Specification Example

Lase SCP-3D
Lase Stack Collision Prevention 3D
With 1 x 2D-Laser scanner and 1 x 3D-Laser scanner

Version 1.9

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CONTENT

TABLES

FIGURES

1 Scope

This document describes the product LaseSCP-2D/3D a stack collision prevention system Used symbols

The book symbol shows, that in the text is referred to additional documents or documentations of the respective manufacturer of the component

ATTENTION! - This symbol with the yellow triangle indicates dangers. Text passages marked with this symbol should be read very carefully and to be followed to avoid accidents!

The “i” symbol indicates text passages with special notes/information. This text passages should be read carefully.

1.1 Abbreviations

API	Application programming interface
ARMG	Automatic Rail Mounted Gantry Crane
ACRMG	Automatic Cantilever Rail Mounted Gantry Crane
CAN	Controller Area Network (standardized Field bus system with communications orientated data exchange protocol)
CEWS	Name of LASE Software Framework
CCS	Crane Control System
CS	Control System
Dll	Dynamic link library
IPC	Industrial Personal Computer
LCU	LASE Control Unit
LMS	2D Laser Measurement System
LSP	LASE Servo platform
PLC	Programmable Logic Controller
RTG	Rubber Tyred Gantry Crane
TCP/IP	Transmission Control Protocol / Internet Protocol – network protocol
2D	2 dimensional
3D	3 dimensional
3D laser scanner	LASE Servo platform (LSP + 2D laser scanner as complete unit)
2D laser scanner	Individual laser scanner without swivel platform

2 Requirement

Ports having identified that there is a risk of a spreader/load colliding with containers in the stack / transport lane, resulting in containers being knocked over and falling down in the yard or in worst case in the transport lane. This is resulting in hazardous situations that could possibly lead to severe incidents involving people working in and around the Crane area.

In the documents are partly drawings from Cantilever aRMGs, the work principle is the same like for the collision prevention system for an RTG. The LaseSCP-2D/3D product is usable for RTG.

2.1 General conditions

For a reliable and accurate working measurement system following general conditions is expected:

- **Temperature range**: -20°C to +50°C
- **Crane height:** max. 26m
- **Distance 2D and 3D-Scanner ➔ LCU** max. 20m
- **Container types** 20', 40', 45', twin 20', Standard, reefer, covered open top
- **Usage of LaseSCP-3D functions** Just in trolley drive direction

3 Solution

The LASE solution is a measurement system working with one 3D-Laser scanner and a 2D-Laser scanner, mounted under the trolley, and a software application which collects the scan data, doing all needed calculation and sending the results to the machine PLC.

The system is based on the following hardware:

1 x 3D-Laser scanner LASE3000D –C2-118 (Optional one or more scanners)

1 x 2D-Laser scanner LASE2000D-118

1 x Control Cabinet with LASE Control Unit (IPC), Display, Indicator lights, Interface Modules, Power supply, Wlan

The layout of the system allows an easy retrofit to the exciting fleet.

Information's which are usually available in the PLC will be generated by the SCP 3D itself, which make the adaptation to the existing fleet much easier.

- Trolley position
- Hoist position
- Position of spreader
- Info empty spreader or container at spreader
- Container size
- Spreader size
- Current speed

Other parameters can be set individual according the behaviour of the machine

- Latency times (PLC)
- Behaviour of the load (sway behaviour according the rope system)
- Slope

Some or partly the same more input information will be extracted from the PLC program.

3.1 Definition

3.1.1 Coordinate system

The coordinate system is defined as follows and based on a so called right handed system.

- Y = Gantry travelling direction
- X = Trolley travelling direction
- Z = Hoist movement

The point of origin is outside the stacking area and the truck lane at one end of the block. All values do have a positive sign. Arrows are pointing in positive direction. The rotation angles (like trolley skew) are defined as follows:

Clockwise (view from the origin) = positive angle

Counter clockwise = negative angle

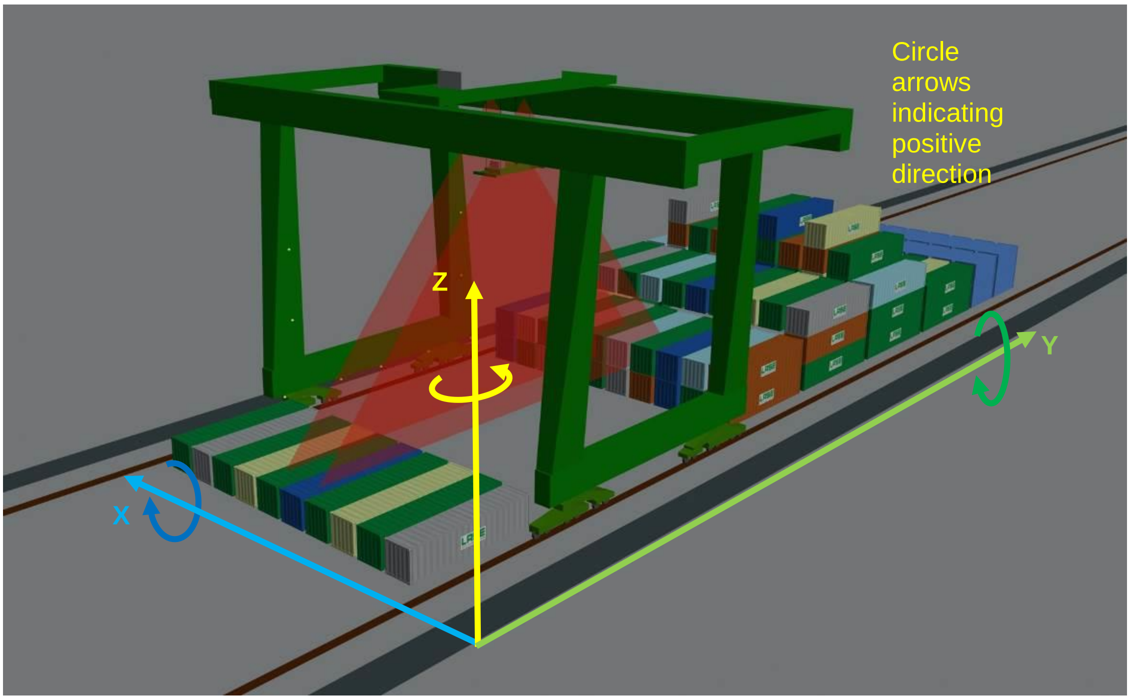

Figure 1: Coordinate system

3.1.2 Yard

The following drawing shows the definitions of the yard.

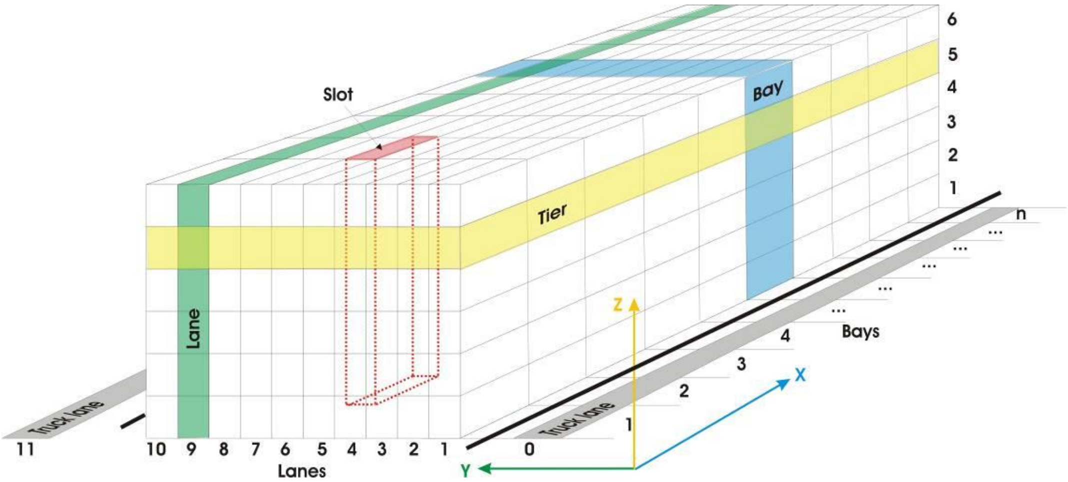

Figure 2: Yard definitions

4 Hardware

The Lase measurement system consists of the following hardware components.

4.1 3D-Laser scanner (LASE3000D-C2-118)

The high performance 3D-Lasescanner based on the components of 2D-Laserscanner and a swiveling platform. The swiveling platform is turned by a servo-drive. A high resolution Encoder inside the servo-drive measures the angle of rotation of the platform. By the linkage of the 2D-Laser data with the Encoder data, high precise 3D profile measurements are produced. For operation, the modular LASE CEWS Application software is controlling the swiveling and evaluation of the scan data.

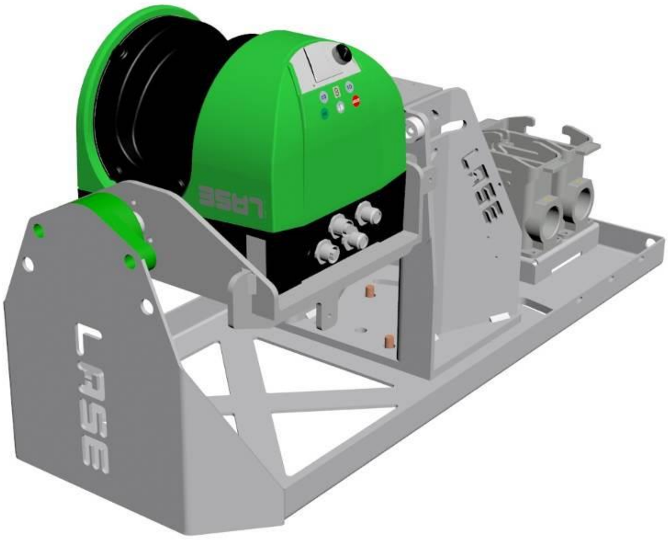

Figure 1: 3D-Scanner LASE 3000D-C2-118

Description	value
Measuring range (at 10% remission)	26m (max 80m / 100% remission)
Measuring frequency	25 – 100Hz
Angle step (scanner)	0,1667 – 1°
Scan range	190°
Resolution	±24mm
Wave length Laser	Infra-red (905nm)
Laser Class	Class 1 (eye-safe), to EN/IEC 60825-1 and 21CFR 1040.10 and 1040.11
Swivel range	appr. ±90°
Swivel resolution	0,002°
Power (Servo, Laser, Heating)	24V DC
Interface Laser	Ethernet 10/100 Mbit/s
Interface Servo	CAN-Bus
Weight	ca. 22,5Kg
Temperature range	-25 – +50°C
Protection category	IEC IP 65

Table 1: Technical data LASE3000D-C2-118

4.2 2D-Laser scanner (LASE2000D- 118)

The high performance 2D-Lasescanner is the same type as is used on the swivelling platform.

Figure 2: 3D-Scanner LASE 2000D-118

Description	value
Measuring range (at 10% remission)	26m (max 80m / 100% remission)
Measuring frequency	25 – 100Hz
Angle step (scanner)	0,1667 – 1°
Scan range	190°
Resolution	±24mm
Wave length Laser	Infra-red (905nm)
Laser Class	Class 1 (eye-safe), to EN/IEC 60825-1 and 21CFR 1040.10 and 1040.11
Power (Laser, Heating)	24V DC
Interface Laser	Ethernet 10/100 Mbit/s
Weight	ca. 3,7Kg
Temperature range	-30 – +50°C
Protection category	IEC IP 67

Table 2: Technical data LASE2000D-118

4.3 Control Unit (LCU)

The LCU is a standard industrial PC (IPC). The LCU is equipped with the state of the art technology with following performance data (final performance data can be deviate):

Component	Description
Operating system	Windows 7 32/64 Bit
Processor	Intel® Core™ i7-2600/3,4GHz or similar
RAM	Min. DDR3-RAM 4 GB PC1333
Drives	HD 500 GB, 7.200, 32 MB, 24h/7d
Graphic controller	External graphic adapter, no on-board graphic!! OpenGL 2.0 compatible 1GB RAM VGA / DVI etc.
Interfaces	2 x LAN RJ45 (Ethernet 100/1000 Mbps) 1 x CAN /Ethernet Converter 8 x USB 2.0 16 x Digital I/O 2 x Analog Output 2 x Analog Input

Table 3: Technical data LASE LCU

4.4 Control Cabinet

The control cabinet will be placed in the driver's cabin. The control cabinet contains the following main components:

- LASE Control Unit LCU (which is an Industrial PC)
- Light indicators
- Can-Ethernet-Converter
- Switch
- Relay
- Power supply 230VAC/24VDC
- Clamps and Fuses
- WLAN device

4.5 Wiring

To avoid influences to the data and power cables for the 3D-Scanner due to electrical fields from high voltage cables for the drives or similar we recommend using shielded cables for the power cables.

LASE expect that a decentralize connection to the PLC is in the driver cabin available, like an ET 200 (when we have Siemens PLC System on the machine).

When the PLC is on another place (resp. the decentralized periphery) then additional cabinets and wiring has to be done.

4.6 Hardware overview

The drawing below gives an overview above the used hardware and the internal connections.

Between the LASE measurement system and crane PLC (Decentralize Periphery) is a Digital I/O connection and an Analog connection.

The slightly blinded out sections are indicating the optional service channel via WiFi (but this Option is highly recommended and wished from LASE side)

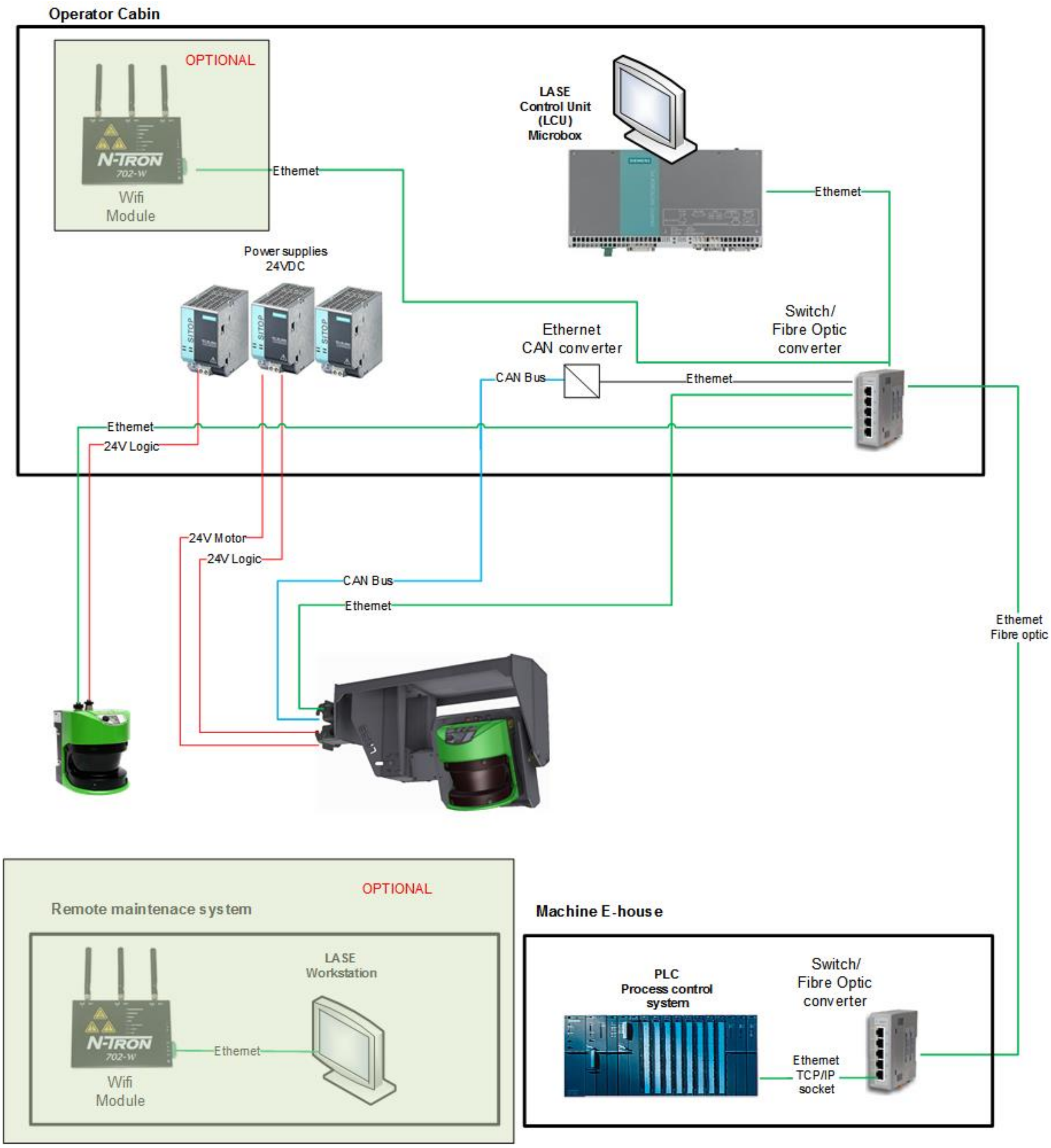

Figure 3: Hardware overview (final layout can vary slightly)

4.7 Mounting position 3D-Scanner

The LASE 3D-Scanner and the 2D-Scanner are mounted under the trolley. Depending on the machine structure it might be necessary to install additional mounting plates or frames.

