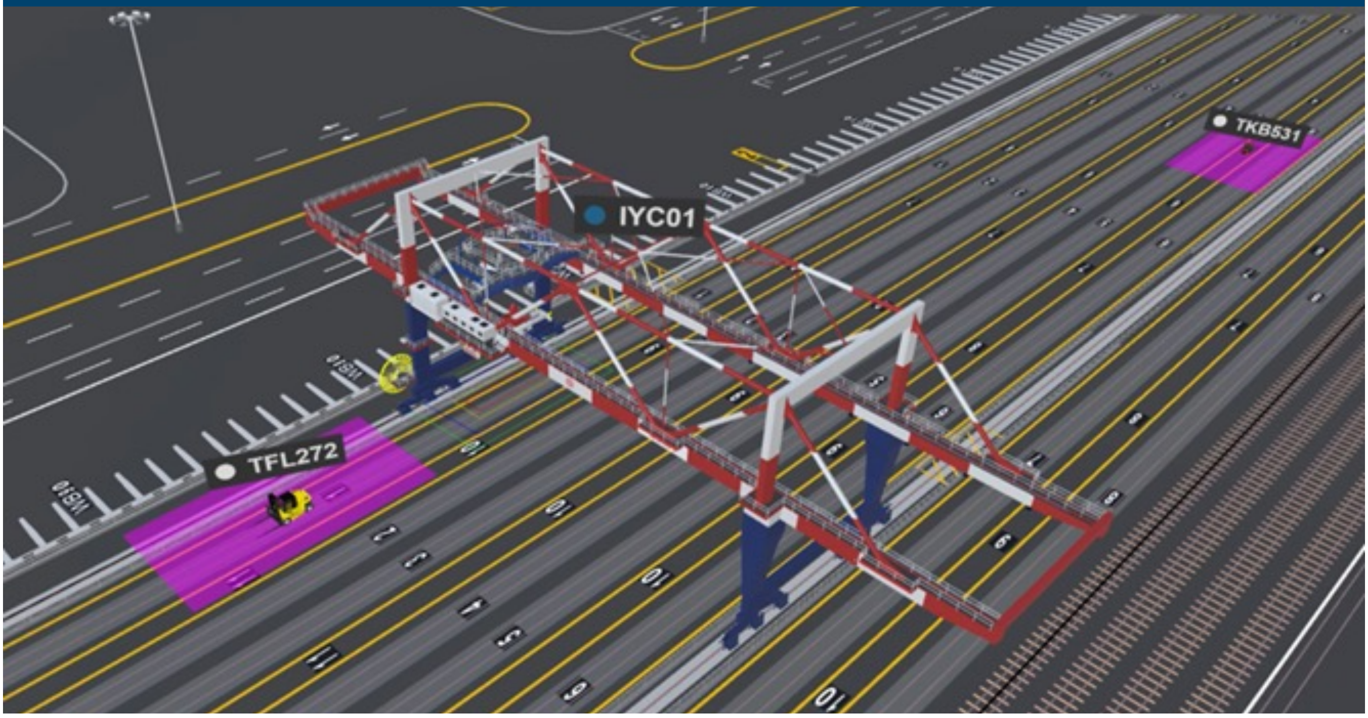


Fig 43: Multi-layered exclusion zones

5 Technologies for Collision Prevention

5.1 Laser

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

Fig 44: 1D-Laser measurement principle time-of-flight

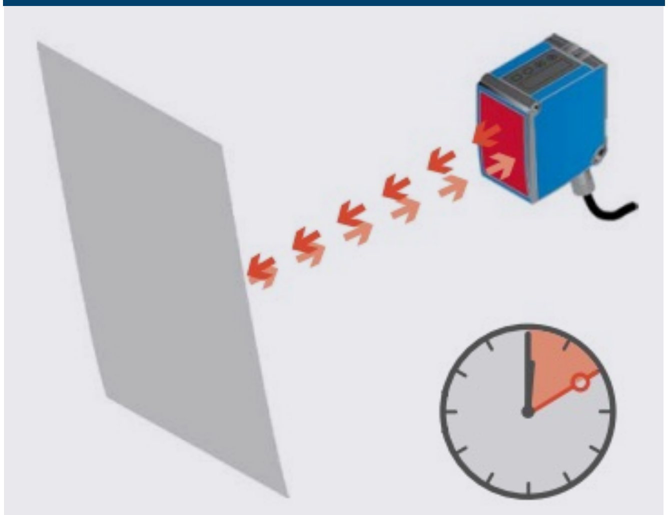


Fig 45: 2D-Laser measurement principle time-of-flight

5.1.1 Types of Sensors

There are different types of sensors from different 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 decision is how many dimensions the laser should measure. Then, other individual parameters must be selected.

5.1.1.1 1D-Laser

Generally, distance sensor meters consist of the following components:

- Laser diode
- Receiver
- Optics
- Processor with a 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. Knowing the speed of light, 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 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.

5.1.1.2 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 a transmitter-receiver-module. The values from the deflection unit, which combines 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 the update rate of the 2D profile ranges from approximately 7 ms to 200 ms.

