SICK AG WHITEPAPER

3D COLLISION AWARENESS SYSTEMS FOR INDUSTRIAL VEHICLES AND MOBILE MACHINES

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Accident statistics involving industrial vehicles and mobile machines

Whether directly or indirectly, a large number of accidents in industrial environments continue to involve floor conveyors and industrial trucks as indicated by different German Employers' Liability Insurance Associations. According to accident statistics released by the German Social Accident Insurance (Deutsche Gesetzliche Unfallversicherung, DGUV), especially counterbalance forklift trucks are frequently involved and account for more than 12,000 reported accidents in 2014. Between 2010 and 2014, the DGUV reported a total of 54,440 notifiable, 1,676 serious and 52 fatal accidents with forklift trucks. In the majority of these accidents people were hit, pinched or run over by the truck (see Figure 1). Statistics by the German Social Accident Insurance Institution for the trade and logistics industry (Berufsgenossenschaft Handel und Warenlogistik, BGHW) and for the woodworking and metalworking industries (Berufsgenossenschaft Holz und Metall, BGHM) show that in 2014 the majority of accidents involving forklift trucks occurred in these two industrial sectors. According to the DGUV figures have remained almost constant in the last five years and there is no trend which indicates any improvement.

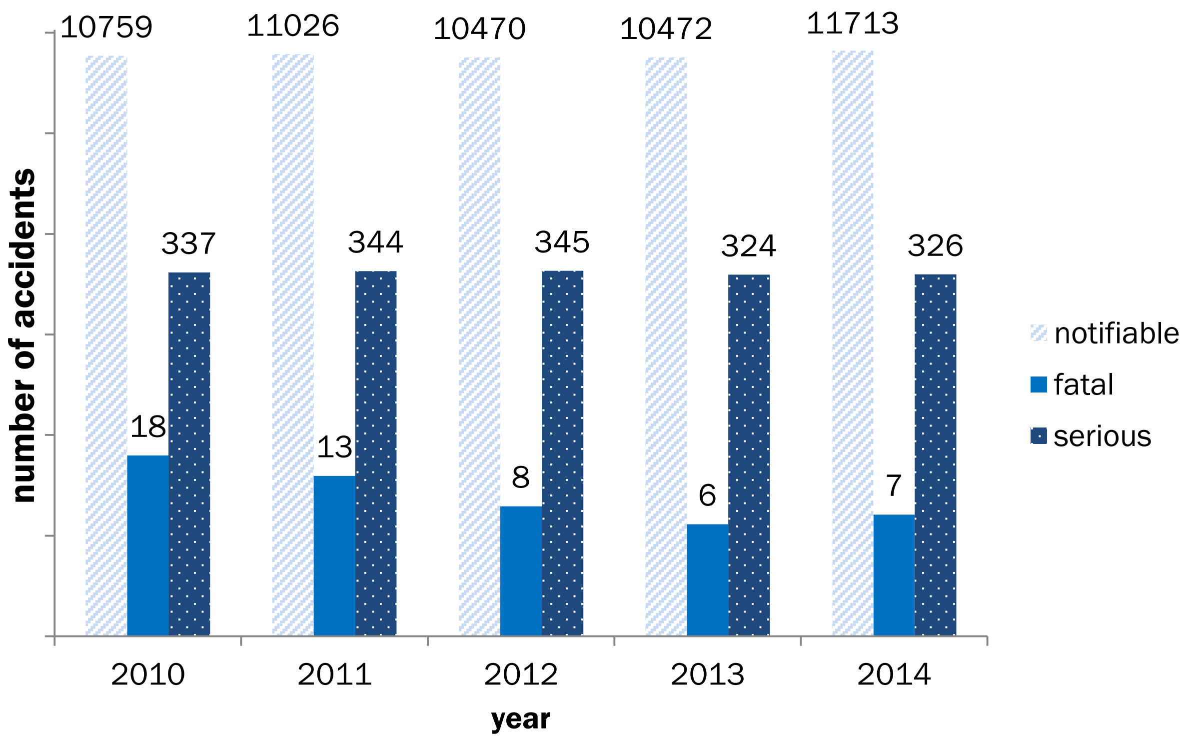

Figure 1: Number of accidents involving counterbalance forklift trucks in the years 2010 – 2014 in Germany. Notifiable accidents are shown in light blue (ruled), serious accidents in dark blue (dotted) and fatal accidents in blue (solid) bars. Source: DGUV.

