The evaluation of laser guidance systems for use on a self escape vehicle after an underground mine explosion.

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ABSTRACT

In the aftermath of an underground explosion there will be vast amounts of smoke and dust in the air. Such conditions make it very difficult for the driver of a vehicle to “see” where to drive. In order to assist the driver to drive the vehicle out of the mine safely a navigation system needs to be fitted to the vehicle.

This paper presents the test methods and results of the evaluation of laser systems for use as a navigation system in the harsh environment after an explosion.

BACKGROUND

One of the basic/classical uses for lasers is distance measurement. The time between a signal being transmitted by a source and received by a detector is used to calculate the distance. The initial most notable application of a laser was made on the lunar ranging experiment of the Apollo II Mission of 1969 when an array of retro reflectors was mounted on the surface of the moon and pulses from a ruby laser were sent from earth. The reflected beams were received by suitable detectors and by measuring the time taken by the pulses in going from the earth to the moon and back, the distance from the moon to the earth was calculated to an accuracy of 15cm. This basic use of a laser will only give an indication of the presence of an object, i.e. one dimensional observation.

SICK has developed the technology further to detect objects in two and three dimensions. This is achieved using rotating mirrors or multi pulse systems. Two of these scanners systems were evaluated, i.e. the LD-MRS and the LMS Series of scanners.

The best summary to describe the difference between the basic application of lasers and the sensor systems SICK developed is the following quote from SICK. With the old systems “*if you can’t see it the laser can’t see it*”, with their new sensor systems you can “*look through rain, fog, snow, dust*”.

LMS Series Scanners

These laser scanners collect and evaluate up to five echoes per transmitted laser pulse (see Figure 1). Once the echo reaches the photo diode receiver in the scanner, the received intensity is transformed into a voltage. A reflected echo of a glass pane yields a low voltage over a short period of time as does the echo of a rain drop. However, the echo of an object yields a high voltage over a longer period. Different detection thresholds allow for a separation and classification of these echoes. The lowest threshold voltage separates the system noise from the relevant reflections. All five echoes are generated by reflections of a single transmitted pulse. The LMS Laser Measurement Sensor scans the surrounding perimeter on a single plane and measures in two dimensional radial coordinates. If a laser beam emitted is reflected from a target object then the position of the object is given in the form of distance, direction and angle. The measuring scanner collects the laser pulse reflections, processes the information, classifies the reflections and issues the data. The process is illustrated in Figure 1.

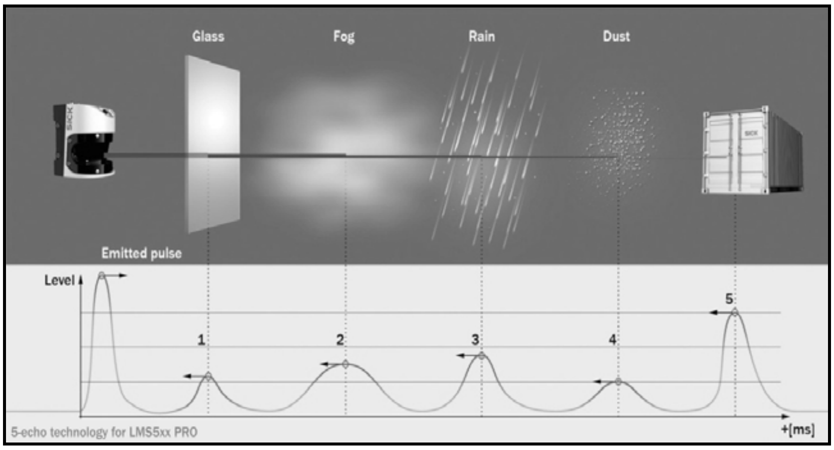

Figure 1

LD-MRS Scanners

The scanner was developed by Ibeo for use on vehicles, to cope with harsh environments, for example rain, dust, fog and snow. The vehicle's pitching motion posed a challenge to sensors installed on a vehicle. An incorrect measurement can easily occur, for example, if a measurement is taken as a tire hits a pothole. The system could lose sight of relevant objects as a result (Figure 2).