For the 2D laser, the laser distance measurement performance is similar to 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 46: Inner architecture of the 2D-Laser

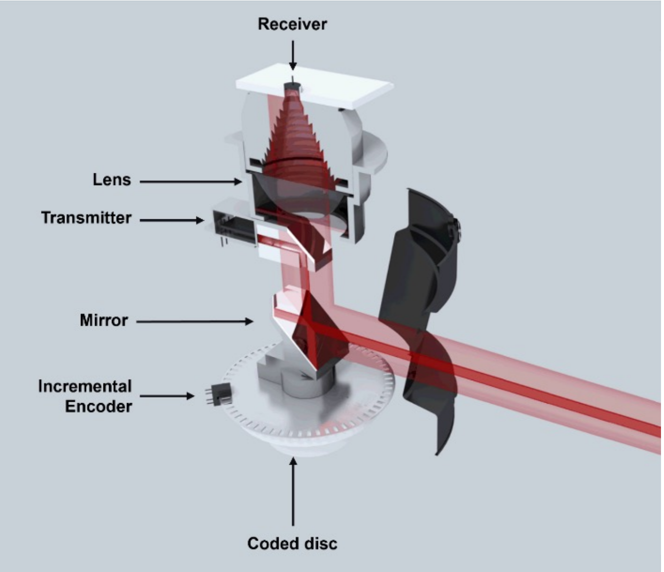


Fig 47: Field of view – 2D laser

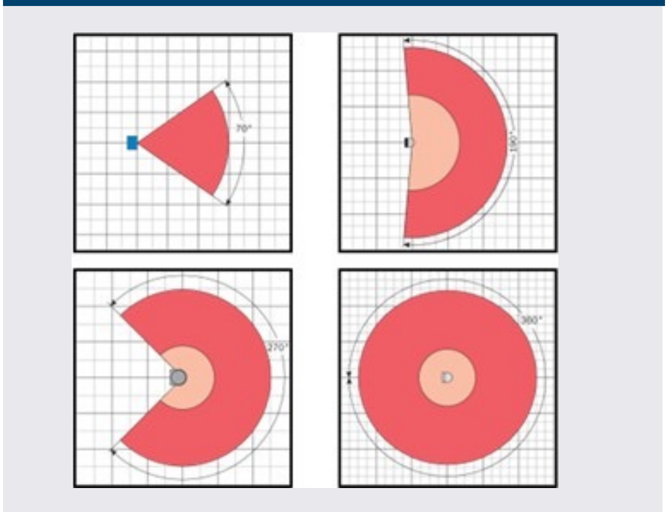


Figure 46 shows the field of view that a 2D laser scanner can have. Typically, the following types are used from 70°, 190°, 270° up to a full 360° angle.

Depending on the scanner type, the measurement of a 2D-Laser ranges from 0.2m – 250m (maximum range) and 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.

5.1.1.3 3D-Laser

Unlike a 2D Laser which creates only one 2D-Scan plane (layer), the 3D-Laser creates multiple scan planes. Typically, a 3D multi-layer laser has between 4 to 192 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 the distance between the layers – is 90° / 64 = 1,406°.

There are safety-certified 3D laser sensors available on the market for outdoor applications that provide safe functionality up to 20 m.

Fig 48: 3D-Laser with 90° Field of View (FOV) in vertical axis.

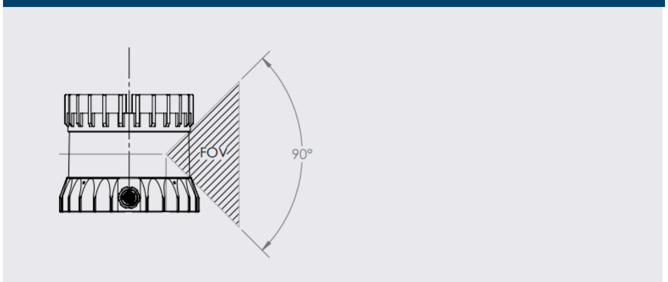
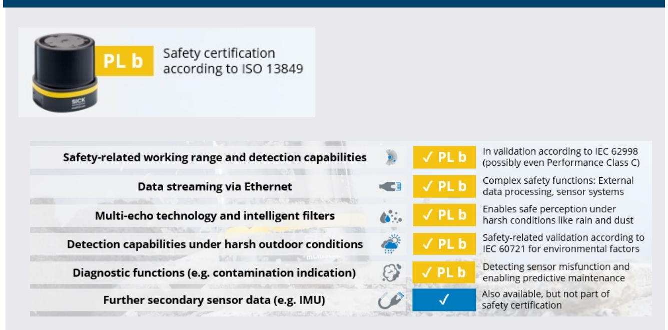


Fig 49: 3D-Laser with 42° (65°) field of view (FOV) in vertical axis 16 layers.

Fig 50: 3D-Laser with 192 layers or 128 layers

Fig 51: 3D-safety certificated laser with 16 layers.



5.1.1.4 3D-TOF (camera) Sensor

A 3D ToF camera sensor emits infrared light signals within a 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").