The distance between the 3D-Scanner systems (in trolley travel direction) should be as far as away from the center line of the trolley as possible. But it is also necessary that the scanners are able to scan a container in tier 1 even if the adjacent stacks are filled to the maximum height.

The following drawing shows this both worst cases which have to be covered but which actually need to have different mounting positions for the 3D-Laserscanner.

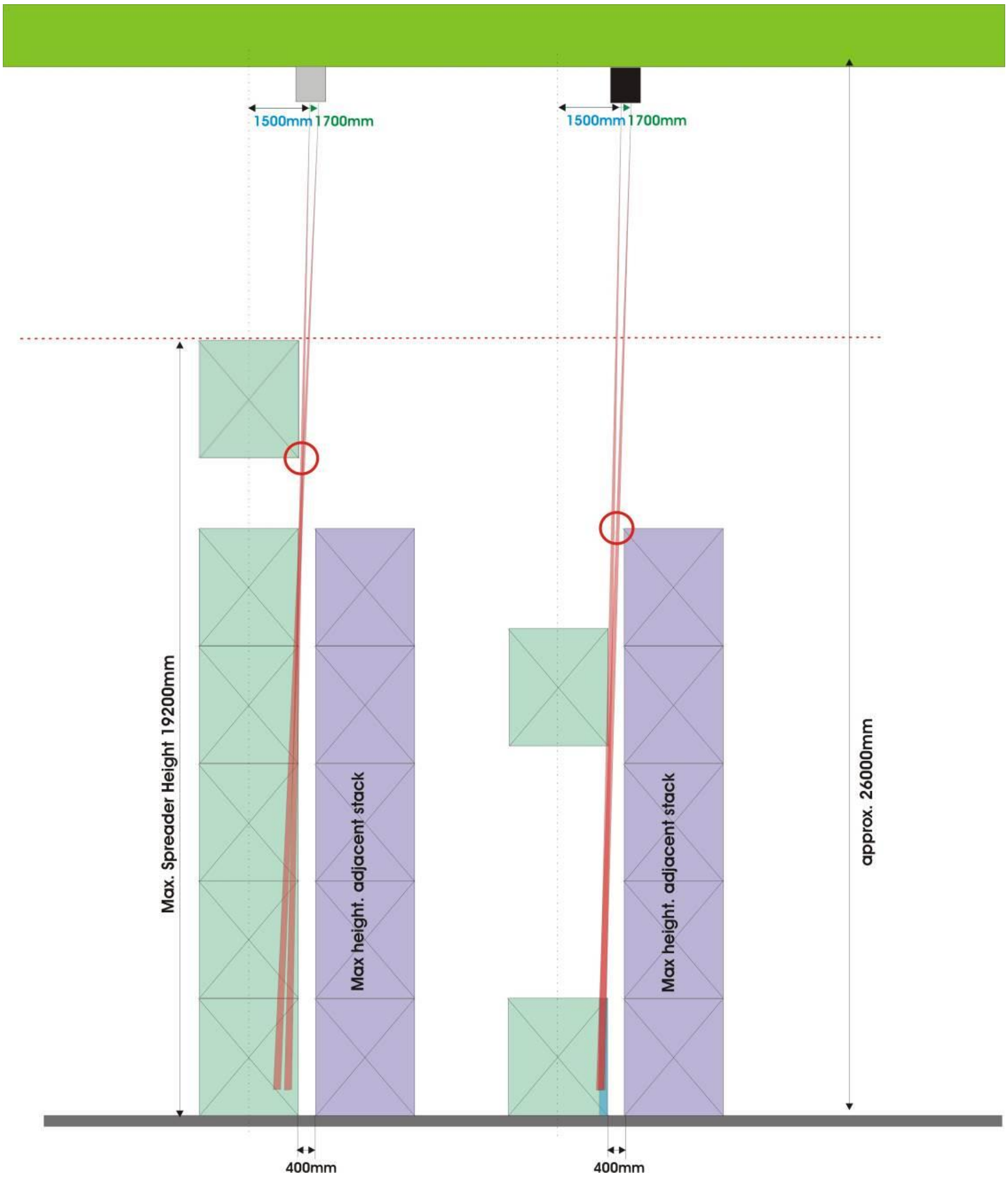

Figure 4: Optimal mounting position for the 3D-Laser scanner

The laser scanning system has to be able to detect the container in the slot directly underneath the trolley center (e.g. for soft-landing, but also for anti-collision purposes). There are different possible situations which have to be covered by the system.

On the left hand side case one is shown. Here the stack under the trolley is filled to its maximum level and a container is hanging at the spreader. The LASE system has to be able to detect the most upper container in the stack. Here it would be helpful to have the scanner more away from the center.

The case shown at the right hand side is the opposite worst case when having a maximum filled adjacent stack and measurement has to be done in tier 1. For this case the scanner should be mounted a bit towards the trolley center to avoid blocking the laser scanners view by the most upper edge of the adjacent stack (small red circle in **Figure 4**).

The standard gap between the containers in a block is approx. 400mm. Thus the distance between the center of the gap on the left and the right side of a container is approx. 2900mm (2438mm (Container) + 2 x 200mm (gap/2) = approx. 2900mm). We recommend having a mounting distance of 1600mm from the trolley center to the scanner to have the best compromise for all measurement situations.

Figure 5: 2 x 3D-Laser scanner on the trolley (they are installed in different heights)

The 2D-laser scanner is as well placed 1600mm from the center of the trolley.

5 Software

The software consists of the LASE CEWS Basic Application Framework and the LASE CEWS Application specific core LaseSCP-3D here named SCP 3D.

Additional some adaptations in the PLC have to be made.

In general the software proves if the so named surveillance cube overlaps with the image (profile of the stack). When this happen the machine should be retard and/or stop.

Only trolley and hoist movements are allowed, no gantry movements (just +/- 300mm with slow speed)!

5.1 LASE CEWS Basic

The LASE CEWS Basic Module is the framework software of the LASE CEWS application core and consists of following modules:

- Communication module laser (parameterisation and data handling for following laser types (LASE 2000D, 2000T, 3000D-Series) following interfaces are usable according to the laser types – Ethernet TCP/IP, RS 422
- Communication module Input/Output, parameterisation and data handling for following Input/Output modules: SPS, Level 2 und Level 3 (further on request); following interfaces are supported: – Ethernet TCP/IP, Profibus (optional), RS 422, RS 232, analogue
- Communication LASE CEWS application core measurement data processing and handover to the application core
- Data recorder function: all measurement- and process data are permanently and completely logged. For analysis- and simulation purposes the data can be written back into the program.
- Graphical operating surface: for a simple and intuitive usage of the measurement system, incl. status messages, result displays, controlling
- 2D- and 3D-Visualisation: For the visualisation and evaluation of the measurement data. Scan image in 2D- and 3D-images, zoom function, free selectable perspective
- Application parameter: dialogue guided input of the process parameters for hardware and software
- Error- and event lists: Logging and display of error and events for a quick diagnostics
- Data logger for measurement and statistics. Also data such as the number of prevented collisions.

5.2 LASE CEWS Application Core SCP 3D

The individual software consists of following functions:

- Image 3D (profile of the stack)
- Image 2D
- Surveillance Cube
- Status machine
- Calibration
- Communication interface

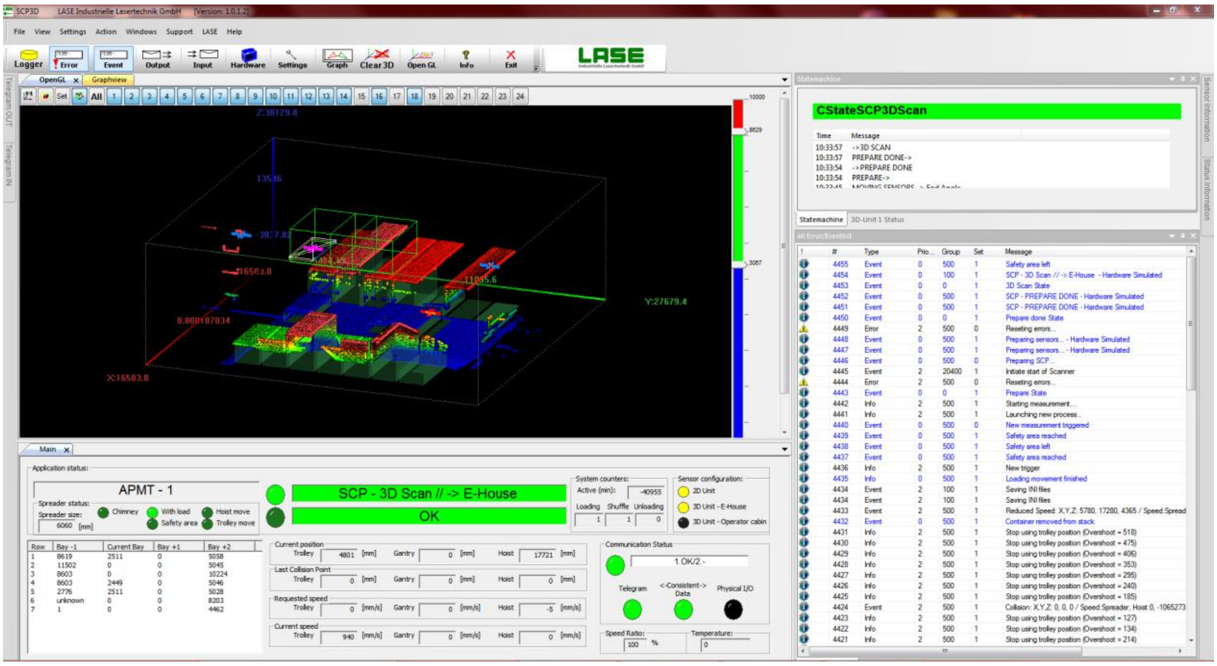

Figure 6: Main mask of the software

5.2.1 Image 3D (profile of stack)

When the load is picked or dropped a 3D-image will be generated. The 3D-laser scanner doing a scan and the 3D-point cloud represent the image (profile of stack). This image is been stored as long the gantry not drive (more than +/- 300mm) and as long the load condition has not changed.

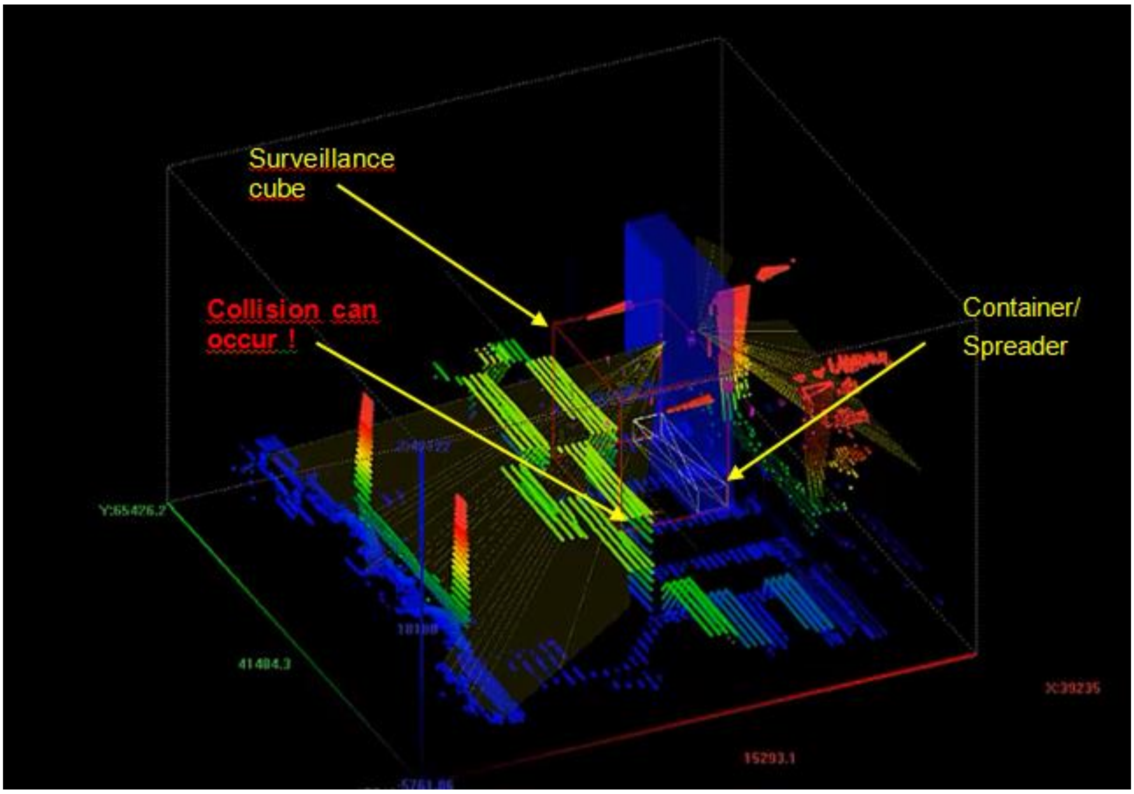

Figure 7: Example 3D-view – collision case (red cube indicate the collision)

The figure above shows a 3D-image of the measurement points. The blue and the green lines are representing the containers. The small yellow box is the spreader/container. The larger red cube is indicating the surveillance cube. It is shown in red because there is a collision prevention case.

5.2.2 Image 2D

The 2D-Profiling by the 2D-laser scanner generate basic information to make the system easy to retrofit to the exciting fleet.

This sensor generates all information which usually has to be extracted from the PLC. Therefore just Digital I/Os can be used for the communication.

The following information's are generated out of the measurement data from this sensor:

- Trolley position
- Hoist position
- Position of spreader (height)
- Info empty spreader or container at spreader
- Container size (normal cube, high cube)
- Current trolley speed
- Check the information received from the PLC as a double channel.

