The application of laser sensing technology to proximity detection in the mining industry

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1 Abstract

SICK MAIHAK, better known to the mining industry as the supplier of mine gas monitoring hardware for underground coal mines, is a technology leader in the application of laser scanning to indoor and outdoor applications.

Building on experience in the development of autonomous driving platforms and vehicle collision avoidance and lane guidance systems based on laser scanning technology, SICK has developed a proximity detection system for the mining industry.

The system operates in real-time and is able to track up to 128 objects simultaneously, e.g. car, truck, pedestrian, motorbike, bike, rocks, berm wall, etc. while automatically compensating for speed.

SICK has been conducting mining industry trials of the technology in partnership with Simtars.

This paper describes the technology, its development for the mining sector and the results of those trials

2 Introduction

During the past few years there have been a number of fatalities on mine sites, which have been the result of interaction between humans and mining equipment [1]. In an effort to address this problem there is a drive to develop and install systems to prevent these collisions/interactions.

Operators of large mining equipment have trouble detecting obstacles in the direct vicinity of their vehicles. This is due to the size of their equipment, which results in large blind spot areas, as well as the dusty environment. Therefore, operating on a mine site can be a challenge, even for experienced drivers. Furthermore, an operator may distracted by information from the in-vehicle-management-system, the navigation system, the radio or could simply be suffering from fatigue. In addition, operators have to deal with information from the environment the vehicle is operating in, like traffic signs, behaviour of other pit users, large rocks or potholes. Just a moment of distraction is enough to cause a collision. Proximity detection systems can assist the operator in avoiding collisions by analysing the area in the proximity of the vehicle. When the potential for a collision is detected the system is able to alert the driver to take evasion action or automatically control the vehicle to avoid the collision depending on the configuration. Therefore any proximity detection system must be able to operate reliably in poor light, weather and visibility conditions.

Although sensor technology for measuring most parameters of engineering interest has been developed, critical sensor requirements for the mining industry have not. Special requirements for underground sensors have not been addressed by commercial sources because of the limited market for their products in the mining industry. Of all the available advanced automation concepts, few have been brought to reality and tested in actual mining conditions. Reliability, maintainability, safety, cost flexibility and market potential play significant roles in the successful implementation of a new technology.

The application of sensors to the operation of a particular type of equipment, must take into account not only the sensor's operational features and physical characteristics, but also the process environment in which it is expected to perform. The constraints imposed by the equipment's design and its surroundings limit the kinds and quantity of data that can be measured reasonably. Proper selection of a sensor will depend on what is to be measured and how this will be accomplished. The major issues to consider are presented in the following paragraphs.

The kinds of sensing to be used depend on what is being measured. More than one way can be developed to measure a parameter. For example, to measure a vehicle's distance to an object, use could be made of sound, light or electromagnetic energy. To determine the most effective sensor the objective of the sensing application needs to be clearly identified. The objective should take into consideration operational and economic factors and not only concentrate on the technical factors. Performance criteria such as speed, reliability and accuracy are additional factors to be considered as well as the ability for integration into the equipment design. To understand the operation of sensors, it is necessary to know what is being measured or what is observed at the different stages of the sensing process.

Proximity detection is divided into two areas, either detection or ranging. The difference lies between detecting the absence or presence of an object or ranging in the sense of classification and distance measurement. Detection is usually used to indicate presence and raise an alarm, while range scanning is used for navigation and obstacle avoidance.

The sensor types usually used in ranging applications are:

- **Acoustic Sensors.** These sensors determine the distance to an object by triangulation, time-of-flight, phase shift or a combination of these methods. The operating principle of the sensors is the conversion of acoustic energy into electrical energy.
- **Electromagnetic Sensors.** In the electromagnetic spectrum, radar systems are commonly used for range sensing. Distance can be calculated by pulsed time-of-flight methods or continuous wave phase or frequency modulation methods. It would appear that this could be a viable solution for detecting objects in front of a vehicle.
- **Optical Sensors.** These sensors determine the distance to an object through time-of-flight measurements. The time between a signal being transmitted by a source and received by a detector is used to calculate the distance. Light detection and ranging systems (lidar) using rotating mirrors generally cover a two dimensional field of view. The latest laser scanning technology, described in this paper can produce a three dimensional view.