3D-TOF cameras with AI can detect objects and people even from a single glimpse of a body part. The intelligent camera reliably distinguishes between persons and other obstacles, giving warning signals in the event of danger. Warnings are only generated if there is a risk of a potentially dangerous collision with people or obstacles. The integrated obstacle detection works completely autonomously, without any additional hardware. The 3D-TOF systems -up on the lens, soiling or voltage drops. Besides, a live video stream can be transmitted via Fast Ethernet, in either H.264, H.265 or MJPEG format

Used as area surveillance sensors they can provide alarm signals via a CAN controller that is connected via Ethernet to the crane PLC to slow down and stop the crane if necessary.

Fig 52: D-TOF Sensors

5.1.1.5 Outdoor Safety Certified Laser Sensors

In the context of protecting people in industrial workplaces, certain critical applications require certified functional safety features. The implementation of applicable standards (e.g. ISO 3691-4) and/or individual risk assessment determines the required safety level. Generally, common automation-related sensors are not certified, for such functional safety solutions.

Safety-related sensors provide defined functional safety features and are certified by an authorised body for the intended application and are rated for a defined safety level (e.g. Performance Level according to ISO 13849-1). Furthermore, a certified outdoor safety sensor must also include defined limits of application, taking into consideration environmental factors such as rain, dust, and fog. The detection capability (Performance Class according to IEC TS 62998) is especially relevant in this context.

Safety-related sensors can provide various safety functions such as protective fields (internal logics, e.g., for detecting people and triggering a safe state) and/or safety-related measurement data enabling advanced or customisable safety-functions based on an external application processing unit, (e.g. safety-related localisation and mapping). Different safety levels can be combined at the system level to achieve safe environmental perception. (e.g. (PL b) in combination with emergency braking (PL d) (SRSS according to IEC TR 62998-2). Implementing safety-related systems might using standard automation sensors may be possible in some cases but the additional equipment and the certification process required can lead to greater effort.

In summary, when compared to standard sensors, safety-certified sensors guarantee specified low failure rates and high detection probabilities under defined limits of use. This is a mandatory requirement for safety-critical applications (e.g. personal safety). The use of such sensors can also be highly beneficial for applications requiring a high confidence level in the required functionality in general, (e.g. preventing damage to automated machines and avoiding cost-intensive downtimes)

5.1.2 Selection of Sensor

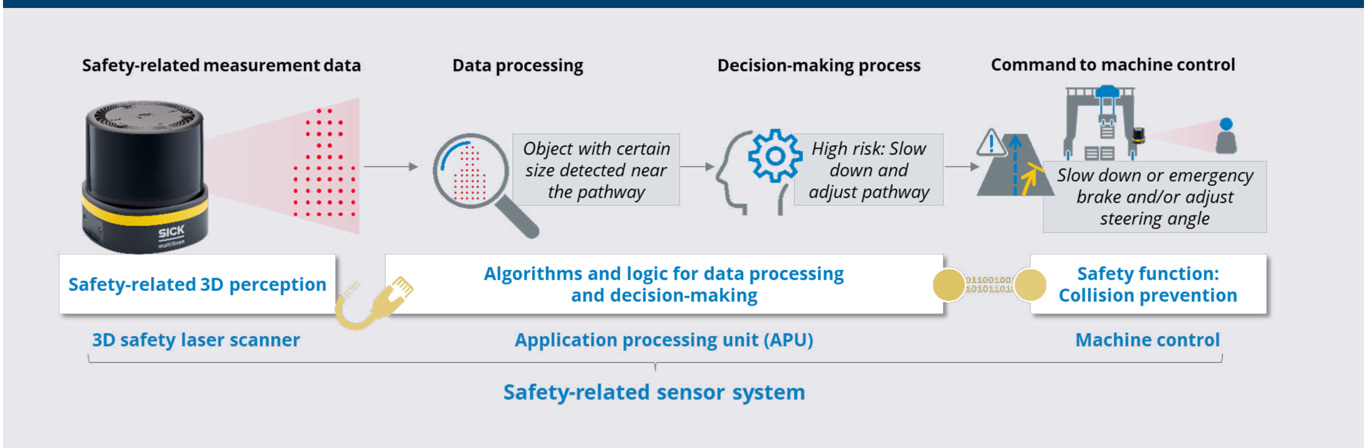
The appropriate selection has to be made depending on the application. Key selection criteria are as follows:

- Distance
- Divergence (spot size)
- Angular resolution
- Accuracy
- Scan frequency
- Environmental conditions
- System design/concept
- Data processing unit
- Application software
- Network Data Requirements
- Software API
- Functional Safety Requirement (Standard, eg. ISO…, DIN EN…)

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.

Fig 53: Safety-related sensor systems



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 along one axis – for example, by moving 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 interpret the proper function of the handling process, then 3D-Lasers are the most appropriate. E.g., Dynamic area surveillance to track objects/subjects around the crane or the detection of the lifting of the truck with the Container lift in the Truck lifting prevention application.