A similar situation is observed on mobile machines in outdoor working areas, e.g., in the construction, port, mining, or agriculture sector. According to the German Social Accident Insurance Institution for the building trade (Berufsgenossenschaft der Bauwirtschaft, BG Bau), earthmoving machinery alone caused 336 collision accidents between 2008 and 2015 – including 36 fatal outcomes. This is substantiated by eurostat's accidents at work statistics which reveal that in 2014 within the 28 member states of the European Union (EU-28) more than one in five fatal accidents (20.9 %) at work took place within the construction sector and 14.3 % within the agriculture, forestry and fishing sector.

The economic impact of workplace injuries is huge. In Great Britain, 2.1 million working days were lost in 2014/15 due to handling injuries (Health and Safety Executive, HSE); in the years 2013/14, the economic costs of workplace injuries were estimated to about GBP 4.9 billion. Considering that the standardized rate of non-fatal and fatal injuries as well as the overall number of injuries in Great Britain is considerably lower than in most of the EU member states, e.g., Germany (see Figure 2), this number is even more significant since the economic costs for other countries will be even higher.

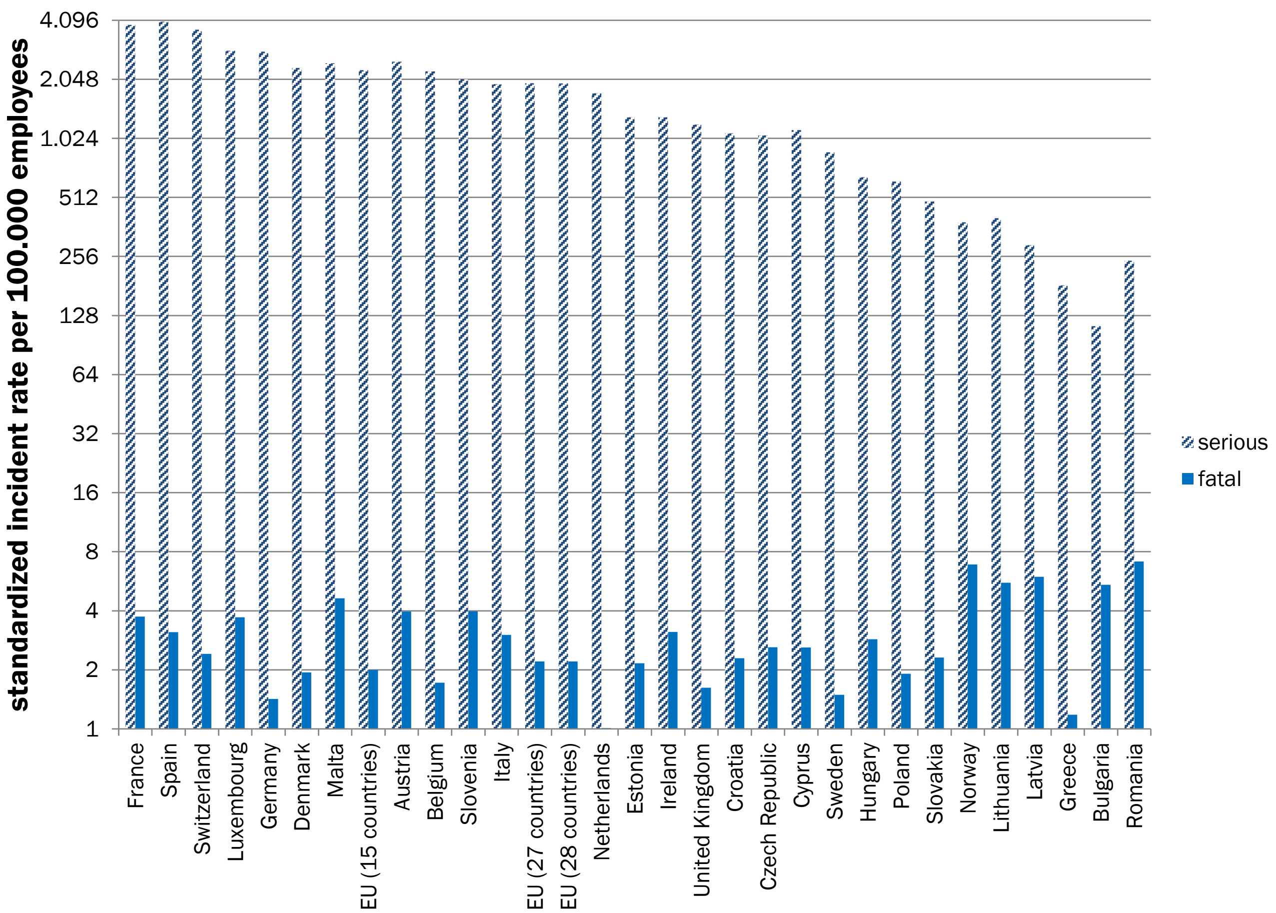

Figure 2: Fatal (dark blue, ruled) and serious (solid, blue) accidents in different European countries. Shown are the number of incidents per 100,000 employees. In the European Union (EU-28) in 2014, more than every fifth fatal accident at work (20.9 %) took place within the construction sector. Source: Eurostat