The rest of this paper will focus on optical sensors that can identify other road users as well as road side objects, while compensating for pitching of the vehicle and uneven road surfaces. A panel computer/display gathers information by means of multiple laser sensors that measure the distances to obstacles around the vehicle, analyses the situation and warns the operator accordingly.

3 Overview of Lidar Based Automation Systems

Autonomous mining equipment has been researched since the 1980s when the United States Bureau of Mines (USBM) invested funds in laser based guidance for underground mining equipment [2]. Right from the outset of the research the danger of interaction between humans and equipment was identified and development of proximity detection was initiated to avoid harmful interactions between humans and equipment [3].

In the late 1990s the development of autonomous trucks by companies like Caterpillar and Komatsu became a reality. At this time the technology employed still required significant further development. GPS and mapping technology was the key for navigation, but only a reliable environmental perception technology can be used to avoid collisions with the infrastructure or other road users.

A system called MINEGEM™ was initially introduced in 2003 on remote controlled load haul dump (LHD) trucks. MINEGEM™ enables the LHD operator to work from a safe and ergonomic workstation using an autonomous steering function delivered by laser scanners which profile the drive walls to verify the machine's position. The system, therefore, is not forced to rely on GPS which is not available in an underground mine or infrastructure such as radio frequency identification (RFID) tags.

Sandvik's Automine System has followed the same path using laser scanners since 2004. Remote Control Technologies (RCT), as the name indicates, has worked in the field of tele-operated systems since 1988. RCT's tele-operated systems also use laser scanners. These modern systems have the added benefit that they can be interfaced to supervisory control and data acquisition systems (SCADA).

Each works under the assumption that no obstacle obstructs the driving path. The combination of these guidance systems with a reliable environmental perception technology can deliver all the necessary functionality for autonomous operation, but more importantly increased safety, productivity and equipment utilisation. Full autonomy can only be achieved by means of:

- accurate vehicle control system;
- integrated proximity detection system;
- interaction with / identification of other machines in the mine using a wireless network system;
- GPS control; and
- a computerised supervisory and management system.

As a manufacturer of sensors and sensor solutions for industrial applications, SICK called on its experience in the field of autonomous driving in the development of lidar scanners. In designing multiple advanced driver assistance systems (ADAS) for automotive applications, SICK's daughter company Ibeo Automobile Sensor GmbH developed reliable obstacle detection, object tracking and classification technology which could be readily ported to mining vehicle applications.

Vehicle control is a means to demonstrate the strength of laser scanning technology. As an example, SICK laser scanners have been used in all autonomous DARPA Challenges on competing vehicles [4]. Ibeo demonstrated in the 2007 DARPA Urban Challenge,[1] with its own driverless car, that autonomous vehicle operation can be achieved solely using lidar technology.

Overcoming the issues of dust and vibration opened the door for the introduction of advanced laser scanning technology to the harsh mining environment. SICK has developed a system based on lidar scanners that delivers a standalone plug and play solution which assists operators to identify and avoid conditions that could lead to harmful vehicle interactions with other vehicles, persons or infrastructure. The system offers a sensor platform with a sophisticated driver warning strategy which can be readily integrated into SCADA systems. The combination of object detection, tracking and classification technology garnered from experience in the development of advanced driver assistance systems, has lead to a system that provides driver aid and guidance as well as an information stream to mine management systems.

4 Lidar Sensor Technology

The SICK laser scanner used for environmental perception sensing is the latest development in the SICK laser measurement system family. The scanner was developed by Ibeo to cope with harsh environmental conditions such as rain, dust, fog and snow. This development breakthrough with the new laser scanner in terms of robustness, especially under the mentioned conditions, enables the advantages in precision and high resolution of detail that is typical of laser technology to be applied where outdoor performance is a prerequisite. Unique dust penetration, multi echo technology and advanced data processing algorithms are the key features of the scanner that provide outstanding performance under any weather condition.