5.1.2.1 Distance (Range)

The maximum distance between the sensor and the object must be evaluated to meet requirements. Typical applications in ports require 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 poorly reflecting colour. Sensor suppliers quote different distance values in their data sheets, but it should be noted that while most applications are on natural surfaces (containers, trailers, etc.), there are occasionally dark surfaces where the reflectivity is reduced to 10% remission or even lower.

5.1.2.2 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, such as, twist locks, corner castings or vessel antennas.

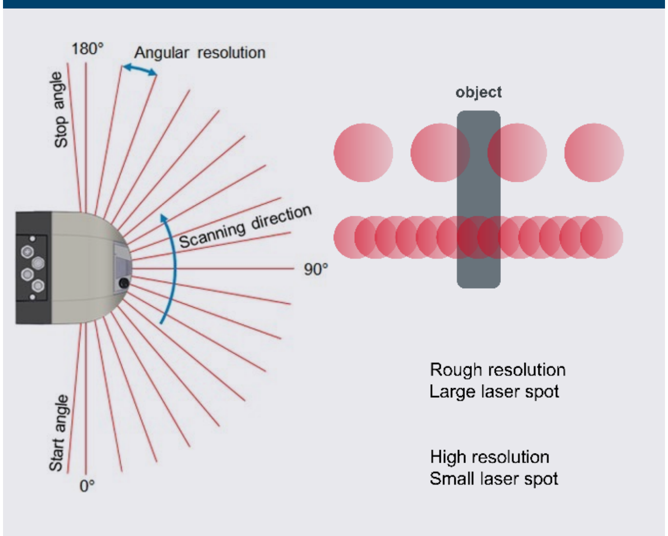
The beam divergence is measured in mrad = mm/m. The value describes the increase of x mm per m distance. Typically, values for outdoor scanners range from 0,4 mrad up to 10 mrad.

Fig 54: Divergence of laser beam

5.1.2.3 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 influence how accurately the shape/position of the objects can be detected. In the case of the 3D-Laser, the resolution in the vertical scan axis depends on the angle between the layers. For the 3D-Laser (2D-Laser + Movement) the rotation speed and the scan frequency are fundamental for the resolution.

Fig 55: Scan angle, angle steps and spot size



5.1.2.4 Accuracy

The sensor's accuracy can be expressed as the distance accuracy of each laser beam. The distance between the spots, the size of the spot at a certain distance and the scan frequency are critically important to determining the position of an object in the 3D space.

5.1.2.5 Scan Frequency

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

The scan frequency is one of the most important factors 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 their movement, and the system needs to match the object's speed with an appropriate frequency.

Every Laser 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.

5.1.2.6 Condition and Diagnostic Features

Sensor data such as contamination indication or IMU (inertial measurement unit) can indicate important information about the device status. Such information can be provided as a remote service for monitoring, analysing, and predicting service and processing data. Of particular importance, 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 transferred 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 such as rain, fog, dust, or glaring lights.

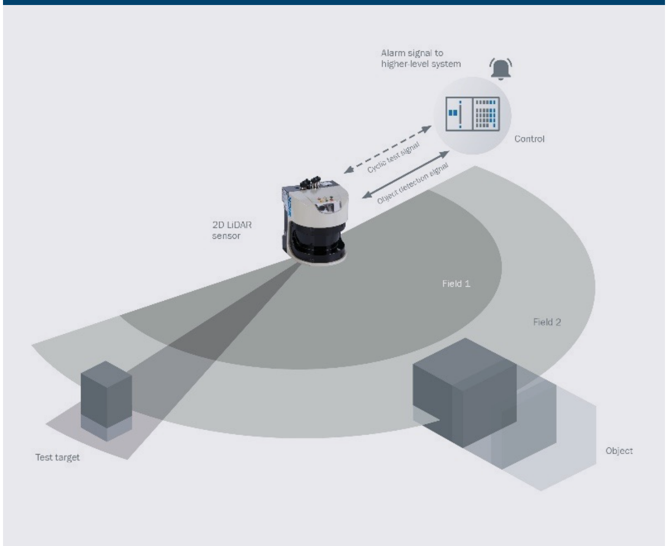
Most laser sensors allow for the addition of enhanced diagnostics. For example, a self-test function can be implemented by evaluating an external test target to ensure detection capabilities. Furthermore, the switching signals can be periodically checked by an external safety controller.

If a correct response is not received, the controller is locked and sends a signal to the higher-level equipment controller. The connecting cables are also cyclically monitored. The high degree of diagnostic coverage also assists with obtaining individual safety certifications for equipment.

Diagnostic functions:

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

Fig 56: Sensor function and alignment check over the external target



5.1.2.7 Environmental Conditions

Very harsh conditions prevail in the ports and terminals. 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.

Robustness is ensured by functions in the sensors themselves but is also further 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 respective application. This should be assessed specifically in the context of mechanical and weather-related influences, as highlighted above, as well as electrical integration, mechanical connections/fixings, sea air, and other special local conditions.

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), that is then received by the laser.