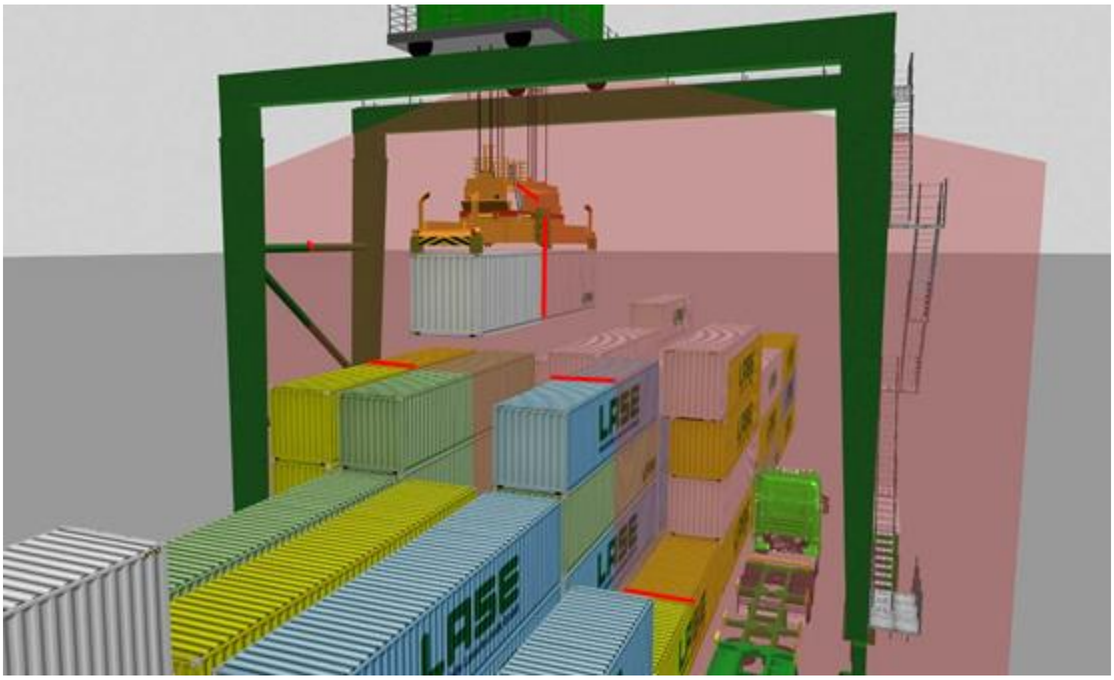

Figure 8: Example 2D-scanner usage

As shown in the picture above the advantage of the 2D-Scanner is that in each scan it can see the position of the spreader and the height of the container hanging at the spreader. By scanning reference points (like a cross pipe or similar) this scanner provide the position of the trolley as well.

The red lines are indication the points were the 2D-Scan hits the surface of the containers in the stack or the reference points at the crane.

5.2.3 Surveillance cube

The surveillance cube is a 3D dimensional cube which is used by the LASE application to prevent collisions between the empty spreader or a container hanging at the spreader and containers in the stacking area.

The position (center of cube) is located at the center point of the spreader. The size of the cube mainly depends on:

- The adjusted length of the spreader (20', twin 20', 40', 45')
- Height of container hanging at the spreader
- The moving direction
- The velocity and position of trolley and hoist
- Delay times (PLC, mechanics)
- Swing behaviour of the load according the rope system
- If gantry driving +/- 300 mm

The calculation of the dimensions is done in the software under consideration of the needed space to warn and finally stop the trolley safely in case of a collision occurrence was detected.

Figure 9: Surveillance Cube (green) – trolley do not move

The picture above shows an example of a surveillance cube. The dimensions of the cube in this example are adjusted in that way that the cube covers the spreader and the hanging container completely. In the example the trolley is not moving. Thus the cube lays around spreader and container quite close.

If now for instance the spreader shall be moved to the right side (see pictures below) the cube will be extended to the right side as well.

The cube is adapted to the direction of the movement, so diagonal, vertical and horizontal cubes will be used during the calculations.

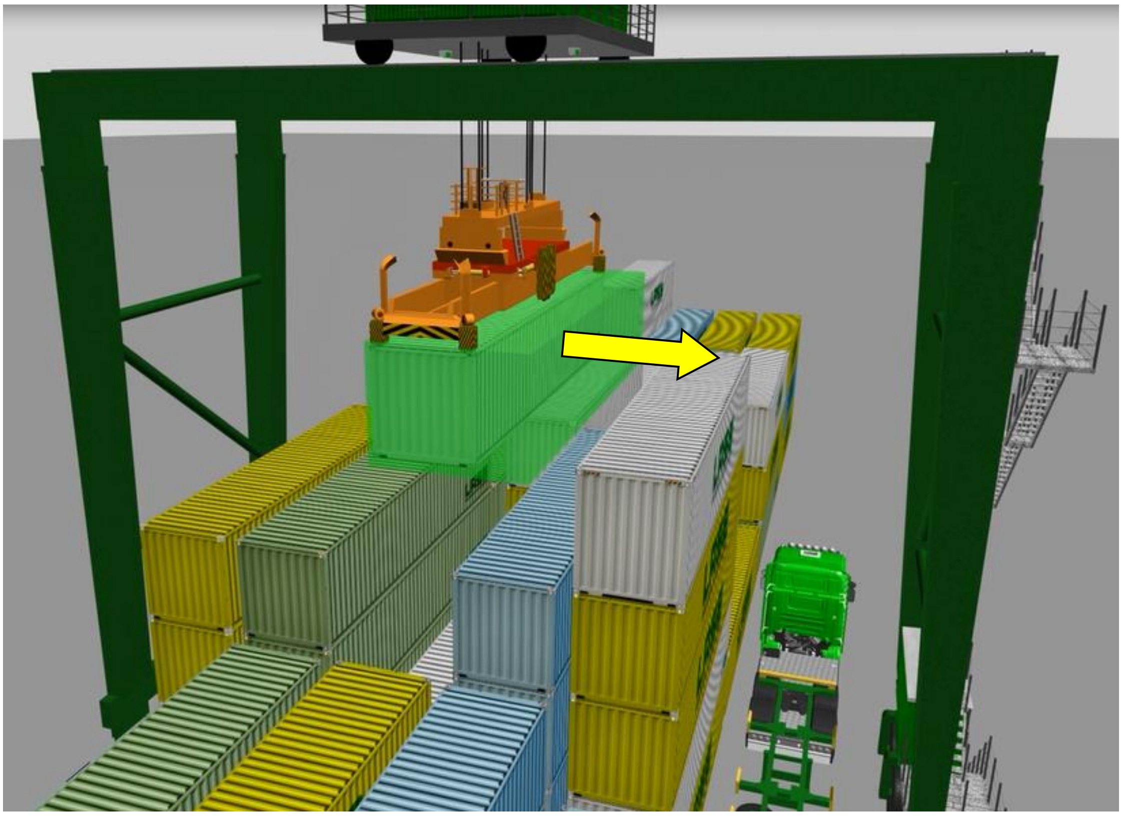

Figure 10: Surveillance Cube – trolley moves to the right

To permit a soft braking and avoid oscillations in the crane the surveillance cubes will be divided in different sections. Every section will limit the set point speed of the driver in an adapted way.

The number of sections and the speed limitation per section can be parametrized according to the crane I/O available and other requirements. The dimension of the section will be adapted to its speed limitation.

In the next example the surveillance cube are divided in 4 sections (might be more in real application) every area could limit the speed in a configured way:

1. 90% of demanding speed
2. 75% of demanding speed
3. 40% of demanding speed
4. 10% of demanding speed

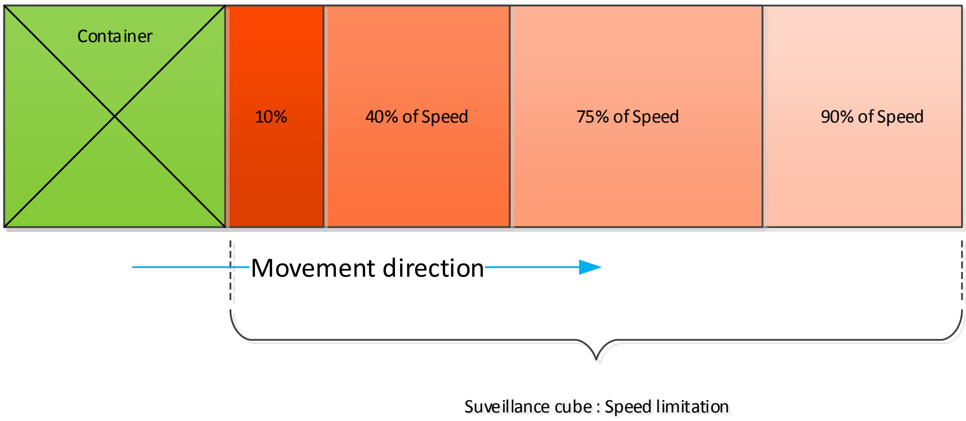

Figure 11: Surveillance cube example

When the operator tries to move the crane, the requested hoist or trolley speed is read. According to the speed and the other parameters the dimension of the surveillance cube is calculated. During the movement it is checked if some object is inside the cube, and when this happen the nearest point of the object relative to the beginning of the cube is processed. Then the speed requested for the operator will be limited according to the section where the point was detected. For example in the Figure 12 the speed will be limited to the 40% of the requested value. In this case the system knows from the beginning of the trolley movement which maximum velocity is allowed if the cube overlaps with an obstacle already. If the distance to an potential obstacle is far enough of course full velocity is allowed.

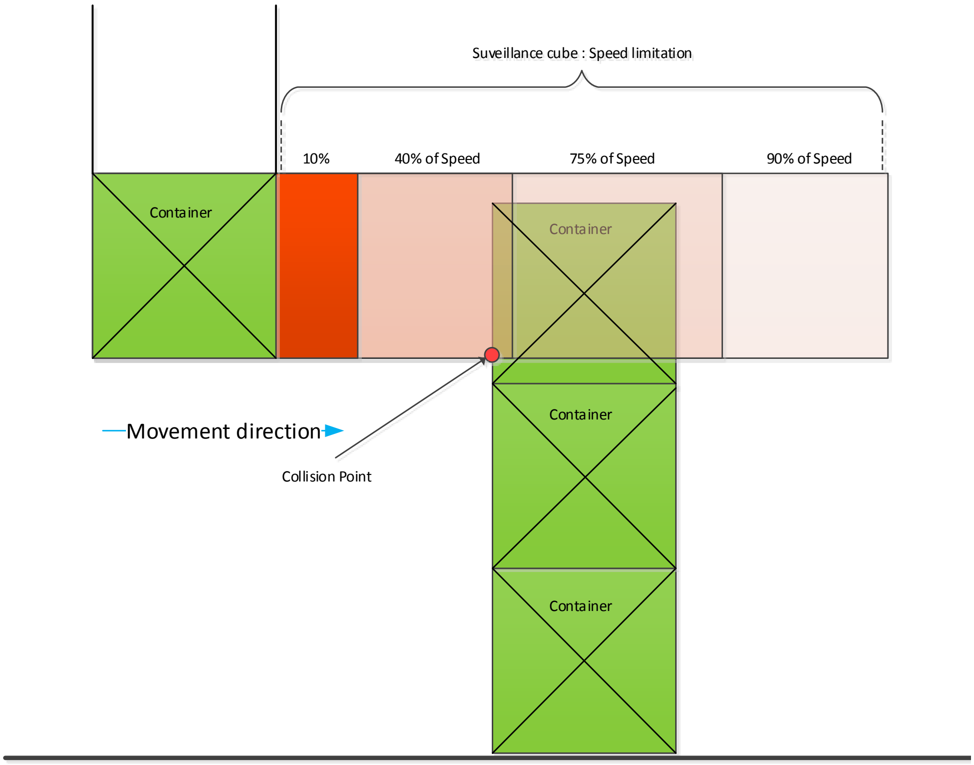

Figure 12: Surveillance Cube - Speed reduction example

In addition to the speed reduction areas some collision areas could be activated. These areas are located around the spreader and the hanging container and could be used to avoid or limit the movement in a specific direction.

The collision areas are four and could be seen in the Figure 13: Surveillance cube – Collision areas.

They are fully configurable and work like the surveillance cube to reduce the speed. When an object is detected inside them the speed reduction is triggered. This was designed to assist the operator during recovery process after a collision situation, considering that the movement will be allowed only in the opposite direction of the collision area or upwards/downwards (configurable).

Some options of these areas and their configuration are:

- Dimension, the size of this areas if defined in a parameter and do not change during the movement
- Speed reduction behaviour, when an object is detected inside this areas the axis linked to it could be stopped or its speed could be limited to a configured percentage

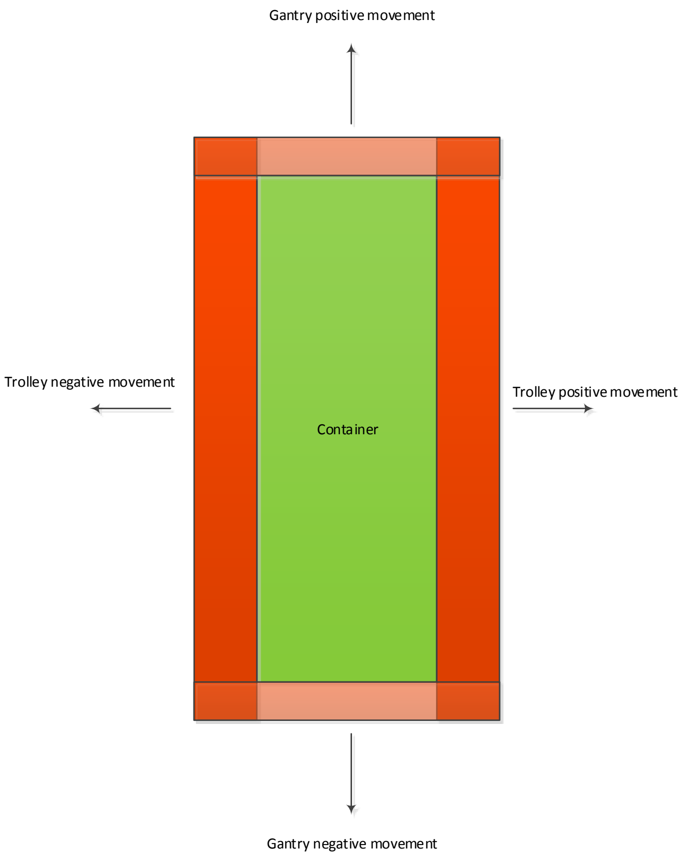

Figure 13: Surveillance cube – Collision areas (Upper view)

5.2.4 Landing cube

To detect when the crane is in a landing operation was designed the landing cube. The landing cube is located under the hanging container or the spreader (if there is no container). It works like the surveillance cube. When an object is detected inside it and the hoist is moving downwards the 3D units and the speed reduction is triggered to perform a landing operation (speed limitation and laser orientation). In addition to this the 2D unit will be used to check that the container is over a slot (the gaps between containers will be controlled) to permit the landing operation.

This permit to control with higher accuracy the landing operation, because the sensor will be oriented to the yard in an angle near to the perpendicular (See **Figure 4: Optimal mounting position for the 3D-Laser scanner**). With the orientation of the sensor the container under the spreader will be monitored and the landing operation could finish without collisions.

The dimensions of the cube, the speed limitation and the laser orientation can be configured with parameters.