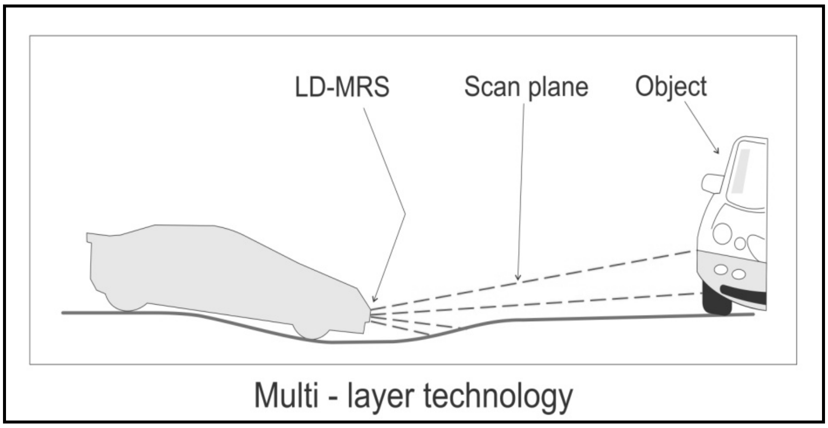

Figure 2

To prevent objects remaining undiscovered SICK is using a four layer technology in their most advanced laser scanners. These scanners measure simultaneously with four layers – which are important to compensate for the pitching movement of equipment or to detect slopes, cliffs, potholes, rocks and ditches. 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 allows pitching of the vehicle, caused by an uneven surface or driving manoeuvres such as braking and accelerating, to be compensated for. The principal is demonstrated in Figure 3.

EVALUATION PROCESS

To comply with requirements, previously identified, the navigation system had to comply with the following specifications. The specifications were set as the base line for testing of the different laser systems:

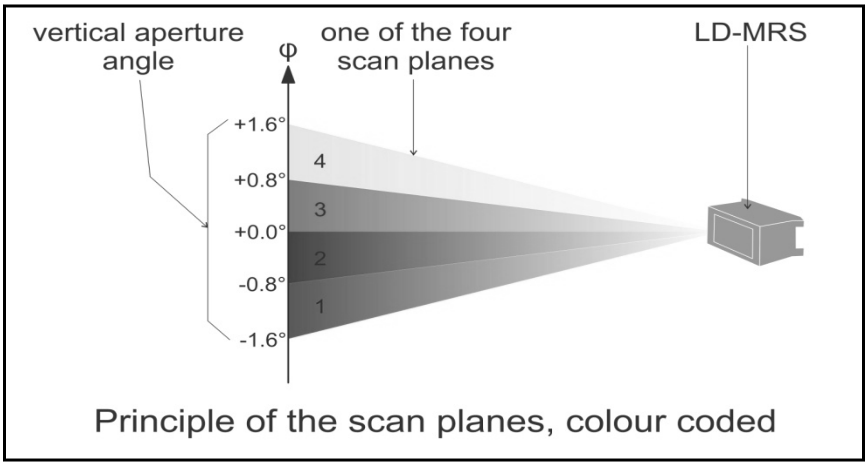

Figure 3

Testing Specifications

i. The system had to detect objects at a distance of 30 m. This would allow the vehicle travelling at 10 km/h to stop in time.
ii. The system had to operate in dust and smoke. The dust had to be small (micro meter range) to allow it to be suspended in air and simulate the dust that would be expected in the air after an explosion; larger particle sizes would fall out quickly. The smoke simulated had to be black (belts & oil) and white (wood). It was felt that the use of theatrical smoke was not appropriate as it would not contain the heat element usually associated with the smoke from fires.
iii. The targets the laser had to detect were a rock shape about 0.5 m high (Figure 4) and a human, height 165 cm (Figure 5).
iv. The laser systems had to be able to operate in an explosive atmosphere. To achieve this it was decided to mount the laser system in a flame proof enclosure. To simulate this, the lasers were tested from behind a lexan window. The type of window was tested in flameproof enclosures before.
v. The cost of the system had to be less than the cost of a vehicle and it should be a off the shelf solution.