These scanners measure with a resolution of up to 1/8°, ranging from 0.30 m up to 200.0 m and have a horizontal field of view of 110°. The laser pulses emitted from the scanner are reflected by objects in the surrounding environment. The distance is calculated from the time-of-flight of the laser pulse and the speed of light. A rotating mirror deflects the laser pulses. The angular position of the mirror during deflection yields the direction of the detected object. The combination of these values builds the basis for a complete profile of the surroundings in the radial scanning range of the laser scanner.

SICK's present laser scanners collect and evaluate up to three echoes per transmitted laser pulse (see Figure 1). The next generation will evaluate up to five echoes. Once the echo reaches the photo diode receiver of the scanner, the received intensity is transformed into a voltage. A reflected echo of a glass pane yields a high voltage over a short period of time. The echo of a rain drop, however, yields a very low voltage over a short period of time. The echo of an object yields a high voltage over a longer period. Different detection thresholds allow for the separation and classification of these echoes. The lowest threshold voltage separates the system noise from the relevant reflections. All three echoes are generated by reflections of a single transmitted pulse. The measuring scanner collects the laser pulse reflections, processes the information, classifies the reflections and issues the data via an Ethernet interface.

[1] The DARPA Urban Challenge is an autonomous vehicle research and development program. It features driverless autonomous vehicles manoeuvring in a mock city environment.

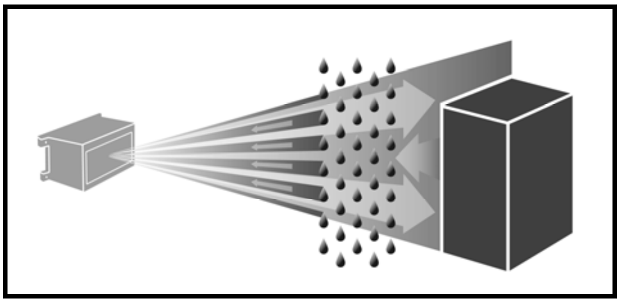

Figure 1 Multi-echo technology

4.1 Detection Probabilities

To be used and to be accepted by the operator, a sensor system that is used as a driver aid needs to have the highest possible detection probability of critical obstacles under various environmental conditions. SICK and Ibeo have done various tests at mine sites to determine these probabilities and, more importantly, to evaluate the limitations of the sensors. The detection probability is calculated at a certain distance (denoted as x in the equation) between the laser scanner and the measured object. At this distance the probability is the sum of all detections divided by the sum of all measurements.

$$\text{probability}(x) = \frac{\sum \text{detections}(x)}{\sum \text{measurements}(x)}$$

These measurements are conducted as interval based probability determinations, where the distance to the object is subdivided into fixed bins (distance intervals of k) and the probability is calculated per bin.

$$\text{probability}(k) = \frac{\sum \text{detections in bin}(k)}{\sum \text{measurements in bin}(k)}$$

The detection probability is, therefore, calculated for multiple objects related to the distance and the measurement conditions. Figure 2 shows the basic principle of the test data collection.