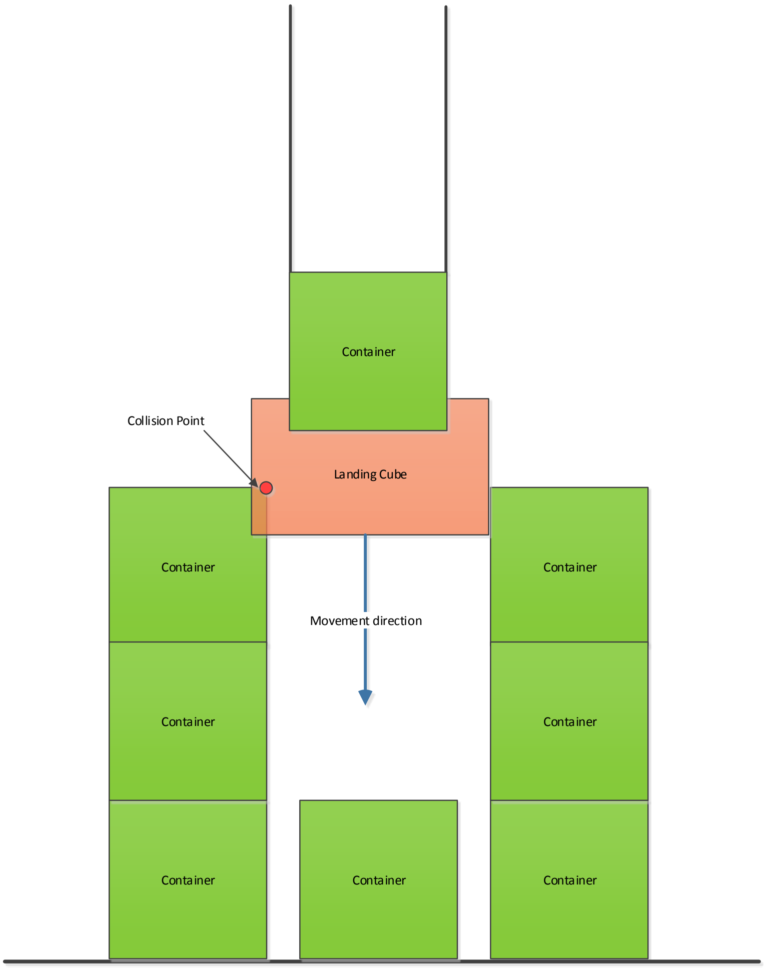

Figure 14: Landing cube - Example

5.3 Process description

To express the function of the system best is to describe it in the operation.

The following drawings are showing a container movement with collision avoidance. The first drawing shows the start situation. The violet container in tier 1 of lane 2 shall be picked up and moved to the trailer in the truck lane.

The green arrow indicates the optimal path of the movement.

As a first step (trigger) after the trolley has reached the nominal position and the spreader landed on the container (detected by the 2D-laser scanner and the twist lock alignment) the LASE application measures the profile of the containers in the adjacent stacks (dotted yellow line) by performing a 3D-Scan (red lines with different angles, just the scan lines of the right scanner are shown in the picture below).

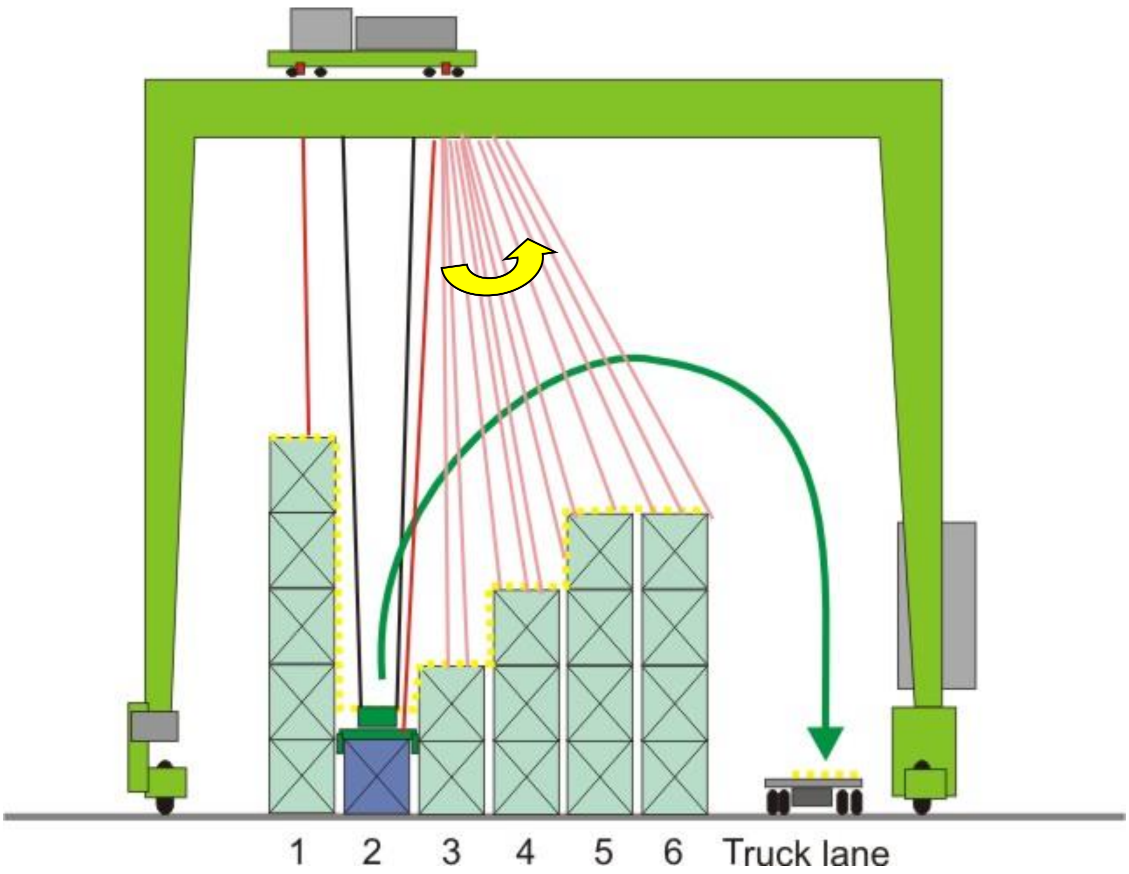

Figure 15: Measurement – Container movement – Start (3D-Scan)

The next drawing shows the same situation in a 3D-picture. The 3D-laser scanner hat finalized its scans and the red planes on all the containers representing the laser spots on the containers and thus a height profile of the container stack in the working area under the RTG.

When the crane starts hoisting the position of the spreader respectively the container hanging at the spreader will be tracked by the 2D-laser scanner.

Additional the profile of the stack in moving direction will be scanned permanently. Therefore the scan plane of the scanner mounted in travelling direction is driven to a certain position. In case the software has detected shadow areas within the first 3D-Scan a new 3D-Scan will be performed when the trolley has passed the before highest measured point.

For the collision prevention function the distance to the outer edges of the spreader/container combination to the outer edges of the containers in the stack (profile) will be calculated permanently.

This also includes the containers of adjacent stacks in gantry travel direction! In case a container is misplaced in X-direction and sticks out into the area the target container shall be moved through the application generates a collision alarm as well.

The LASE system internally stores 3D-data for the operating bay and the adjacent bays. The data will be deleted if the gantry has moved for a certain distance (parameter) or the move has finished

The drawing below shows a movement with a collision case.

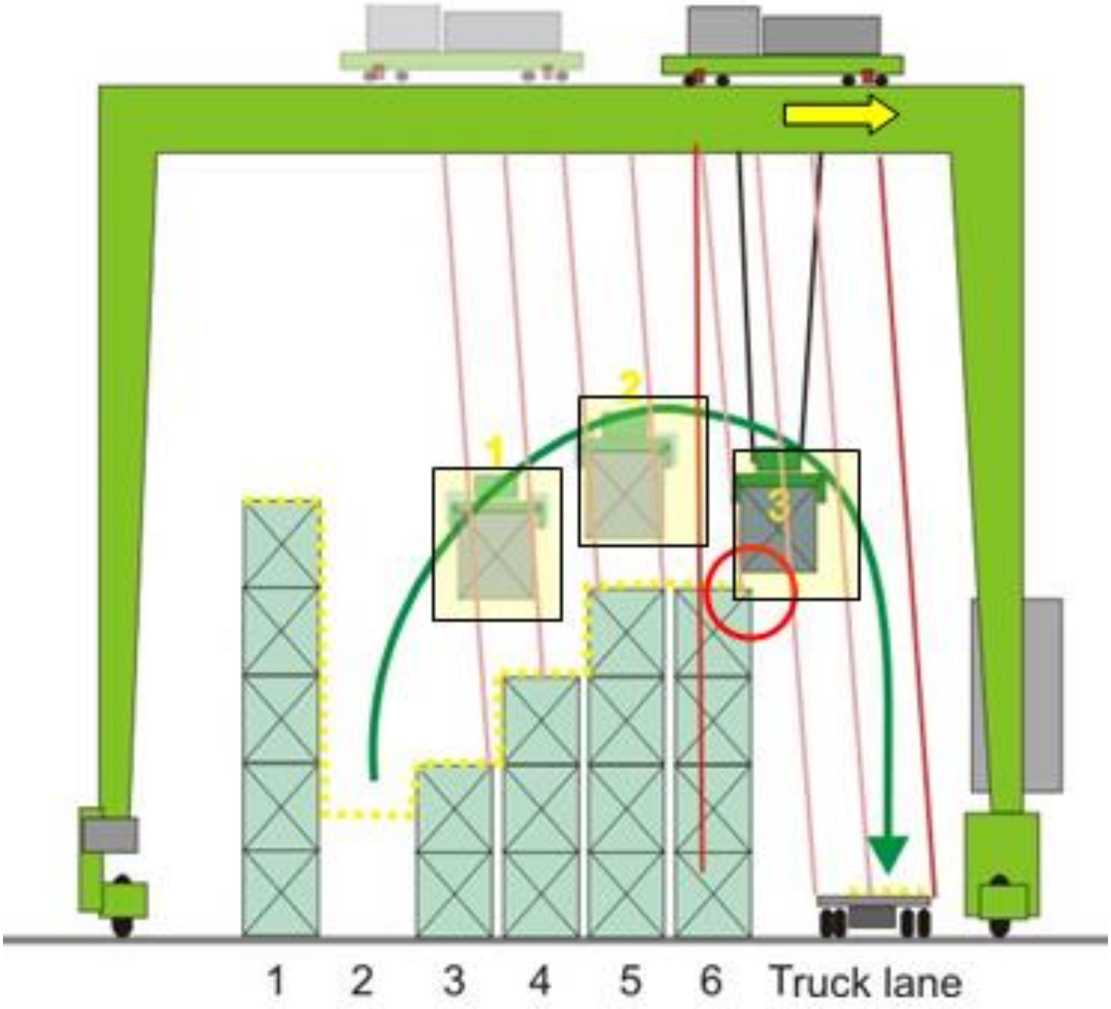

Figure 16: Measurement – Container movement – side view (collision)

The drawing above shows the trajectory of the violet container, picked in lane 2, in different steps (1, 2 and 3).

The yellow rectangles are indicating the dimension of the surveillance cube checked by the LASE measurement system. For the snapshot 1 and 2 everything went well. The cube did not overlap with the scanned container stacks for this movement.

For snapshot 3 the distance to the top edge of the container tier 4 of lane 6 is too small. That is indicated by the red circle.

In this case the software would create first a signal to the PLC to slow down speed and when the collision occurrence is still possible an alarm message so that the crane PLC can stop the move.

The light red angled lines are showing the scan plane during the movement of the trolley.

The drawing below shows a situation (top-view) were a container (red) is misplaced in Y-direction. In case the optimal path is just in a height of tier 2 and the misplaced container in located in tier 4 the surveillance field should be high enough to protect the spreader or the ropes.

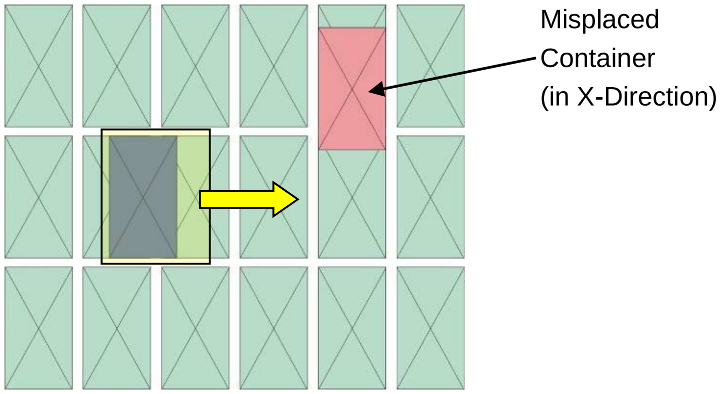

Figure 17: Measurement – Container movement – top view (collision)

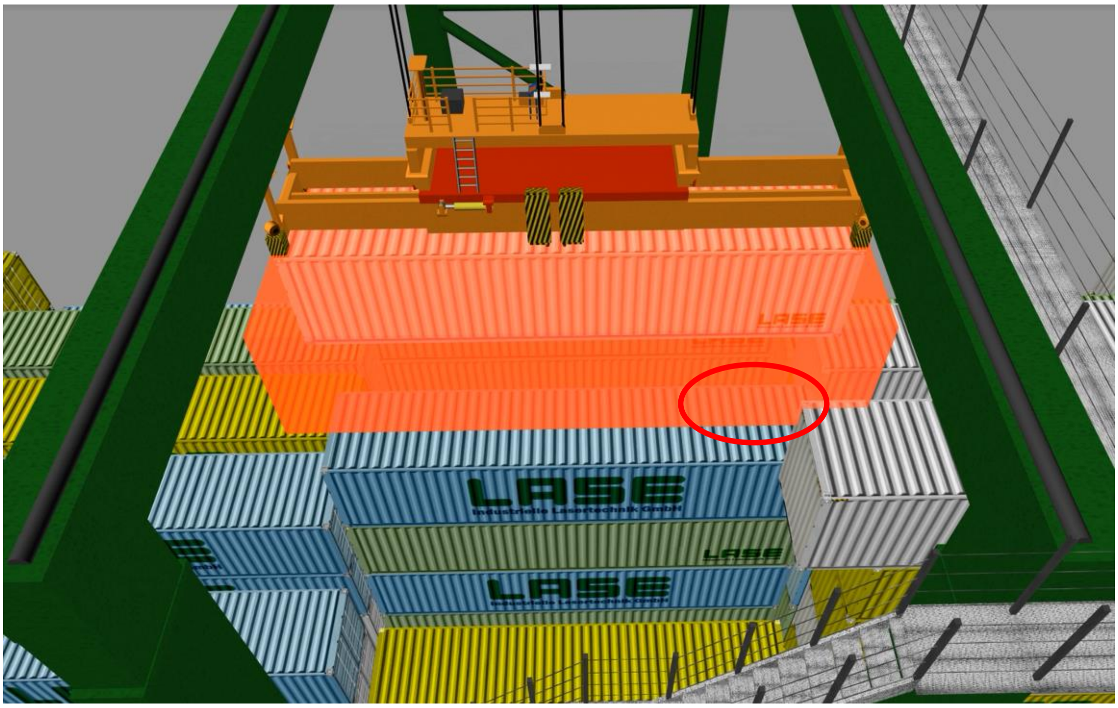

Figure 18: Collision with adjacent bay (surveillance cube is red)

The collision prevention function can only work if the scenario was scanned properly. There might be situations where the LASE system is not able to scan all parts of the stack because of shadow areas.

Example:

- Trolley moves from lane 1 towards lane 8, target lane is 5.
- In lane 4 is a stack of 5 high.
- In lane 5 only one high is stacked

If now the trolley is moving the scanner in front is adjusted to a certain angle to ensure the collision prevention in moving direction. When now the container shall be placed on top of the container in lane 5 SCP 3D function cannot fulfill the collision prevention check because the area in/above lane 5 could be scanned during the movement.