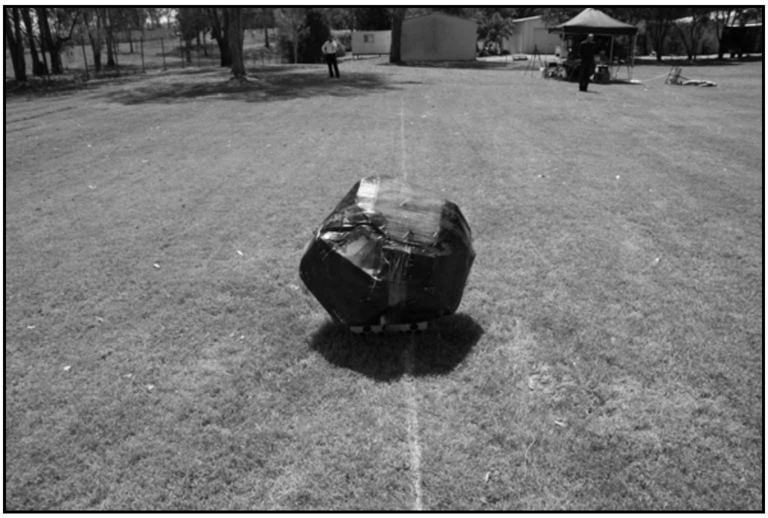

Figure 4 Rock shape "Rock"

Test setup and methods

To address the specifications, three test areas were setup. The first area (Open air) was used to investigate the effect of the lexan window on the performance of the lasers. The second area (Shed) was setup to evaluate the performance of the lasers in smoke. The last area (Container) was prepared to determine the performance of the lasers in a dusty environment. The three areas are discussed in more detailed below:

Figure 5 Average human "Fred"

i. ***Open Air.*** A 40 m x 40 m square grid pattern, marked in 1 m squares, was marked on a flat open area. The targets were mounted to a skid, to which ropes were attached. Using two operators allowed movement of the skid in a forward and reverse direction, allowing positioning on each cross point on the grid. Once the targets were at a reference point a reading was taken and the targets moved to the next point. This process was repeated for all the reference points on the grid.

ii. **Shed.** These tests were conducted in a 33.5 m x 7 m x 2.7 m shed. In the shed 4 tracks, 1 m apart, were mounted on the floor. Some of the existing infrastructures were left in the shed. The whole area was enclosed to minimise the amount of smoke escaping during the testing. Castor wheels and guides for the tracks were attached to the skid. The rope was used to move the skid, with the targets, along the tracks. The targets were moved along the tracks and observations recorded at 1 meter intervals.

    White smoke was generated by burning wet wood and smothering the fire when it turned into a fire consisting mostly of flames. The black smoke was the result of burning a diesel and petrol mix. Testing was conducted with the lights in the shed switched on and off.

iii. **Container** Three hi-cube shipping containers were joined and sealed, resulting in a 36 m x 2.5 m x 2.9 m area. The dust testing was undertaken in this area. A single track was mounted in the centre of the containers, for the skid to move along. At the end of the containers an EXIT light was placed on the floor. At the same location a "C" (450 mm x 350 mm) marked on a cardboard and illuminated by 2 cap lamps were installed for some of the tests**.**

    Coal dust with a mean particle size of 25 μm and a concentration of 60 g/m³ were used for the test. Dust trays were suspended from the ceiling of the containers and were operated by a carrier pipe which could be rotated to invert the trays and drop coal dust. Air pipes were setup on the floor at each side of the container. The air pipes carried air from a compressor at a pressure of approximately 120 psi. The air was used to thoroughly mix, and keep the coal dust particles suspended for the length of each test. Both the targets were used and moved along the track. Observations were made at each meter along the track.