For example, in 2014, the incapacity for work due to accidents and injuries caused a loss of 55.4 million working days in Germany. This led to an estimated deficit of EUR 9.2 billion in gross value added (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin).

Taking a closer look at the kinds of accidents that involve forklift trucks, the 2014 statistics of the DGHW reveals that in 65% of the cases the truck hit a person or an obstacle (see Figure 3). Besides, more than half of the collisions with people (55%) occurred when the truck moved backwards at low (47%) or moderate (51%) speed. 77% of the injured people were thereby in a range of less than 3 m from the vehicle.

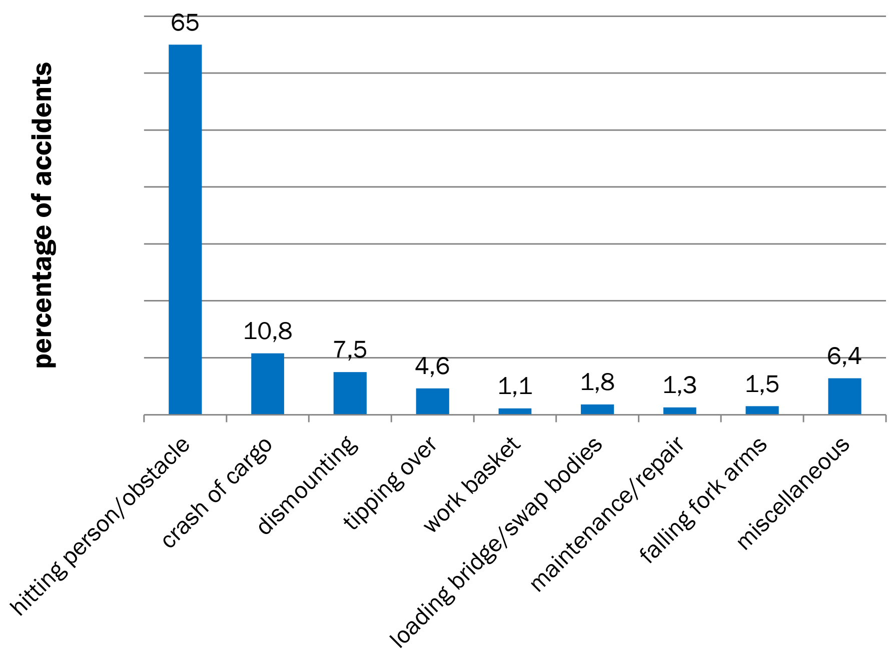

Figure 3: Relative frequency of the kinds of accidents with forklift trucks in 2014 as reported by the BGHW.

Unlike as with private cars, assistance systems are currently not part of the standard equipment neither of industrial trucks nor of mobile machines, but remain rarely used extras. Even in 2017, blind spots surrounding industrial vehicle remain a hot topic (see Figure 4). This is mainly due to the non-uniform environments, the varying working conditions, as well as the different prevailing ambient conditions in the respective working environments. In cars, driver assistance systems are normally only needed for short periods of time, whereas in industrial environments they can be in use for several hours a day, for example, when mobile machines like excavators or wheel loaders are maneuvering or driving backwards. Especially for these situations the operator requires an active system helping him to stay aware of possible danger.