The drawing below shows an example of a possible shadow area. To have the scan plane angled is a must because of the collision prevention function and the needed space to stop the crane safely.

The dotted red line shows the area which could be scanned during movement. The dark blue dotted line shows the area which can be scanned if trolley moves on.

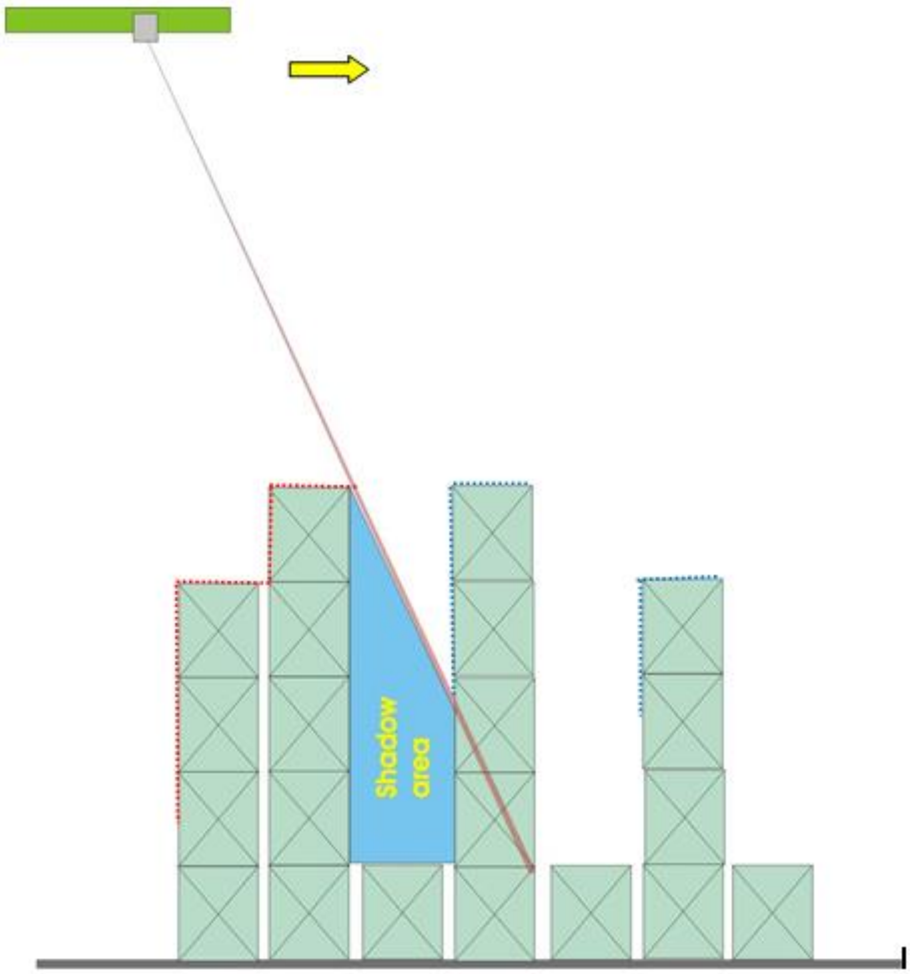

Figure 19: Measurement – Shadow areas

This situation only affects when the spreader shall be landed in the slot were the shadow area occurred. On the other hand this is a so called chimney stack which is not allowed to build. Due to the reason that two 3D-Laser scanners are mounted under the trolley the second scanner is able to detect the gap when the trolley is above the slot. The scan plane of the second scanner is aligned a bit towards the trolley center. Means it can scan objects located under the trolley. When now the trolley approaches the slot which was not scanned before the second scanner can scan at least a part of the slot.

In addition to the second scanner configuration two functions were developed to minimize the shadows areas:

- Scan during movement
- Scan at the yard limit

The first one triggers a new 3D scan when the spreader is near to the highest point of the yard in the direction of the movement. The scan will permit to capture the information in the shadow area and after it the scanners will return to the previous position.

The second function is used to guarantee that the profile in the first and the last slots are read. A new 3D scan will be made when the scan in the direction of the movement has captured the data at the maximal height of the last slot in the direction of the movement.

Anyway if the system detects that the operator tries to perform a landing/picking function in a shadow area the operator will be advised and the speed of the crane will be reduced permitting the operation in a safety way.

5.4 Operation cases

5.4.1 Movement in safety area

If the operator only makes spreader movements inside the safety area no limitations will be made in the speed reference values (See **Fehler! Verweisquelle konnte nicht gefunden werden.**- **Fehler! Verweisquelle konnte nicht gefunden werden.**). The 3D unit will travel to the idle position (configurable).

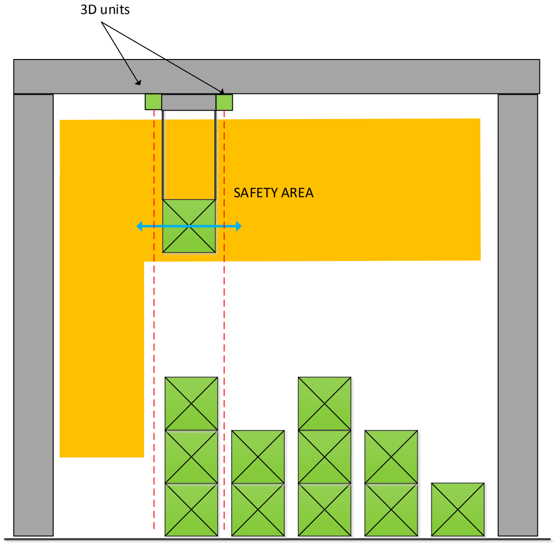

Figure 20: Operation cases – Movement in safety area

5.4.2 Movement out of safety area

If the operator makes spreader movements outside the safety area some operations will be performed:

- Limit gantry requested speed
- Move 3D unit to pre-movement position (configurable)
- Take position like reference for gantry movement and trolley
- Control that gantry movement is less than 300mm since reference point
- Adapt 3D unit angle when the trolley has shifted more than 1000mm (configurable)
- Check reduced speed condition (Surveillance cube)
- Check soft-landing condition (Landing cube)
- Check collision condition (Surveillance cube – Collision area)
- Check shadows areas
- Check end of movement

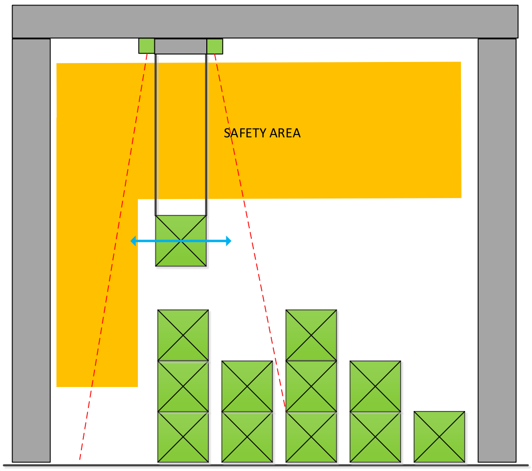

Figure 21: Operation cases – Movement out of safety area

The gantry requested speed will be limited to 10% (configurable) of its maximal speed out of the safety area. If the operator make movements with the gantry out of the safety area and no hoist or trolley movement were performed before, after 300mm the gantry speed would be reduced and only could be moved in the opposite direction. If a hoist or trolley movement are requested a 3D scan will be performed and the current position will be defined like reference point, the gantry could move only to 300mm from the reference point, after this the gantry axis will be stopped and it could be moved only in the opposite direction.

5.4.2.1 Adaptation of 3D unit angle

When the trolley moves more than 1000mm (configurable) the 3D units will adapt their position to the direction of movement, the rear sensor will look under the spreader and the front sensor forwards (angles are configurable).

If the direction of trolley movement changes after 1000mm (configurable) the 3D unit will adapt their position to the new direction.

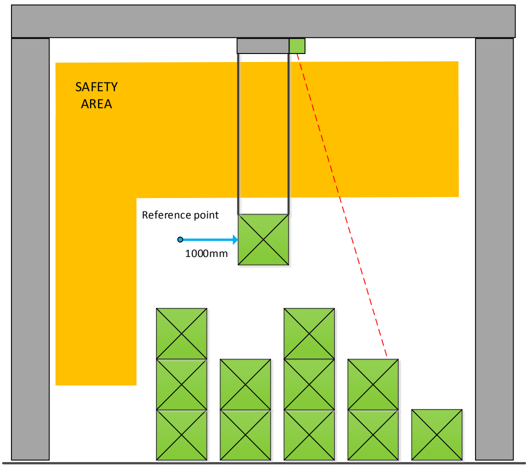

Figure 22: Operation cases – Adaptation of 3D unit angle

5.4.2.2 Check movement conditions

During the movement, independent of scanner angle, the surveillance cube, the collision areas and the landing cube will be checked. If some object is detected inside of them some special operations will be performed.

The cubes and areas are processing simultaneously, in the Figure 23 could be seen how the surveillance area around the spreader and the hanging container is during a horizontal movement.

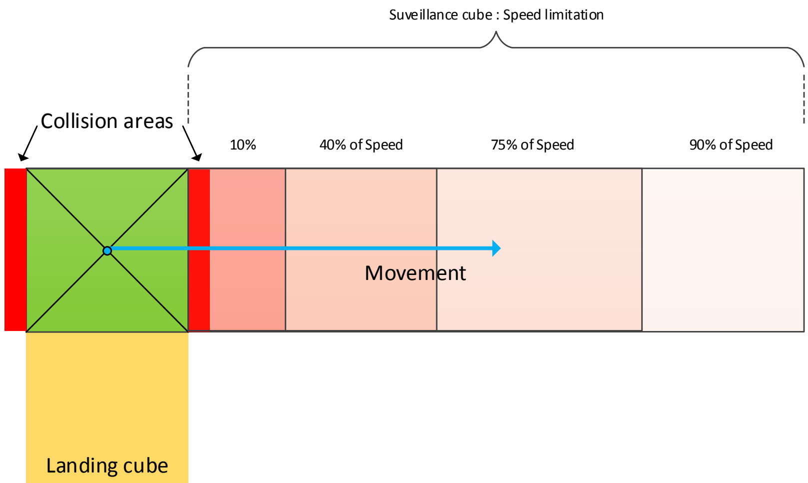

Figure 23: Operation cases – Check movement conditions

- **Check reduced speed condition**

When an object is detected inside the surveillance cube, the requested speed for the driver will be limited to a percentage (See Figure 12: Surveillance Cube - Speed reduction example).

This function was designed to avoid sharp movements and oscillations when the operator tries to move (start movement) at high speed near of an object.

- **Check collision condition**

When an object is detected inside the collision area of the surveillance cube, the direction of the movement should be opposite to the collision area. Otherwise the requested speed will be reduced or stopped (configurable). (See Figure 13: Surveillance cube – Collision areas (Upper view))

5.4.2.3 Check shadow areas

During the operation sometimes shadow areas could appear after a 3D scan. When it occurs and the spreader is near of these areas a new 3D scan will performed by the front sensor according to the direction of movement, after the capture of data in the shadow are the 3D unit will return to the original angle.

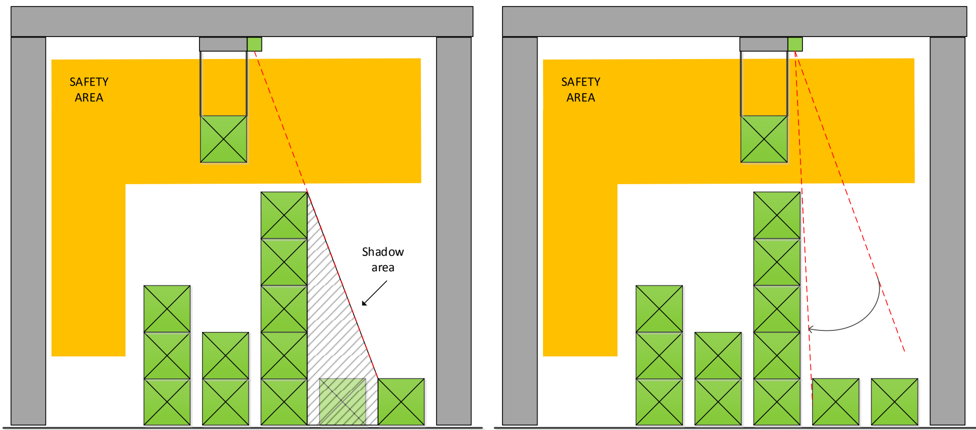

Figure 24: Operation cases – Check shadow area

5.4.2.4 Check end of movement

To avoid unnecessary movement in the 3D scanners, and to reduce delays, the 3D scanner will maintain their last angle if no movement is request.

This is design to avoid problems when the operator moves the machine at low speed or is trying to reach an exact position.

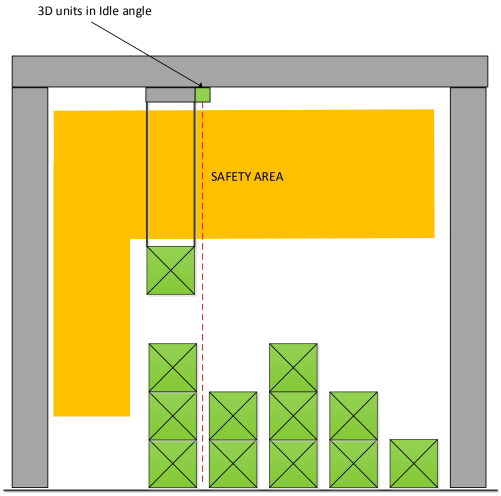

Figure 25: Operation cases – Check end of movement

5.4.3 Soft-landing

The LASE system is designed to detect soft-landing operations. The soft-landing operation prepares the 3D scanner to control the containers under the spreader during a landing operation.

This function will be activated when a container is detected inside the landing cube, the pending container is over a single slot and the crane performs only a downwards movement in hoist. At this moment both 3D scanners will be oriented with a configured angle to capture the area under the spreader. In addition to this, the surveillance cube and collision areas will be working in parallel, for this reason the requested speed will be controlled or set to zero when it is necessary.

In Figure 26and Figure 27 could be seen how the soft-landing detection works. In these figures only the landing cube is shown, but surveillance cube with the collision areas are working parallel and simultaneously.

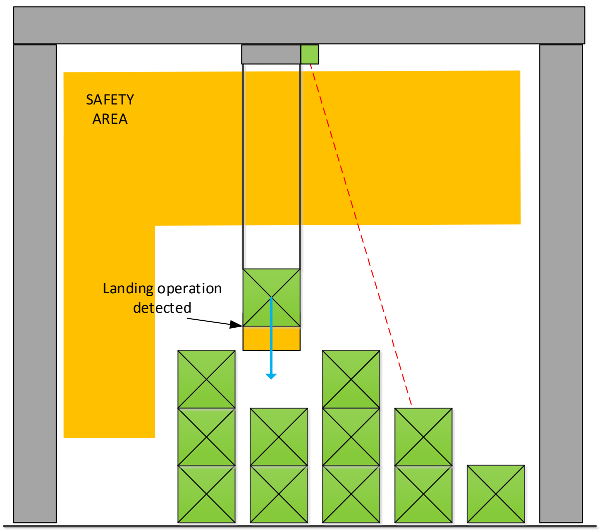

Figure 26: Operation cases – Soft-landing detected

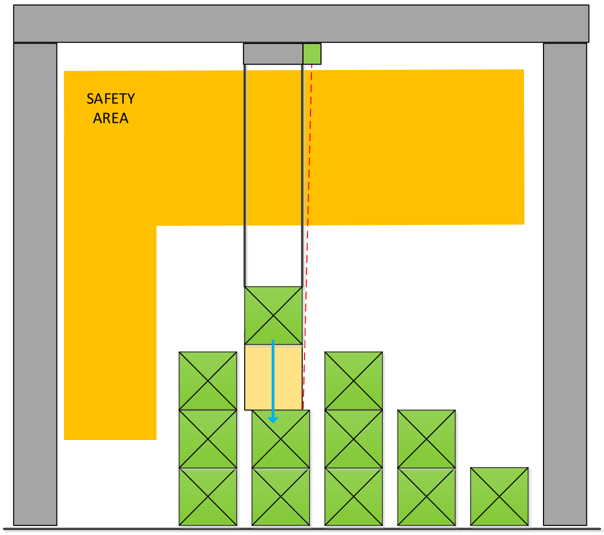

Figure 27: Operation cases – Soft-landing activated

During a picking operation, the landing cube will be located around the spreader, for this reason the soft-landing function will be activated too.