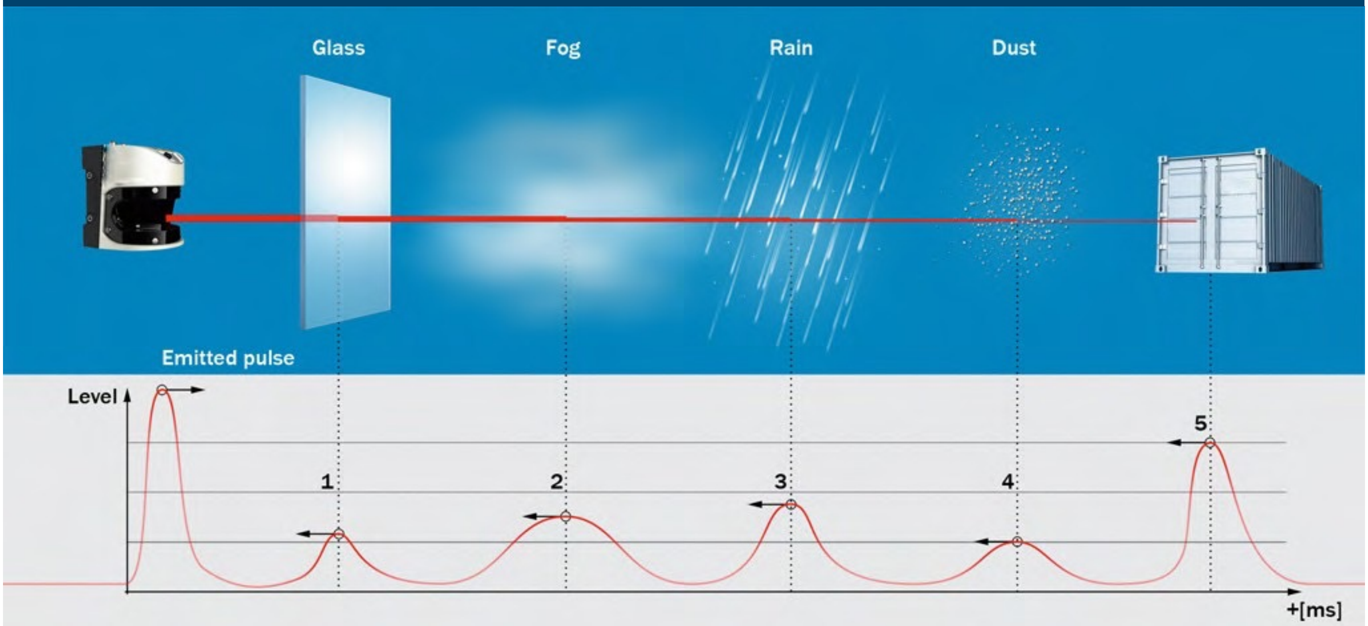
Disturbing objects include:

- 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.

In any case a selected Laser sensor needs to be tested extensively in real application conditions to ensure its reliability and usability in an operations environment.