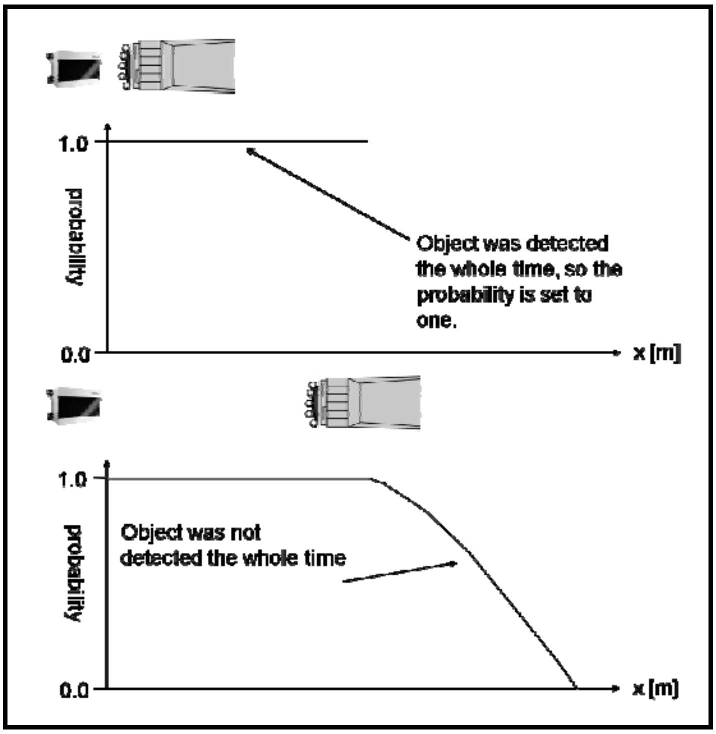

Figure 2 Detection probability

An illustration of the principle is shown in Figure 3 for a pedestrian with a reflective vest using a haul truck for dust generation to simulate poor measurement conditions. Figure 3 illustrates the general detection probability and dust penetration of the scanner for long ranges. In most mining applications a heavy duty version of the scanner is used, that is better able to cope with dust but with a slightly reduced range. The trade off between reduced, but still sufficient, range, and reduced dust sensitivity provides for optimal sensor performance in the mining environment.

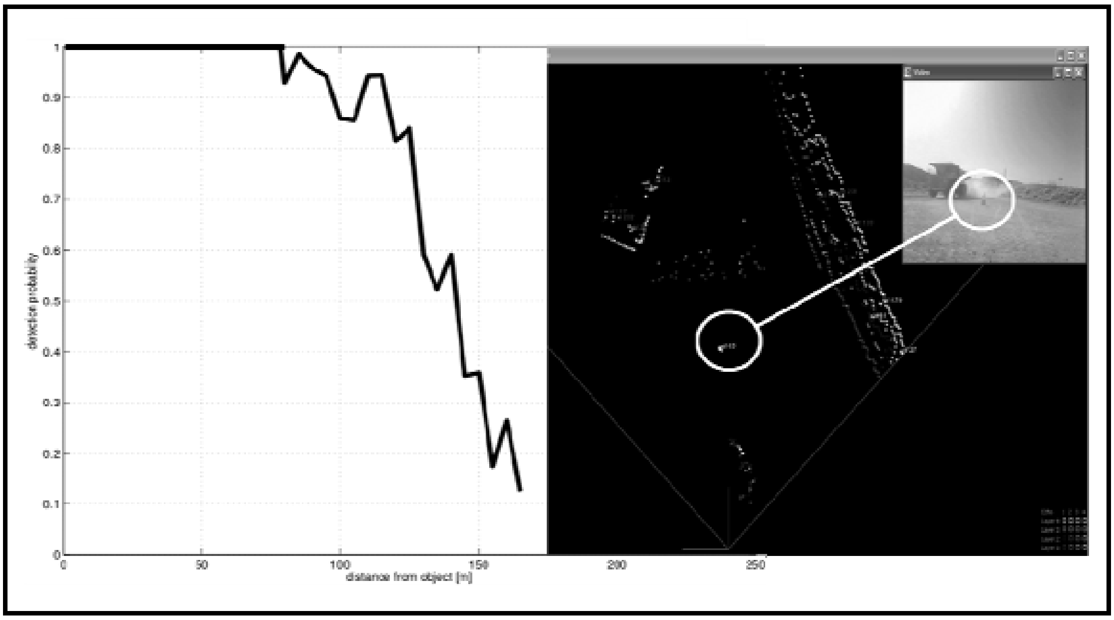

Figure 3 Detection probability of an adult with a reflective vest in dusty conditions

4.2 Multi Layer Technology

A vehicle's pitching motion while in motion poses a challenge to sensors installed on a vehicle. An incorrect measurement can easily occur, for example, if a measurement is taken as a tyre hits a pothole. The system could lose sight of relevant objects as a result. To prevent objects remaining undiscovered, four layer technology is employed by SICK in their most advanced laser scanners. These scanners measure simultaneously using four layers. The scanner splits two laser beams into four vertical layers. Distance measurements are taken independently for each of these layers with a total aperture angle of 3.2°. This is a key feature, and unique to the SICK scanner technology, necessary to compensate for the pitching movement of a vehicle caused by an uneven surfaces or driving maneuvers such as braking and accelerating or to detect slopes, cliffs, potholes, table drains, rocks and ditches.