The avoid delays in the picking/landing operation the signal **Twistlock locked/unlocked or landing pins** (See **Table: Digital PLC -> SCP 3D**) will be used. During a soft-landing operation a change in this signal will perform a 3D scan and the LASE system waits in this state till detect the direction of the following movement.

5.5 State machine

The LASE system works internally like a state machine, where every operation is controlled in a different way. To understand how the software works some flow diagrams were created.

5.5.1 Main view.

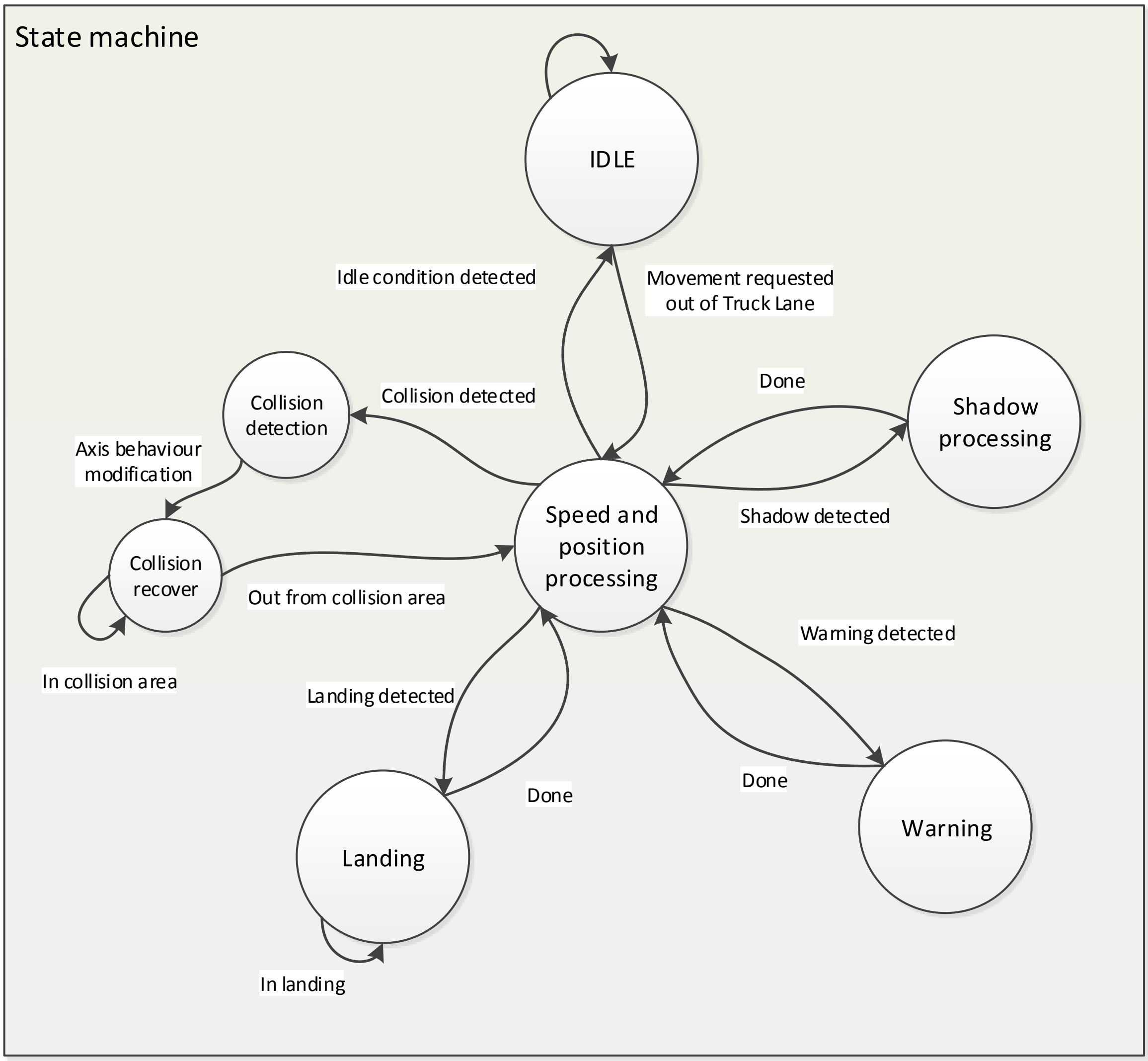

Figure 28: State machine.

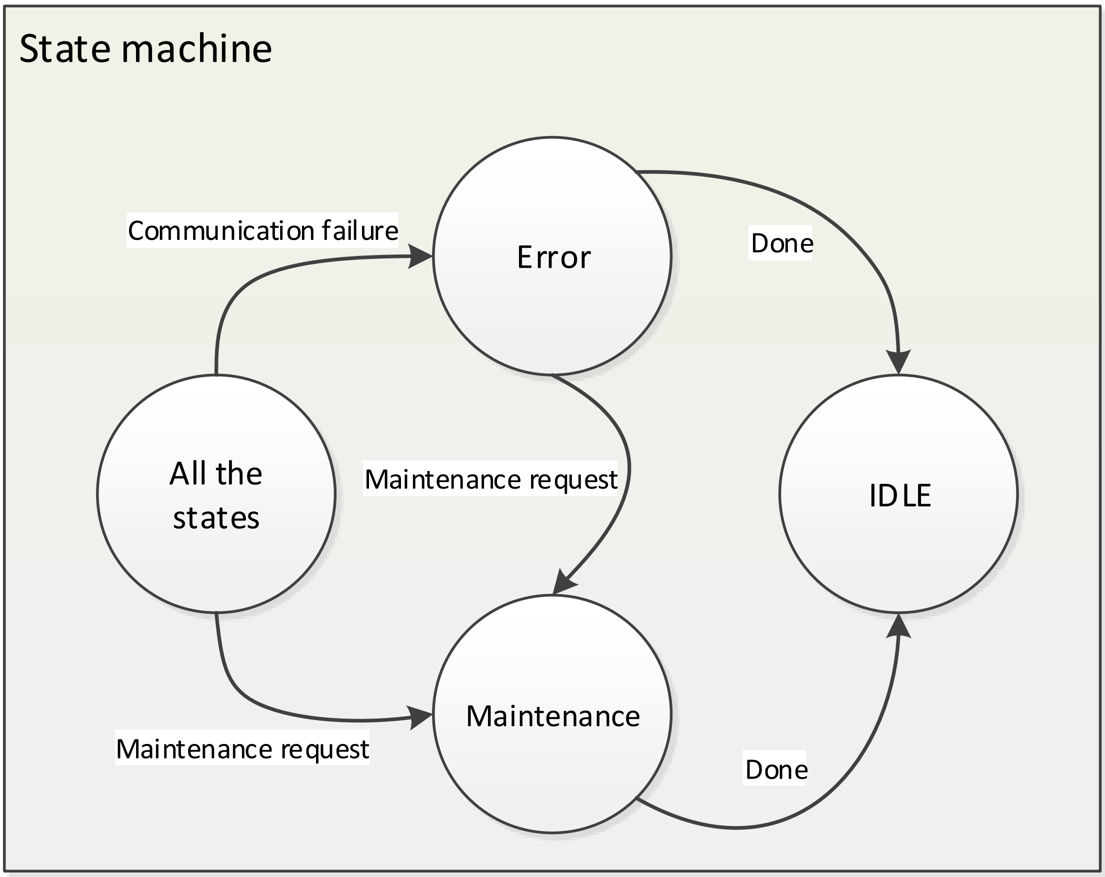

Figure 29: State machine extension.

5.6 PLC Programming

5.6.1 Overview

Some standard functional modules have to be programmed (with the functionalities mentioned below), being the basis for all the PLCs.

Individual feeding of the functional modules has to be adapted according the individual programming and hardware of the different PLCs.

In the PLC the following functions has to be programmed:

- Collecting information to feed SCP 3D
    - Using datablocks of PLC or creating new ones
- Control the machine according the Input from SCP 3D (warning, stop, etc.)
    - Creating compatible functions that could be used in every PLC model (e.g Ladder programming)
    - Programming FC or FB to control SCP 3D information (e.g decision if load is in the safe height, …)
    - Using and transferring information to modules which control speed setpoints and safety stops in servomotor and drives
    - Soft-landing

The interaction with the program is performed with new FB, which will read and write in his own DB instance and status DBs.

This FB will read the SCP 3D I/Os, PLC status, DBs and I/O and will work like responsible (when SCP 3D active) for:

- Stop the RTG in case of collision
- Reduce the RTG speed in warning state
- Reduce hoisting speed for soft-landing
- Reduce the RTG speed when hoist is out of safety-area
- Process and distribute SCP 3D signals in PLC program
- Isolate PLC from SCP 3D signals if this is not active

The by-pass switch and the programming modification structure isolate both systems, allowing them work together or separated in case of error or need.

Figure 30 – PLC Siemens (Modification example)

5.7 Interface

5.7.1 Profibus/Ethernet interface

When the PLC is prepared to communicate with the SCP 3D by Ethernet or ProfiBus, other information could be read from the PLC, for example hoist or trolley position, current speeds, calibration confirmation and other information could be written into the PLC, for example maximal hoist or trolley speed permitted.

These options are completely compatible with the easy-interface architecture and only increase the end user interface to monitoring data in SCP 3D and logs files and could give more flexibility during the braking process because the easy-interface works with speed bands, and with an Ethernet or ProfiBus interface could work with real speed values.

5.7.1.1 Profibus/Ethernet signal PLC ->SCP 3D (telegram 100)

Byte No.	Length (Bytes)	Format	Description	
0	2	WORD	Telegram identification number (100)	
2	2	WORD	Telegram size in bytes	
4	2	WORD	Telegram counter	
6	1	BYTE	Control bits I	
			Bit 0	System Watchdog
			Bit 1	System OK
			Bit 2	Hardware OK
			Bit 3	Warning (Speed reduction)
			Bit 4	Alarm (Collision detected)
			Bit 5	Error (Communication state)
			Bit 6	Shut-down SCP 3D
			Bit 7	Restart SCP 3D
7	1	BYTE	Control bits II	
			Bit 0	Acoustic control
			Bit 1	Twist lock locked/unlocked
			Bit 2	Spreader Code1
			Bit 3	Spreader Code2
			Bit 4	Landing pins
			Bit 5	Micromotion Y Code1
			Bit 6	Micromotion Y Code2
			Bit 7	Flipper status
8	1	BYTE	Control bits III	
			Bit 0	Trolley request forward
			Bit 1	Trolley request backward
			Bit 2	Hoist request forward
			Bit 3	Hoist request backward
			Bit 4	Gantry request forward
			Bit 5	Gantry request backward
			Bit 6	Micromotion X Code1
			Bit 7	Micromotion X Code2
9	1	BYTE	Calibration + By-Pass	
			Bit 0	Active
			Bit 1	Hoisting
			Bit 2	Error
			Bit 3	In position
			Bit 4	Level 0
			Bit 5	Level 1
			Bit 6	Level 2
			Bit 7	By-Pass Key-switch
10	2	SHORT	Hoist requested speed	

12	2	SHORT	Trolley requested speed
14	2	SHORT	Gantry requested speed
16	2	WORD	Reduced speed code
18	2	WORD	Hoist current speed
20	2	SHORT	Trolley current speed
22	2	SHORT	Gantry current speed
24	2	SHORT	Hoist current position
26	2	SHORT	Trolley current position
28	2	SHORT	Gantry encoder1 current position
30	2	SHORT	Gantry encoder2 current position
32	2	SHORT	Inclination X
34	2	SHORT	Inclination Y
36	2	WORD	Container Height
38	2	WORD	Container Weight
40	2	SHORT	Head block shift X
42	2	SHORT	Head block shift Y
44	2	SHORT	Head block skew
46	2	WORD	Crane hoist slip
48	2	WORD	Crane trolley slip
50	2	WORD	Crane hoist brake delay
52	2	WORD	Crane trolley brake delay
54	2	SHORT	Spreader tilt angle
56	2	SHORT	Spreader roll angle
58	2	WORD	PLC delay
60	10	Bytes	Reserve
70	2	WORD	Telegram counter (same as Byte 4)

Table 4: Profibus PLC -> SCP 3D

6 Safety design criteria

The SCP 3D will be designed and developed to prevent and avoid risks and collision during the work of the RTG. For this reason some functionality check functions will be integrated into the system:

- 3D Sensor Reference-Object
- 2D Sensor Reference-Object
- Double-check routines and functions in software
- I/O Monitoring strategy
- By-pass key-switch
- Warning to operator
- Hardware specification

With these functionalities we are intent to reach the required safety level.

6.1 3D Sensor Reference-Object

In order to increase the security of the measuring system a test procedure is described below.

The LASE3000D-C2-118 uses a servo motor and therefore an encoder, due to which the position of the scanner can be rotated. This complete system provides the possibility to orientate the scanner to different angles increasing its functionality. However, in case of bad encoder measurement, a risky situation arises.

Beside the 3D-laser scanner a reference object will be installed. This reference object is a metal plate which can be seen over the complete swivel range of the 3D-scanner. This plate will be rotated around the Z-axis by certain degrees. The proposed solution triggers a procedure which checks if the position of the encoder is in fact correct. The success of it depends on the reference plate installed in the crane for every single scanner.