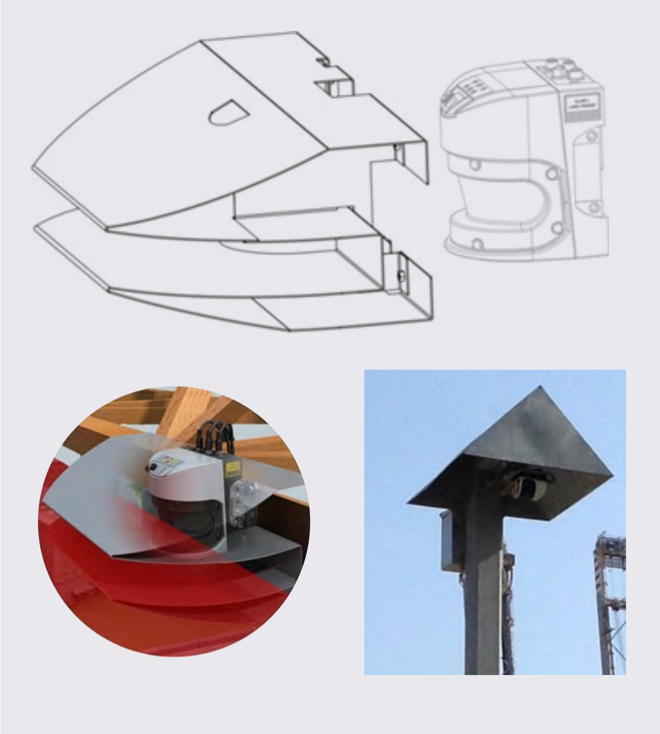
Fig 57: 5 echo technology

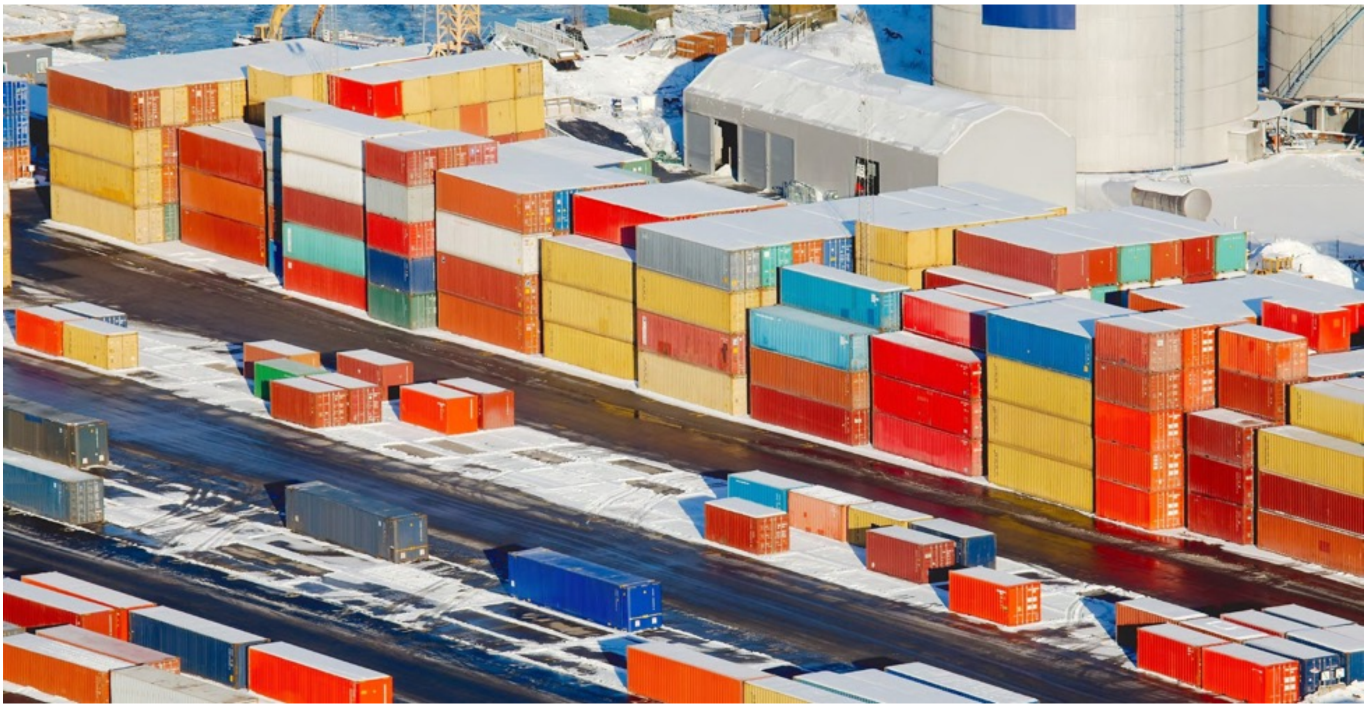


Weather Accessory

The impact of weather conditions such as snow and rain can be minimised by using mechanical solutions, like 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 risk of sunlight heating the sensor above its permissible operating temperature range. The use of a simple weather hood (and/or sunroof in some climates) is therefore highly recommended.

Fig 58: Weather hood





5.2 Radar

Modern radars can track several objects simultaneously and provide a list of detected objects, including the strength of the echo (Radar Cross Section, RCS), distance, direction and the relative speed of the object. The item's material and orientation have a large influence on the strength of the reflection (measured RCS). In general, the reflection from metallic surfaces is stronger than from other materials, e.g., plastic, wood, people etc.

Safety-certified radars for people detection up to safety level PL d are available on the market today. The benefit of radar technology is that these sensors are practically immune to outdoor weather conditions. However, the range and relative speed of safety-certified sensors are limited.

5.3 Camera

Camera Technology utilises two operating principles namely: Image Processing and Stereo.

5.3.1 Image Processing

The camera-based systems rely on cameras combined with image processing technology to continuously monitor the machinery surroundings.

The cameras capture visual data within a defined field of view and analyses this data in real time using image evaluation algorithms. Objects and subjects such as containers, vehicles, infrastructure elements, and personnel can be identified based on their visual characteristics. By applying AI-based object recognition, the system can distinguish between relevant obstacles and non-critical elements in the operating area.

When the system detects an object or person within a predefined safety zone, it evaluates the situation according to configured risk parameters. If a potential collision risk is identified, the system can automatically trigger a safety response. This response may include issuing a warning to the operator or immediately stopping the machine to prevent an accident.

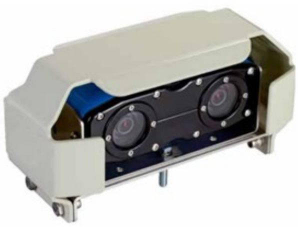
5.3.2 3D-Stereo Camera

A 3D stereo camera with active object detection and tracking in near and middle fields.

3D stereo cameras record objects around installation points, (e.g. a crane or vehicle), with two images from slightly different perspectives. These images are used to calculate information about distance, representing a third dimension. This is the way humans perceive space.

The sensor head captures raw 3D data and transmits it to the evaluation unit. This unit is programmed to analyse the vehicle's environment and warn the operator only in critical situations. The sensor operates as a standalone solution and includes an integrated recording function for continuous data capture.

3D sensors detect relevant objects around their installation location, and provide live feeds. The technology is based on evaluating not only the width but also the height of objects. Algorithms filter irrelevant information, such as curbs, small stones, rain or fog. This ensures that the operator assistance system only warns the user in critical situations.