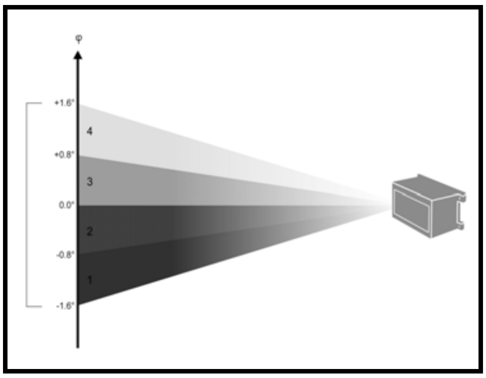

Figure 4 Four layers cover a vertical aperture of 3.2°

4.3. Object Tracking and Classification

Taking multiple images of the surrounding environment enables the scanner to use tracking algorithms to calculate speed, position, size and direction of movement of objects in real time. The sensor therefore offers a description of its environment in the form of objects with relevant dynamic characteristics and classifies these objects as trucks, light vehicles, or persons. This technology gives rise to reliable object detection, which entails not only the exact evaluation of relevant object data, but also the exact classification of data points received from the ground (earth), which is used for pitch compensation and the elimination of irrelevant data, typically arising from a dirty cover, dust, heavy rain, fog or even snow. These artifacts are removed by filtering and/or reported to the operator.

5 SICK Collision Avoidance Application

5.1 Proximity Detection System Requirements

Mine operations require a system that prevents incidents and accidents, and reduces repair costs and downtime to optimise productivity and increase safety. A system based on proximity detection sensors needs to be simple and to be able to operate with different types of mining equipment. The selection of warning zones and levels depending on the individual mine operation's safety processes, needs to be configurable at the mine. The choice of the appropriate proximity detection technology is, furthermore, dependent on an open design. Hence, the system needs to provide an interface to existing or future mine management systems. Installation time and effort is also an important consideration.

Equipment operators are concerned about performance. To be accepted by the driver, a proximity detection system needs to be an aid and not a disturbance. If a proximity warning system is used, false warnings need to be eliminated or, at least, reduced to a minimum. It must be robust and easy to use. It needs to be active and be designed such that the driver does not have to watch a display, because the driver's focus must remain on the tasks at hand. Drivers need an unmistakable warning sound or active intervention by the system that reacts before it's too late.

5.2 SICK Collision Avoidance System Description

With the SICK collision avoidance system, detailed information is provided by the SICK laser scanners to form the basis of a complex driver warning strategy. Up to four laser scanners constantly observe the vehicle's surroundings. The system is aware of the positioning of the scanners on the vehicle and the vehicle's physical dimensions. Three warning zones - green, yellow and red – can be defined to suit the specific mine operation's safety process for shovel, excavator, haul truck or dozer (see Figure 5).

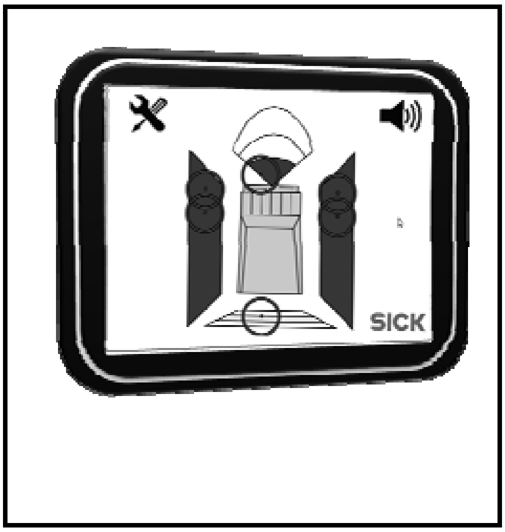

Figure 5 Operator display: warning zones with obstructions

If an object is detected encroaching upon a warning zone an alarm is raised with visual and aural feedback provided to the operator. The operator therefore, is not required to continuously monitor the display and will be warned audibly. All events are also provided on the network interface for external logging and transfer to mine management systems.

To predict a potential collision an area of interest must be monitored. The length of this area is dependent on the vehicle's own speed. It consists of three parts, the safety distance, the system delay distance and the braking distance.