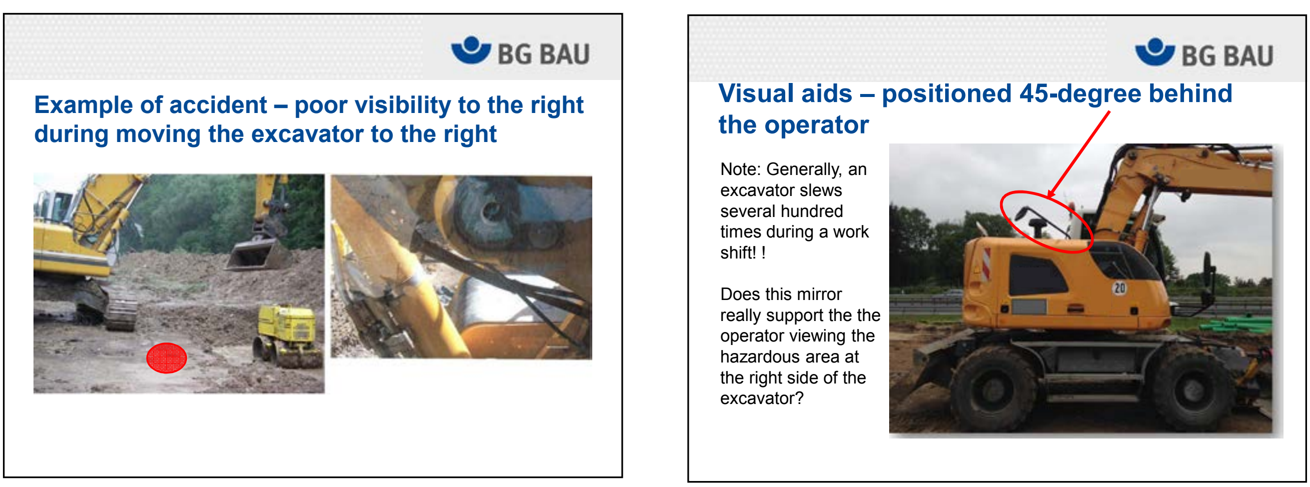

Figure 4: Even if the construction vehicle stays at one position, the risk for collisions is still high, e.g. when slewing the excavator (the red spot in the image on the left marks a blind spot). Either the operator's field of view is limited or he simply does not have the time to look on a screen or in a mirror (see picture on the right). Mainly because he has other tasks to accomplish, such as excavating soil. Source: German Social Accident Insurance Institution for the building trade (Berufsgenossenschaft der Bauwirtschaft, BG BAU).

Existing solutions for reducing accidents

The market offers a range of sensor-based solutions. One approach to enhance the collision awareness is to use RFID tags. Mobile receivers on the industrial vehicles can detect transponders that are within a certain range around the vehicle. Staff is supposed to wear the tags while the trucks are being operated. If the amplitude of a received transponder signal is above a predefined threshold, i.e., the tag is within a particular distance from the vehicle, a warning signal is issued. The driver is thereby warned about an imminent danger and has the possibility to react in time. Another solution with an entirely different approach is represented by warning spotlights. Very bright LED lights are mounted on the forklift truck and project a highly visible, large light spot (usually blue or red) onto the path in front or behind the truck. Pedestrians and other forklift drivers are therefore warned of the nearby vehicle. Since the driver himself is not alerted to the potential harm he can cause, warning spotlights represent a passive signaling concept. Normal 2D cameras are very popular when it comes to providing information to the driver of a vehicle. Although the operator can look at the camera live view and does not have to turn his head, e.g., when reversing, a 2D camera is a passive system. This means that it does not provide any active warning for the driver. Even if using the 2D camera as an additional tool, the operator's continuous monitoring of the possible danger is a prerequisite. Otherwise he will not look at the live view on the screen and might overlook potential obstacles.

There are systems that are based on radar and ultrasound technology, usually mounted on the rear side of vehicles. Radar systems work well in outdoor environments. However, due to the principle of operation the detection of non-metal objects is a quite challenging task. Ultrasound technology involves sound cones and allows 3D object detection within these cones. Yet, the responsiveness of ultrasound systems is quite sensitive to ambient conditions, such as temperature changes. In addition, both radar and ultrasonic technologies cannot offer object classification based on 3D vision, as, for example, the human eye does. All these factors influence the detection and might cause a high rate of missed or false alarms. In industrial environments frequent false alarms are at least as dangerous as missed ones. That is because truck operators or other staff working around the vehicle might get used to hear the alarm even if there is no imminent danger. As a result, they will possibly ignore the alarm, not realizing any more if it is true or false. Recurring false alarms therefore pose a serious danger.
The advantages and disadvantages of existing solutions for collision awareness are briefly described in Table 1 below.