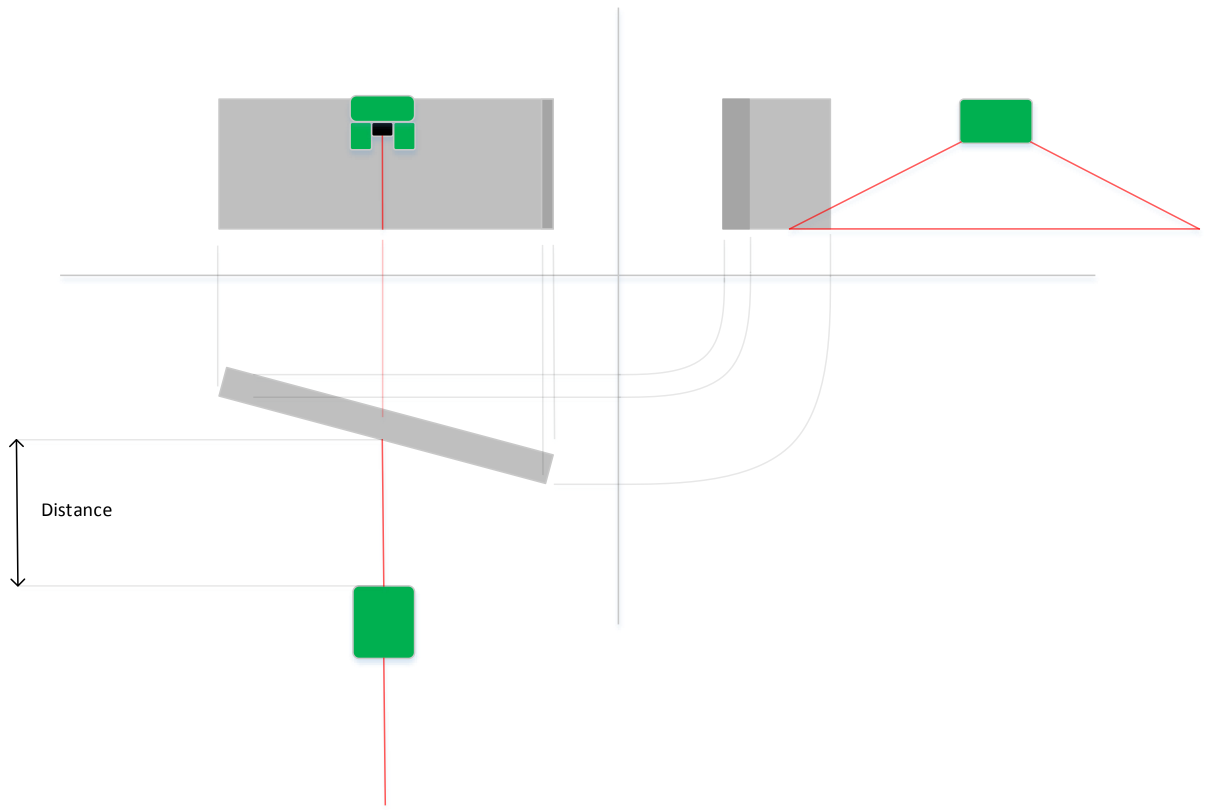

Figure 31: Reference shield Scanner straight

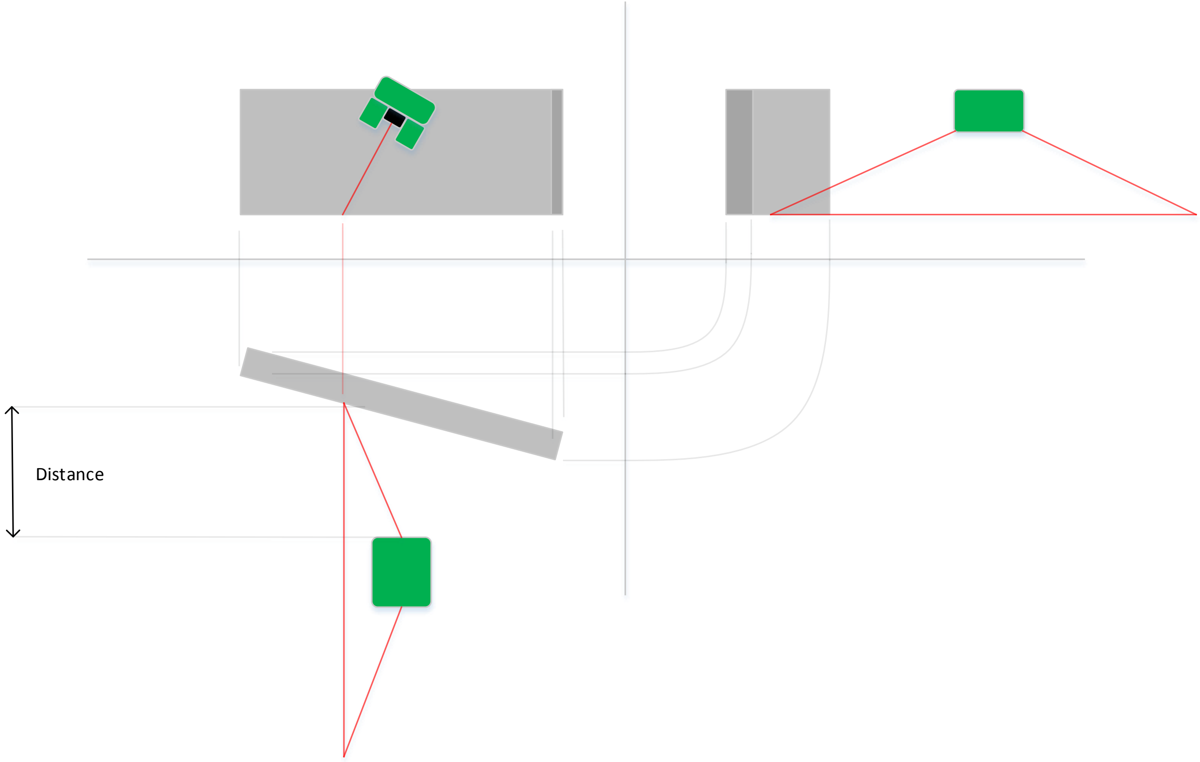

Figure 32: Reference shield Scanner left shift

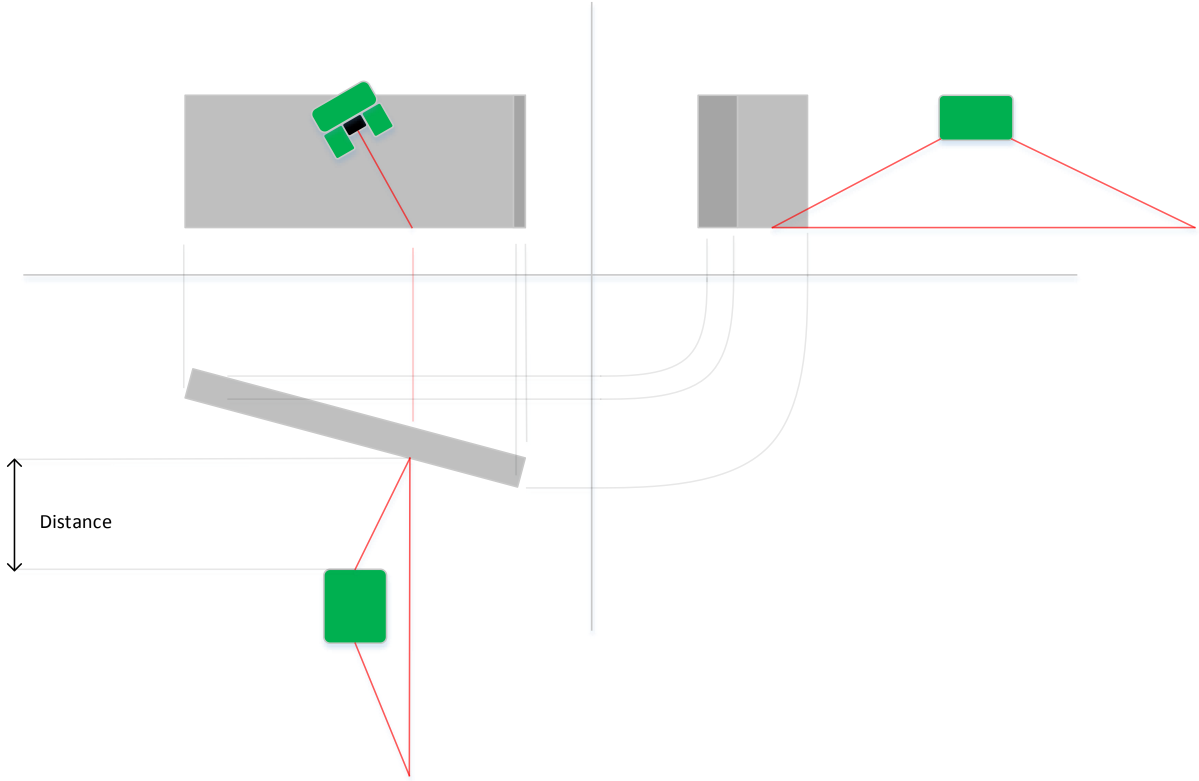

Figure 33: Reference shield Scanner right shift

Because of the inclined installation of the shield, depending on the position of the encoder the measured distance of the scanner changes. This is actually the basis of the solution. Taking into account that the measured distances are changing, a reference data base can be created at the beginning of the commissioning. This data remains on the system providing information that should be compared with the current one.

The recorded data is a table which makes a connection between the angle of the encoder and the measured distance.

...	...
38°	1,355 m
39°	1,345 m
40°	1,335 m
...	...

Figure 34: Reference shield table

During normal operation the software runs as follows:

1. The motor moves the scanner to a certain position controlling the position through the encoder.
2. The scanner makes a measurement.
3. The software analyses if the distance until the solid reference and the one provided by the data base match.
4. In case of success the program follows in normal operation.
5. In case of negative cross match:
   a. Process stop.
   b. Informative error will be shown. Maintenance personnel should be requested for an inspection.

Additionally the pollution of the scanner can be checked as well.

With these function the system has a permanent performance check for the laser hardware.

6.2 2D Sensor Reference-Object

The 2D-laser scanner will also get a reference object to have a permanent function check of the laser hardware.

There should be a reference plate mounted under the trolley in a fixed distance to the scanner. Additionally the scanner is detecting reference plates (or cross bars of the crane structure) at the crane itself for determining the current position of the trolley.

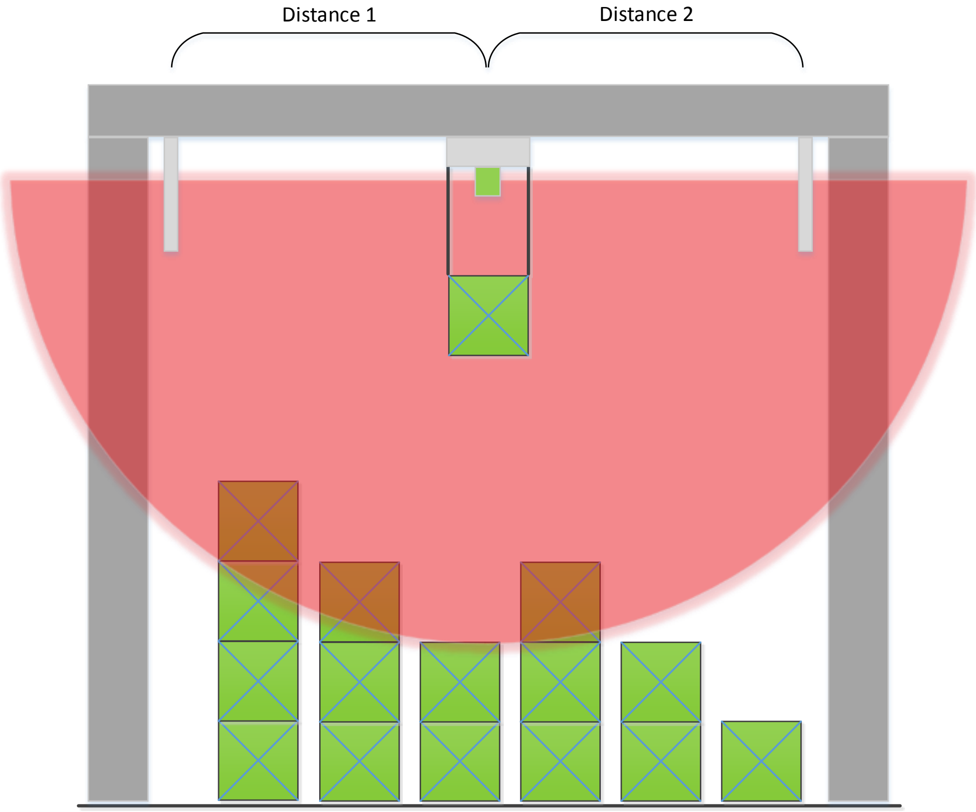

Figure 35: 2D reference object

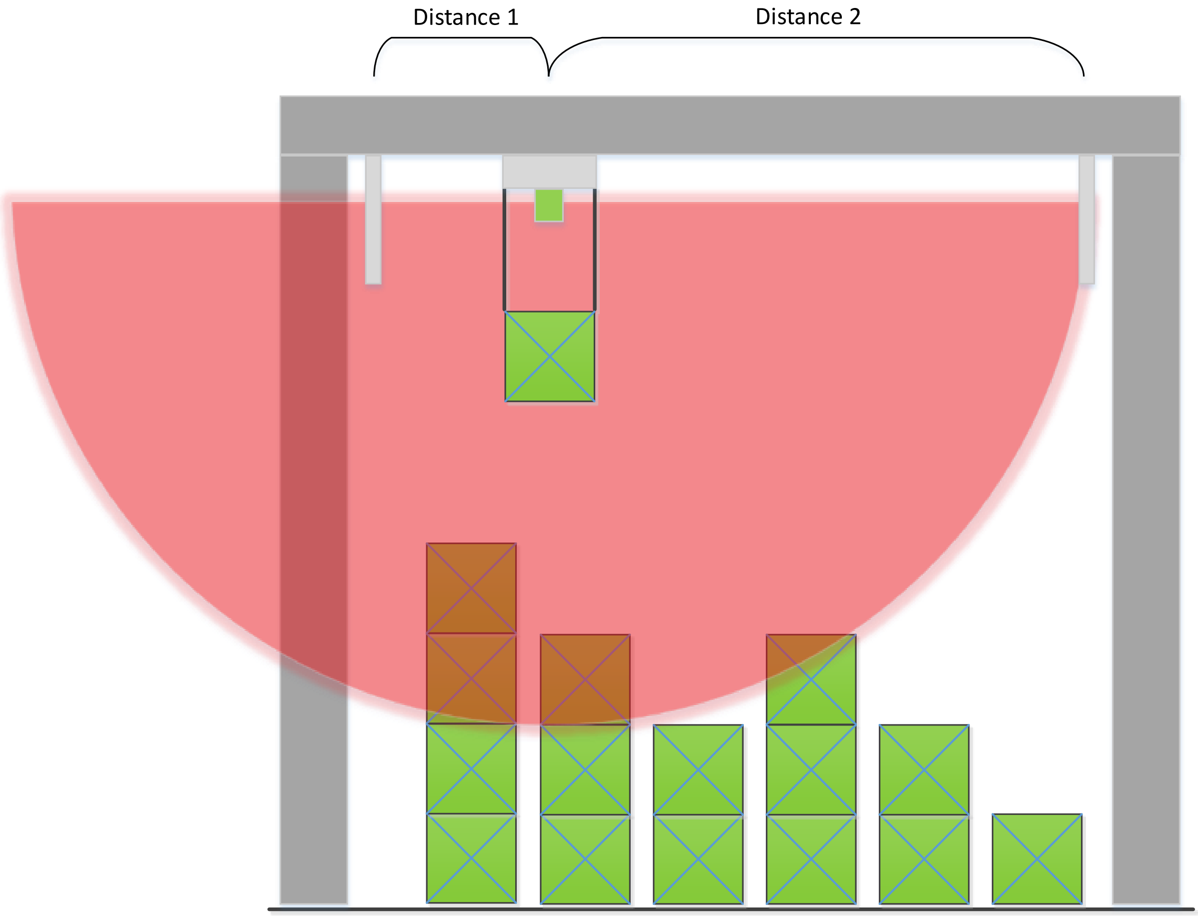

Figure 36: 2D reference object shift

Depending on the position of the trolley axis the measure until the reference points change. In this case, after moving the trolley some meters, it is clear that the distance1 is smaller than the distance2. Furthermore, a cross check safety protocol can be stablished which compares the data received from the PLC and the distances measured by the scanner.

6.3 Double-check routines and functions in software

The Lase software was developed to assure a perfect operation and total reliability. For these reasons double-check routines are and will be presents in the SCP 3D Software.

This routines and function check for example calculations, I/O updates and internal states and variables.

6.4 I/O Monitoring strategy

The software is not the only important part of the system, for this motive the interface with PLC and external components has safety redundant checks implemented.

The critical output will be checked to assure that are working correctly; closed-loop connections are used in the system to check continuously that the output value is according with the software.