The safety distance, is the minimum safe distance acceptable between the vehicle and an object after the vehicle comes to a halt. Several tests have been conducted with different drivers to determine a safety distance. This covers the driver's reaction time and the distance the driver perceives as safe.

The delay time (denoted as *t*) of the braking system is responsible for the second part, the system delay distance (denoted as s_d). The system delay distance depends on the speed (denoted as v_{ego}) and the maximum deceleration (denoted as a_{dec}). The delay time varies between different vehicle types and is the time for the brakes to achieve full deceleration. Therefore, a worst case analysis was required to cover different brake types and to be scalable for different types of equipment. The relationship is presented in the following equation:

$$s_d = \frac{a_{dec}}{6} t^2 + v_{ego} t$$

The braking distance (denoted as s_b) is solely dependent on the speed and maximum deceleration a_{dec}. Its effect is to increase the size of the warning zones automatically between low and high speeds, given by the following equation:

$$s_b = \frac{v_{ego}^2}{2a_{dec}}$$

5.3 The Advantage of Measuring Detail

It is the high degree of detail the laser scanner is able to capture from the vehicle's surrounding environment coupled with the advanced algorithms used to process and meaningfully display the captured data that leads to high operator acceptance of the system. The ability of the system to assess the situation before a collision is likely to occur and to process and present the data in a detailed real time visual view have been found to be key to system acceptance. As a further example, the system's reverse assist mode automatically switches to a detailed rear view that offers operator's a visual guidance function while reversing onto walls or crushers (see Figure 6).

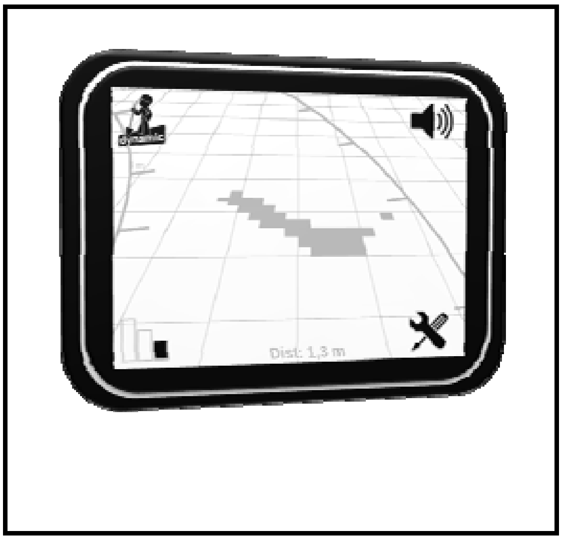

Figure 6 Operator display: reversing mode

5.4 SICK Laser Scanners in the Field

Some field applications where SICK long range dynamic-measuring and ranging scanners (LD-MRS) have demonstrated their robustness include:

- ship-loader automation systems at two terminals located at Dampier – Parker Point
- adoption by CSIRO and CRCMining for surface profiling applications in open cast mines, e.g. stock piles, rolling stock, and shovel and dragline automation;
- the remote underground LHD systems mentioned earlier where SICK laser scanners profile the drive walls and deliver an autonomous steering function; and
- collision avoidance trials conducted at two open cast coal mines in South America on excavators, wheel loaders and haul trucks.

Lessons learnt from field trials have resulted in the simplification of the operator's display, more advanced operator assistance, and improved filtering algorithms against the effects of dust, rain, fog and snow as discussed earlier in this paper.

6 Conclusion

SICK's laser scanners are proven to be reliable in applications with harsh weather conditions and dusty environments. Their capability has been demonstrated on a range of mining equipment for autonomous operation, proximity detection and collision avoidance. The next development stage will be the establishment of a proximity detection system suitable for use in underground coal mines.

7 Acknowledgement

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References

[1] S.L. Bell, “Message from the Commissioner for Mine Safety and Health”, Queensland Mines and Quarries, Safety Performance and Health Report 2008-09.

[2] D. Anderson “Laser Based Guidance for Underground Mobile Mining Equipment”, First International Design for Extreme Environments Assembly, November 1991.

[3] A.C. Love and R.F. Randolph “Radio remote control continuous miner operator positioning”, New Technology In Mine Health And Safety, February 1992.

[4] http://www.darpa.mil/grandchallenge/index.asp