Solution	Description	Advantages	Disadvantages
Warning spotlight/focused LED light	Light spot on the ground	• Simple installation • Pedestrians can see the light spot	• Passive solution, no sensor • Endangered person has to move out of the way
2D camera	Live camera image on the monitor	• Driver can evaluate the danger visually • Relatively cost-effective solution	• Passive solution, no sensor, no warning • Driver has to watch the monitor constantly
RFID tag	Mobile detection of tags	• Relevant objects are tagged • Detects objects behind corners	• Organizational effort • Non-tagged objects are not recognized
Radar	Radio cones	• Outdoor rugged • Active detection	• Non-metal objects are difficult to detect • Visualization and object positioning are not accurate
Ultrasound	Ultrasound cones	• Cost-effective solution • Active detection	• False alarm possible due to environmental influences • Visualization and object positioning are not accurate
Laser scanner	Laser scanning with infrared light	• Very precise scanning principle (active) • Wide horizontal field of view	• Detection only in 2D plane/s • Difficult to avoid blind zones

Table 1: Advantages and disadvantages of existing solutions for collision awareness.

Collision awareness sensors based on 3D snapshot technologies

Compared to existing technologies, 3D snapshot has the advantage that it is able to detect objects in three-dimensional space using only a single image.

3D snapshot technologies can capture the scene three-dimensionally (see Figure 5) without the necessity of actuators or mechanical parts inside the sensor that have to move. This means that the entire blind zone surrounding a vehicle can be analyzed, even if the vehicle is moving slowly or standing still. With one snapshot such a 3D sensor does not only evaluate the object's width and height but also the distance to it. What's more, this technology provides the possibility to classify objects on a 3D vision basis. This makes it possible, for example, to reliably differentiate between a shelf, a crate, a curb, a pedestrian or an electrical cabinet in real time. This possibility constitutes a clear advantage compared to existing technologies in terms of developing an effective collision awareness sensor.