This detects for example electronic or mechanical problems in relays and contactors.

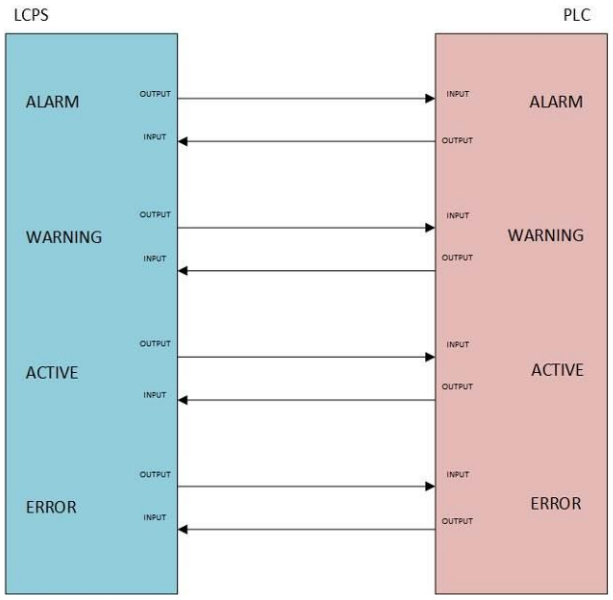

Figure 37 - SCP 3D/ PLC Safety Signals Connection

Due to the Double-Check verification when the system starts the ALARM, WARNING and ERROR signals are sent before the ACTIVE signal, this avoids an emergency stop of RTG. The PLC considers whether the system is ready to work when all signals are on high level, and verifies the status only when ACTIVE is on high level as well.

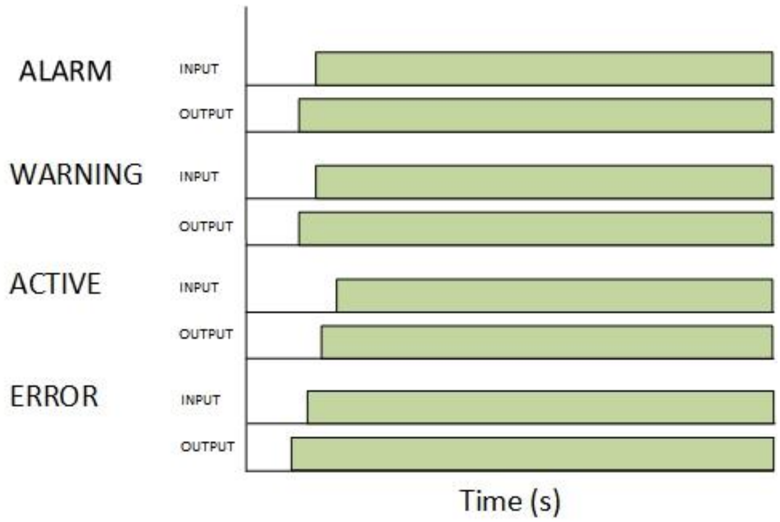

Figure 38 - SCP 3D/PLC Double-Check Communication

All the safety related signals of the system (Error, Collision Alarm and Collision Warning) will be inverse logic signals. When an Error, Alarm or Warning should be informed to the PLC, a low level signal will be send. This avoids problems if the connection is lost or damaged. For other signals the positive logic (high level means activated) will be used.

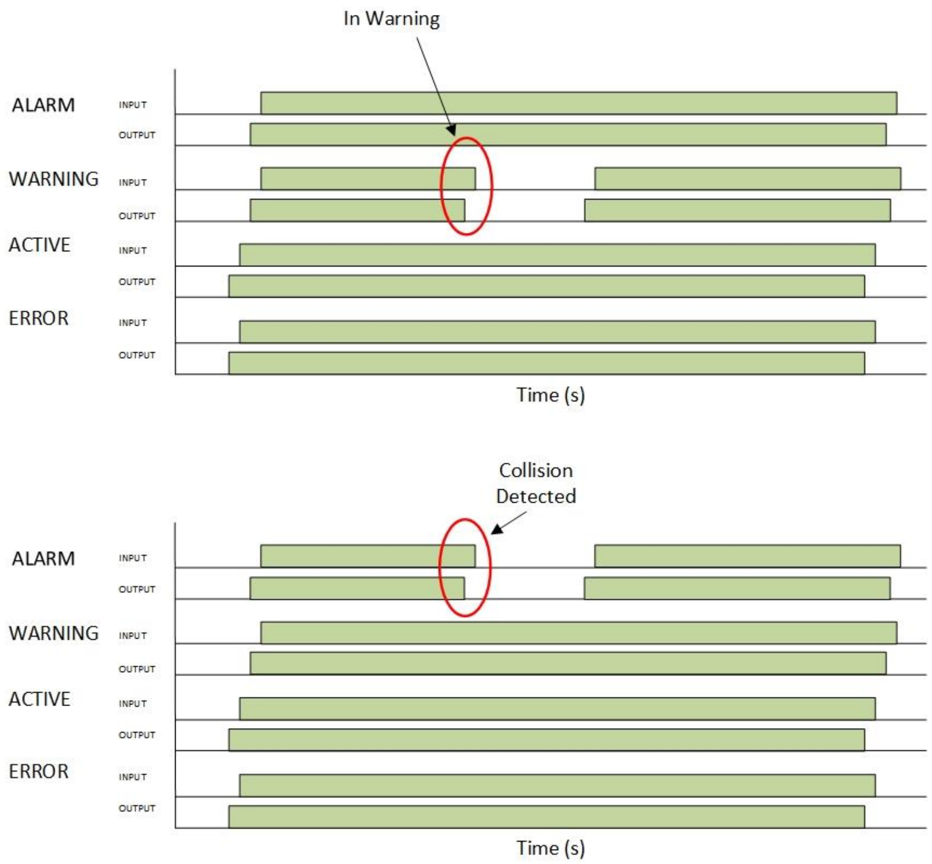

Figure 39 - Warning and collision detection

Example:

This logic detects for example electronic or mechanical problems in cable, I/O modules, relays and contactors.

Every signal will be send to the PLC where an echo-signal will be send back to the SCP 3D, with this method it will be checked that the communication between components is established.

The SCP 3D verifies continuously that output and input coincide, if during the process a signal has different values in input and output in the SCP 3D side, it will be considered like a malfunction and an error will be generated, after this the SCP 3D will be deactivated (ACTIVE will be low level). The system will be designed to permit a manual or automatic backup when an error is detected. The signal ACTIVE will be the switch signal inside the PLC, when this is Low-level the RTG could continue working normally without consider other SCP 3D outputs.

In the next example a malfunction is detected in the WARNING signal, the SCP 3D will proceed:

- Report an error in system (the error will be reported till the next restart)
- Report an alarm to stop the RTG
- ACTIVE signal will be active till the RTG will be stopped
- ACTIVE signal will deactivated to permit a manual or automatic backup of RTG

When a Malfunction is detected in ALARM signal the ERROR is used to stop the RTG.

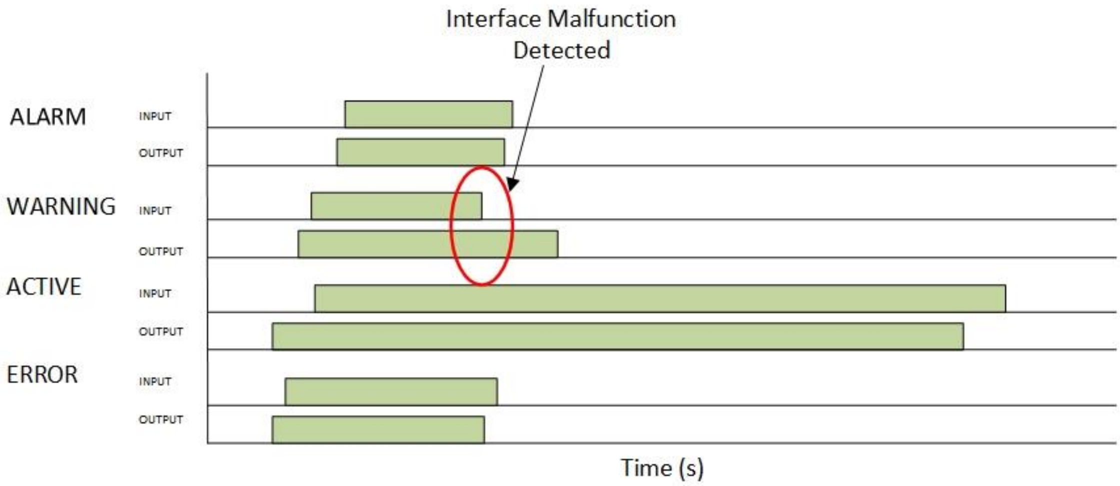

Figure 40 – Interface Malfunction detection

To prevent errors during long periods of activity some periodic testing at suitable intervals will be made, these test consist in switch the signals states for a short time verifying that the communication between elements continue working perfectly.

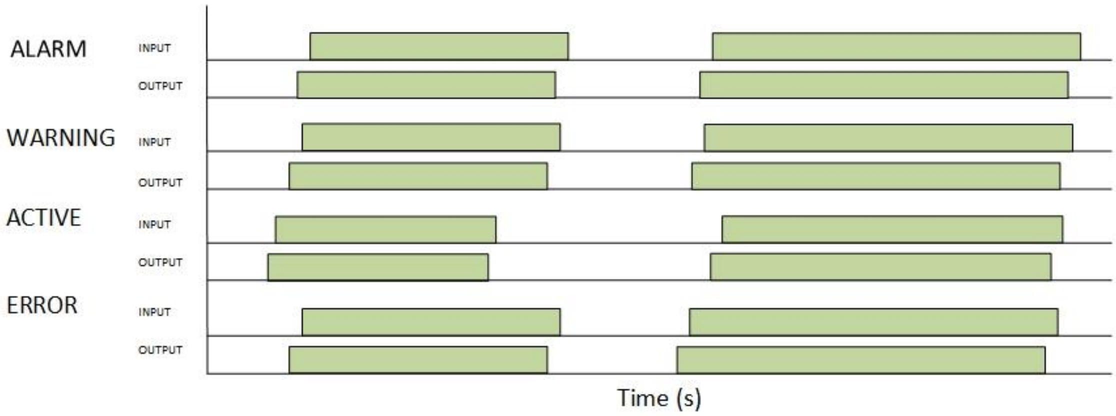

Figure 41 – Periodic testing of interface

To avoid malfunctions in the system during the testing the ACTIVE signal will be disconnected, for this reason during the testing the PLC considers the system is inactive and will not report alarms or stops the RTG.

When the test is finished the SCP 3D returns automatically to active status and continue working normally if not error were detected.

The restart function will be made like the standard start-up (first prepare the safety bits and second the ACTIVE signal).

Due to cycle times in PLC and SCP 3D programs the signals value are not immediately updated. This is considered in SCP 3D safety concept and a delay time between signals changes is permitted.

6.5 By-pass key-switch

The SCP 3D offer the possibility of been deactivated using a by-pass key-switch. When the authorized personal need to switch-off the system this by-pass switch will be used.

The by-pass is connected to an input of the SCP 3D and PLC. When a by-pass is requested the SCP 3D will deactivate the ACTIVE signal and the RTG could be operated manually, ignoring other SCP 3D signals.

6.6 Warnings to operator

Due to safety reasons, the operator will be made aware of the status of the SCP 3D, for that issue, information lights and a buzzer are provided.

The following table summarizes the cabinet information:

Element name	Light colour/sound	Signal meaning
Status led	Red light on	Communication or system failure detected
Status led	Yellow light on	Hardware needs maintenance
Status led	Green light on	No communication failure and no hardware problems.

Table 5: Cabinet information

In the operator cabin some leds and buzzer will be installed to inform the operator of the current status of the system.

The buzzer could be deactivated permanently externally independent of the status of the bits, this could be only made for maintenance department.

This deactivation is controlled from the SCP 3D and will not affect the data coming from the PLC to activate the buzzer. The SCP 3D will act directly in the hardware (buzzer) that could not emit any kind of sound.

In addition to this the PLC will control the buzzer for the case of System not OK (Buzzer 3) using some parameters. If a System not Ok is detected and no movement is requested in the crane a timer in the PLC will be started. After a time, configured in a parameter, the buzzer will be deactivated. If a new movement is requested again the counter will be set to 0 and the buzzer 3 will be activated again.

The following table summarizes the operator cabin information:

<table>
<tr><th>Element name</th><th>Light colour/sound</th><th colspan="2">Signal meaning</th></tr>
<tr><td rowspan="4">Status led</td><td rowspan="4">Red light on</td><td colspan="2">Communication or system failure detected</td></tr>
<tr><td>Bit from SCP 3D</td><td>Value</td></tr>
<tr><td>System OK</td><td>0</td></tr>
<tr><td>Hardware OK</td><td>-</td></tr>
<tr><td rowspan="4">Status led</td><td rowspan="4">Yellow light on</td><td colspan="2">Hardware needs maintenance</td></tr>
<tr><td>Bit from SCP 3D</td><td>Value</td></tr>
<tr><td>System OK</td><td>1</td></tr>
<tr><td>Hardware OK</td><td>0</td></tr>
<tr><td rowspan="4">Status led</td><td rowspan="4">Green light on</td><td colspan="2">No communication failure and no hardware problems.</td></tr>
<tr><td>Bit from SCP 3D</td><td>Value</td></tr>
<tr><td>System OK</td><td>1</td></tr>
<tr><td>Hardware OK</td><td>1</td></tr>
<tr><td>Warning led</td><td>Yellow light on</td><td colspan="2">Warning detected (Bit Warning = 0)</td></tr>
<tr><td>Warning led</td><td>Yellow light off</td><td colspan="2">No warning detected (Bit Warning = 1)</td></tr>
<tr><td>Collision led</td><td>Red light on</td><td colspan="2">Collision detected (Bit Alarm= 0)</td></tr>
<tr><td>Collision led</td><td>Red light off</td><td colspan="2">No collision detected (Bit Alarm=1)</td></tr>
<tr><td>Buzzer</td><td>Sound 1</td><td colspan="2">Collision detected (Bit Warning = 0)</td></tr>
<tr><td>Buzzer</td><td>Sound 2</td><td colspan="2">Warning detected (Bit Alarm= 0)</td></tr>
<tr><td rowspan="4">Buzzer</td><td rowspan="4">Sound 3</td><td colspan="2">System not OK</td></tr>
<tr><td>Bit</td><td>Value</td></tr>
<tr><td>System Ok</td><td>0</td></tr>
<tr><td>By-Pass Key-switch</td><td>0</td></tr>
</table>

Table 6: Operator cabin information

6.7 Software check

The LASE system is working on Windows operating systems (Win7™). To ensure that the software is running an additional small application is installed beside the measurement application. This small auxiliary application is checking whether the main application is still proper running.

7 Installation, Commissioning, Maintenance

7.1 Installation

7.1.1 Mechanic

The sensors and the cabinet have to be adapted to the structure of the trolley. Therefore some mechanical supports have to be build, individual to the local situation on all the different machines.

7.1.2 Electric

The SCP 3D coming with a complete cable set (length 20m). The cabling to the PLC has to be done via a 3m cable to the for example ET200.

Here are also the different local situations on all the different machines have to take into consideration.

7.2 Commissioning

The SCP 3D is designed to be easy-configurable, for this reason hardware, parameters and software options could be easy accessed for qualified personnel to make the commissioning.

7.3 Maintenance

The SCP 3D is conceived to be an easy low maintenance system, components and sensors were chosen to be 24/7 active, easy to replace in case of malfunction

The system manager log all the relevant information - status and events of the system are saved.