5.4 Real-Time Locating System Positioning Technologies

The RTLS is based on a multi-sensor positioning architecture that combines several tracking technologies, each selected for its suitability under specific operational and environmental conditions. The solution integrates multiple technologies, including Ultra-Wideband (UWB), Bluetooth Low Energy (BLE), Differential GNSS (DGNSS), and Real-Time Kinematics (RTK), and is supported by Inertial Measurement Units (IMUs) for dead reckoning. This combination provides redundancy and improves reliability in areas where signal availability is limited or variable.

Dead Reckoning (IMU-Based)

Dead reckoning determines an object's position using motion data from an Inertial Measurement Unit (IMU) without relying on external signals such as GNSS or UWB. This method is particularly useful in situations where such signals are temporarily unavailable or degraded.

It is especially effective for vehicles, as their regular and predictable movement patterns allow for relatively high accuracy—typically within 0 to 1 meter. In contrast, its accuracy for pedestrian tracking is lower, making it more suitable for rough position estimation in fallback scenarios.

Dead reckoning is mainly used to maintain position continuity when primary localisation technologies lose signal or fail to deliver reliable data. In such cases, it ensures that the system continues to provide positional information, enabling uninterrupted tracking. This makes it a valuable component in hybrid positioning systems. In addition, dead reckoning supports mobile and infrastructure-independent deployments, making it suitable for use in complex or obstructed environments.

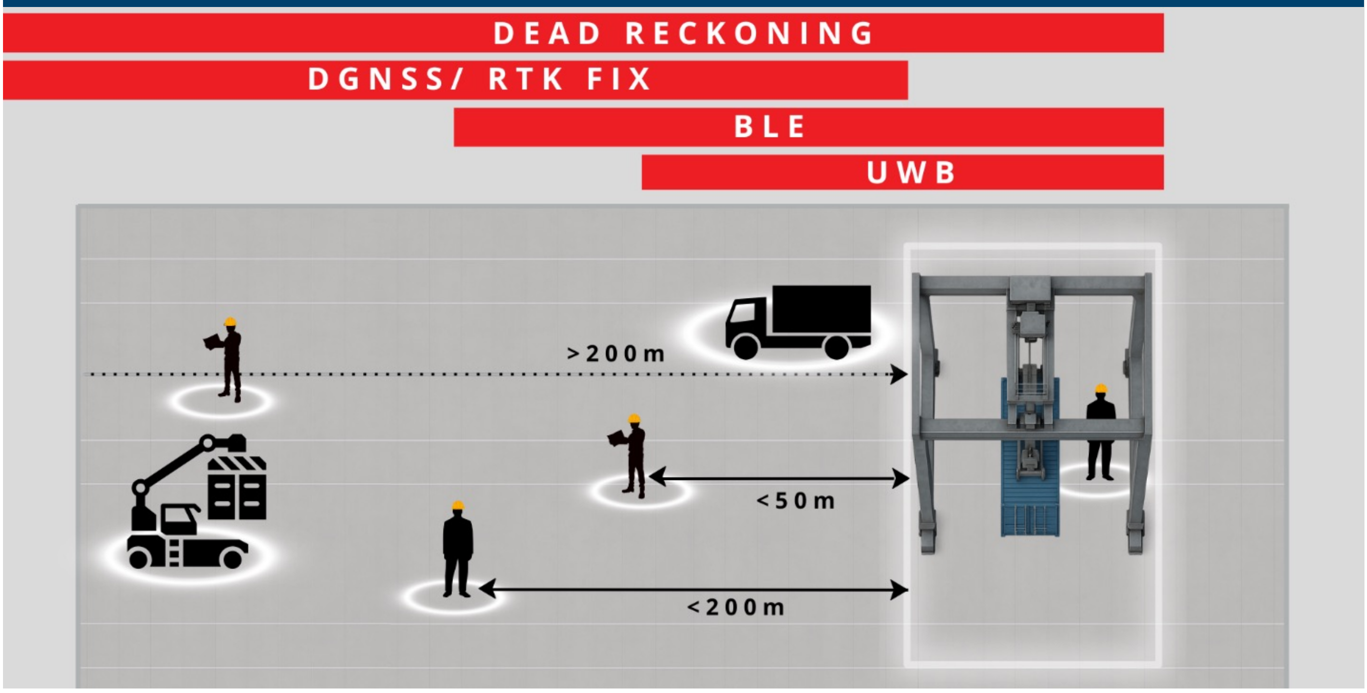
Ultra-Wideband (UWB)

Ultra-Wideband (UWB) enables high-precision distance measurement between devices by using time-of-flight calculations. It achieves centimetre-level accuracy, typically within ≤ 10 cm, and remains reliable even under challenging environmental conditions such as rain, dust, or metal interference.

UWB is particularly suited for short-range, high-resolution tracking applications, especially in areas around or beneath cranes where other positioning technologies may be less effective. It plays a central role in collision avoidance systems, where precise spatial awareness is critical.