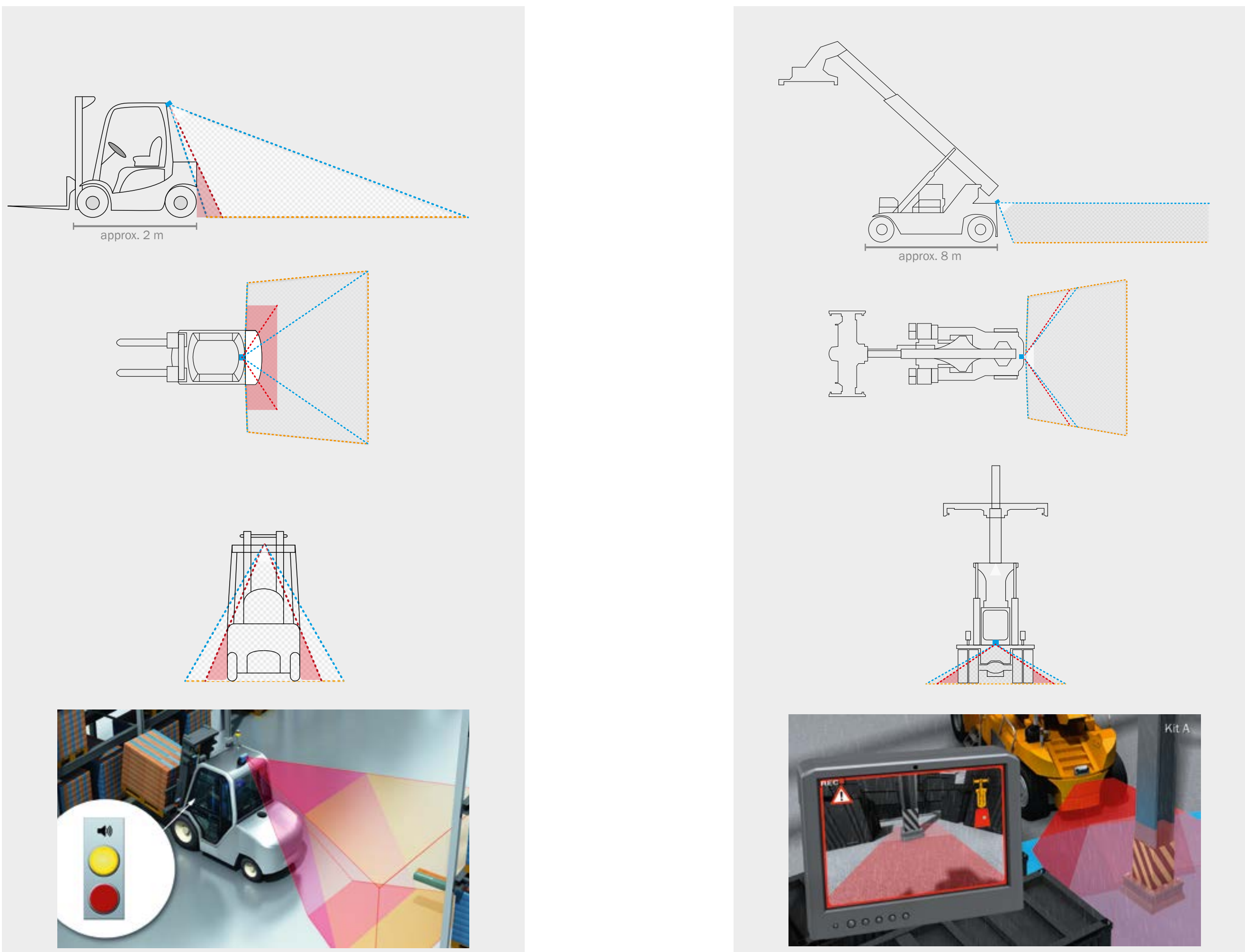

Figure 5: Typical sensor installations on a counterbalance forklift truck (left) and on a reach stacker (right). Side, top and front views of 3D detection zones.

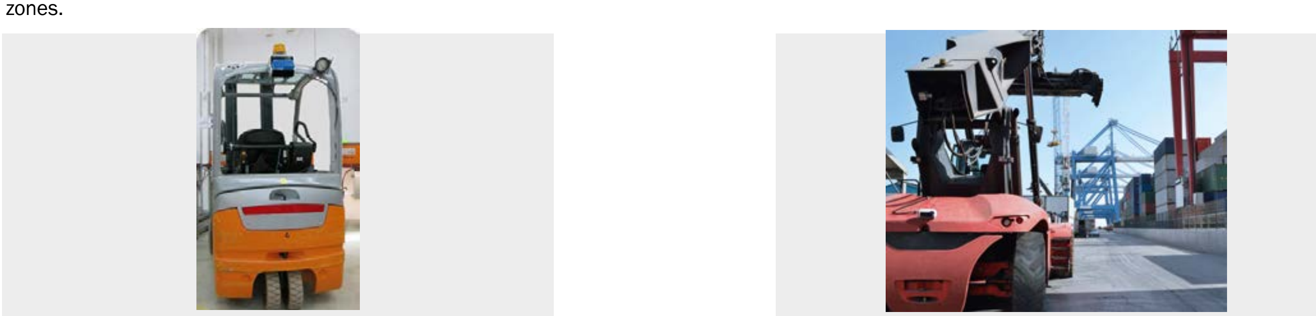

Figure 6: Examples for the use of 3D collision awareness sensors in indoor and outdoor areas.

In general, there are two techniques that enable 3D snapshot: time-of-flight and stereoscopic triangulation methods. 3D time-of-flight (ToF) means measuring the time of flight of light pulses between the sensor and the target object for each pixel of the image. As soon as the arrival time or phase shift of the reflected light is known, the distance to the target object can be determined (Figure 7). Stereoscopy means that the depth information is derived from two images that are taken by two synchronized cameras. The cameras are positioned such that the scenery is captured from slightly different perspectives. By that the depth information can be calculated using a triangular relationship for each point of the image (see Figure 8).