The implementation of UWB requires fixed infrastructure. Anchors must be installed on cranes and material handling equipment (MHE), while personnel are equipped with mobile UWB units,

Fig 59: Range of RTLS technologies



often integrated into wearable devices such as helmet-mounted tags. This setup allows the system to calculate precise distances between moving and fixed objects in real time.

Bluetooth Low Energy (BLE)

Bluetooth Low Energy (BLE) is a low-power radio technology that uses small beacons to transmit signals at regular intervals. The proximity of a beacon can be estimated by the receiving device based on the signal strength (RSSI), enabling basic location awareness.

BLE is primarily used for coarse positioning in areas where high-precision systems such as UWB are not available. It is well suited for zone-based detection and presence monitoring, for example, to determine whether personnel or equipment have entered or exited specific terminal areas.

With a range of up to 200 meters and a typical accuracy of around 5 meters, BLE is not intended for precise localisation but serves as a useful supplementary layer in sensor fusion architectures. Its low infrastructure requirements and easy deployment make it a flexible option for supporting broader spatial awareness in large or complex environments.

Differential Global Navigation Satellite System (DGNSS) and Real-Time Kinematics (RTK)

Differential Global Navigation Satellite System (DGNSS) and Real-Time Kinematics (RTK) are satellite-based positioning methods that enhance the accuracy of standard GNSS signals by using correction data from fixed reference stations.

DGNSS applies correction data to improve positional accuracy to approximately 0.5 to 1 meter. It offers broad coverage with minimal infrastructure requirements and can be deployed quickly. This makes it suitable for general vehicle tracking and system initialisation across large areas. However, its performance is limited in obstructed environments—such as under crane booms or between stacked containers—where signal quality may degrade.

RTK further increases positioning accuracy by processing both correction data and satellite carrier-phase information. In optimal conditions, RTK Fix achieves accuracies of 1 to 3 centimetres, while RTK Float, used as a fallback when full fix is not possible, provides 10-to-30-centimetre precision. RTK requires a stable satellite signal and continuous access to real-time correction data, typically via a base station or a correction service.

Together, DGNSS and RTK form a scalable solution for GNSS-based tracking. DGNSS supports area-wide coverage with moderate precision, while RTK enables high-accuracy applications, such as automated crane control and precision guidance of terminal vehicles.

The positioning system combines multiple technologies to ensure robust and continuous tracking performance across different operational contexts. Each method contributes specific strengths that complement the limitations of others.

TECHNOLOGY	ACCURACY	STRENGTHS	LIMITATIONS	TYPICAL USE CASES
DEAD RECKONING (IMU-BASED)	0–1 m (vehicles), lower for pedestrians	Signal-independent, useful in obstructed areas	Drift over time; lower precision for humans	Fallback tracking in signal loss; tunnels; sensor fusion
Ultra-Wideband (Uwb)	≤ 10 cm	High precision; robust under harsh conditions	Requires fixed infrastructure; NLOS reduces accuracy	Collision avoidance around cranes; short-range tracking
Bluetooth Low Energy (Ble)	Approx. 5 m	Low power; simple setup; large coverage	Low accuracy; sensitive to signal fluctuations	Zone detection; presence awareness; supplemental layer
Differential Gnss (Dgnss)	Approx. 0.5–1 m	Wide-area coverage; minimal infrastructure	Limited performance in obstructed areas	MHE tracking; system initialization
Real-Time Kinematics (Rtk)	1–3 cm (Fix), 10–30 cm (Float)	Centimetre accuracy for automation systems	Needs stable signal and correction data	Automated vehicle/crane guidance; high-precision control

Summary

Dead Reckoning is primarily used to maintain position continuity during short-term signal loss, especially in GNSS- or UWB-denied environments. UWB offers highly precise, short-range localisation and is particularly effective in areas with limited GNSS reliability, such as beneath crane structures. BLE, DGNSS, and RTK complement these technologies by extending coverage, enabling zone-based detection, and supporting both general and high-precision tracking depending on the operational needs. By combining these technologies, the system achieves a high level of resilience, precision, and spatial awareness, even in complex or obstructed terminal environments.

About the Authors and PEMA

About the Authors

This Information Paper has been jointly developed by TT Club, ICHCA International and PEMA, with their senior experts, based on the information available at the time of publication. It does not constitute professional advice, nor is it an exhaustive summary of the information available on the subject matter to which it refers. This document should always be read and used in conjunction with the relevant national and international legislation and any applicable regulations, standards and codes of practice. This Information Paper provides comprehensive and state-of-the-art guidelines for high level risk reduction and collision prevention at Ports and Terminals.

This paper was prepared on PEMA side by Lars Ambrosy, CEO, LASE Industrielle Lasertechnik GmbH as main author, together with Jörg Spiegelhalter, Global Industry Manager Ports & Terminals, Cranes, SICK AG., James Gabbard (Chief specialist Automatic crane systems) TMEIC, Stephan Trauth CEO Mi-Jack Europe, Sebastian Simon Liebherr Product Manager Port Equipment and Frank Spitzer of IFM Port Industry Manager with contributions from the TT Club and ICHCA.

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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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