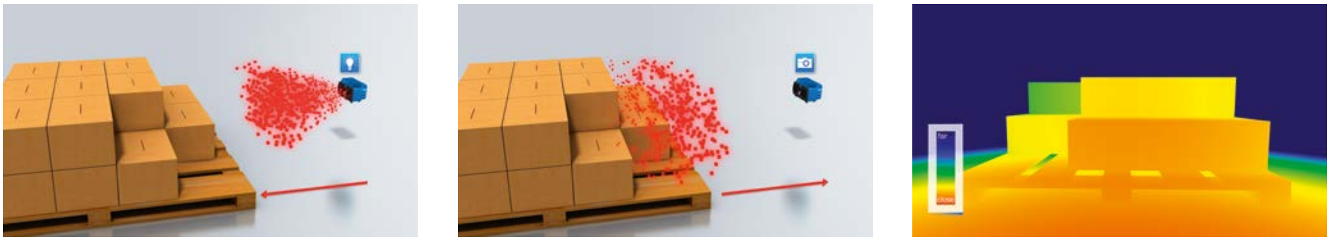

Figure 7: Principle of operation of 3D time-of-flight technology.

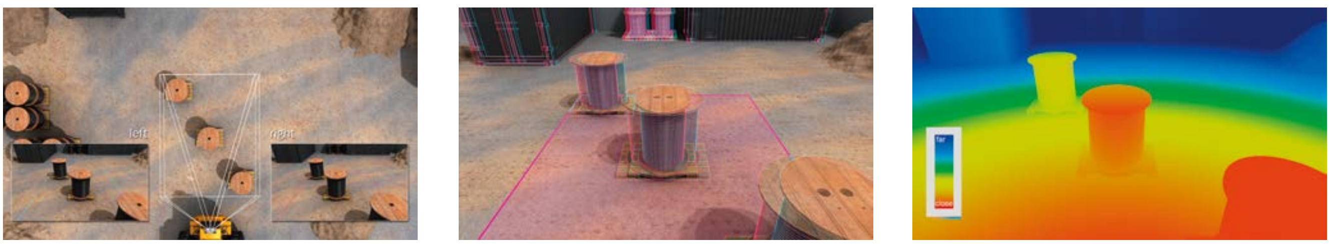

Figure 8: Principle of operation of stereoscopic vision technology.

Due to the fact that both technologies are based on different physical principles, they show different characteristics. For example, solutions based on the 3D ToF principle usually supply 3D data with a high level of accuracy. Stereoscopy-based measurements, on the other hand, are barely influenced by objects with differing reflective properties. Regardless of the physical source, both 3D snapshot technologies provide warning signals based on 3D vision data in real time.

The detection zone of a 3D snapshot sensor depends on different parameters, like the configuration, the distance to a delimiting flat surface (e.g., ground, ceiling, wall, etc.), or the installation angle of the sensor in relation to the ground. The following table describes the typical properties of 3D collision awareness sensors based on the two technologies described above.

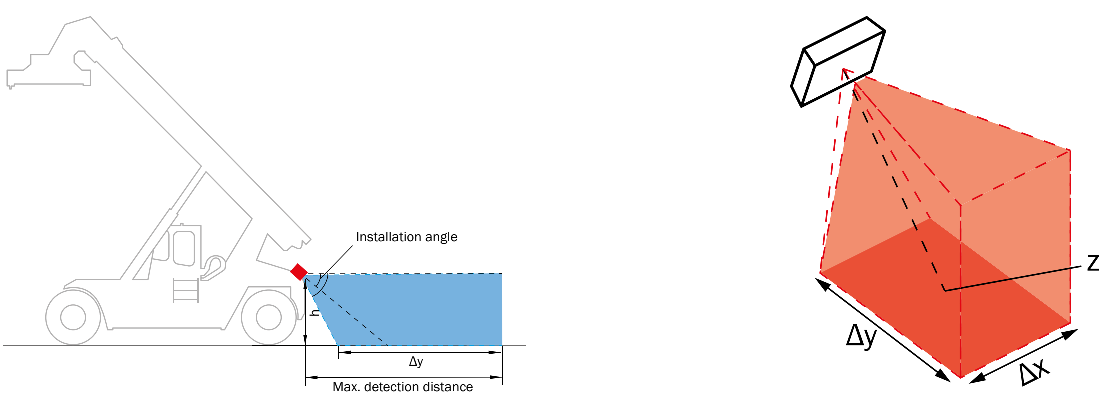

Figure 9: Installation height and angle have a direct impact on the working distance (Δy) (left). Perspective view on 3D detection zone and its projection on the ground (Δx x Δy area) (right).

Parameter	Visionary-T 3D collision awareness	Visionary-B 3D collision awareness
Technology	3D time-of-flight with IR light	Stereoscopic vision
Main area of usage	Indoor	Outdoor
Recommended installation height (h)	0.1 m ... 2.5 m	1 m ... 3 m
Recommended installation angle	Should be delimited by the ground	
Recommended minimum and maximum working distance (Δy, ground projection, see Figure 8)	0.3 m ... 3 m	0.3 m ... 7 m
Recommended maximum detection area (Δx x Δy, see Figure 8)	1.5 m x 3 m	4 m x 6 m
Typical detectable object size	About 20 mm x 20 mm	Various object classes
Minimum response time	< 150 ms	< 300 ms
Temperature range	0 °C... 50 °C	–40 °C ... +75 °C
Weight	1.5 kg	5 kg
IP class	IP 67	IP 69K
Detection angle	69° x 56°	105° x 70°
Number of distance pixels	176 x 144	250 x 496
Light sensitivity	0 klx ... 50 klx	200 lx ... 80 klx
Power consumption	16 W	30 W
Application	Integrated into the sensor	In the evaluation unit
Supply voltage (DC)	24 V	12/24 V

Table 2: Typical technical data of 3D collision awareness sensors.

Detection performance of 3D snapshot sensors

The detection performance of 3D snapshot sensors can vary depending on environmental influences, which can lead to deviations in the captured 3D zone. Light conditions and interferences, rain or dirt, fog, lack of contrast, and reflective properties of objects can influence the performance. However, there are ways to efficiently deal with and to overcome these challenges.

Similar as with the human eye, the 3D detection performance based on stereoscopy is not optimal in case of uniform surfaces, e.g. unicolored walls or surfaces that are completely covered with snow. In this case, finding corresponding points in the two images – a necessary process to calculate the distances in 3D space – is a challenging task. In addition, with passive stereoscopy, the image sensor relies on ambient light. Therefore, it cannot be used effectively in complete darkness. In comparison to passive stereo cameras, a 3D ToF sensor has an integrated light source. However, due to the 3D ToF principle, the detection ability partly depends on the presence of other light sources and more important on the reflective and scattering properties of the objects' surfaces. That means that highly absorbent materials, e.g. black boxes, might not reflect the amount of light that is necessary to perform a reliable 3D ToF calculation. On the other hand, highly reflective and glossy materials, such as mirrors, might cause multiple reflections and lead to erroneous distance calculations (artifacts).

The key to overcome the challenges described above is to utilize the advantages of the technologies in such a way that the influence of the disadvantages on the result does not become evident or is suppressed. As an example, for 3D ToF sensors this can mean to predominantly use them indoors to avoid interferences through direct sunlight. Further, the optical power within a scene can be distributed in such a way that the detection of objects with weak reflective properties is enabled. Stereoscopic sensors can easily overcome their dependency on ambient light by using additional light sources, e.g. the vehicles' headlights should be sufficient to enable a good sensor performance. The projection of stripe or point patterns poses a solution for the detection in unicolored surroundings.

In addition, the performance of both types of sensors strongly benefits from the implementation of intelligent algorithms. For example, object classification or filters that cope with high contrasts in dynamical scenes. Both reduce the false alarm rate considerably and have proven themselves in practice. All SICK 3D collision awareness sensors, such as Visionary-T and Visionary-B, are developed and built in a way that they leverage intelligent algorithms like the ones mentioned above.

Summary

The operator of an industrial vehicle or a mobile machine has to take care of many tasks. Of all these tasks, driving the vehicle itself is not the operator's most challenging one. Instead, the driver must be able to focus on his main tasks, such as the rapid handling of goods. In addition, maneuvering e.g. a forklift truck or a wheel loader is not like driving a car, as it can entail driving backwards not just for brief periods but for hours at a time. This is where solutions based on 3D snapshot technology can help to enhance the collision awareness of the driver. By using acoustic and optical alarms, as well as a real image, they warn the operator in critical situations. The effective 3D vision detection reduces the false alarm rate so that the operator does not ignore the warning in case of a real danger. Intelligent algorithms developed by SICK filter information that is irrelevant for the driver, e.g., curbs at a construction site or unevenness of the ground in an outdoor working area. This allows the operator to focus on the key tasks while ensuring that he will be warned of critical situations whenever they occur.

Figure 10: Typical environment in construction site. The 3D snapshot sensor from SICK helps the operator to focus on his main tasks. The sensor actively warns the operator in critical situations with an acoustic and visual alarm.

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