RESULTS AND DISCUSSIONS

Open Air

The aim of the tests was to determine whether the laser detected the targets at each of the reference points on the grid. The process was repeated with and without the lexan window.

The first testing was with the LMS151 laser. In both instances, with “Fred” and the “Rock” as targets, there was a dead band in front of the sensor. As this is the area of interest for use on the escape vehicle, it was, therefore, decided not to further investigate the LMS151 for use with a lexan window, smoke and dust.

The LMS511 HR was evaluated with and without the lexan window. The results with “Fred” as the target are presented in Figure 6. The larger area is the result without the lexan window and the smaller area is the result with the lexan window in front of the laser.

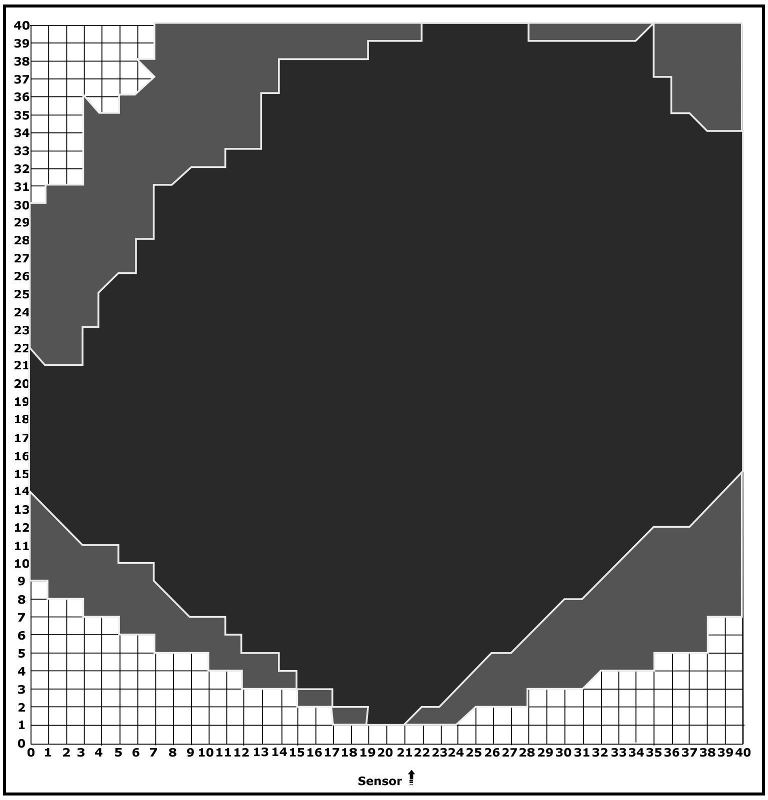

Figure 6 LMS511 HR; Lexan, "Fred"

Simular detection patterns were recorded from testing with the “Rock” as the target and using the LMS511 SR laser with both targets.

Based on the result that there were not large differences between using the lexan window and not using the lexan window, it was decided to use the lexan window in all the remaining evaluations and not continue testing without the lexan window. This resulted in reducing the testing time.

The detection patterns measured for the LD-MRS laser, from behind the lexan window, with both targets, was simular to those measured for the LMS511 laser.

Shed

All the tests in the shed were conducted with the lasers mounted behind the lexan window. The first series of tests was to determine the effect of florescent lights on the performance of the lasers. Results obtained for the LMS511 laser with “Fred” as the target and the light on are presented in Figure 7. Results recorded for the same measurements except the lights turned off are presented in Figure 8. Using the “Rock” as a target the measurements were repeated and are presented in Figure 9 and Figure 10. The same trend was recorded for tests with the LD-MRS laser, for both targets.

The outcome of this series of tests proved the lights did not have any influence on the performance of the lasers.

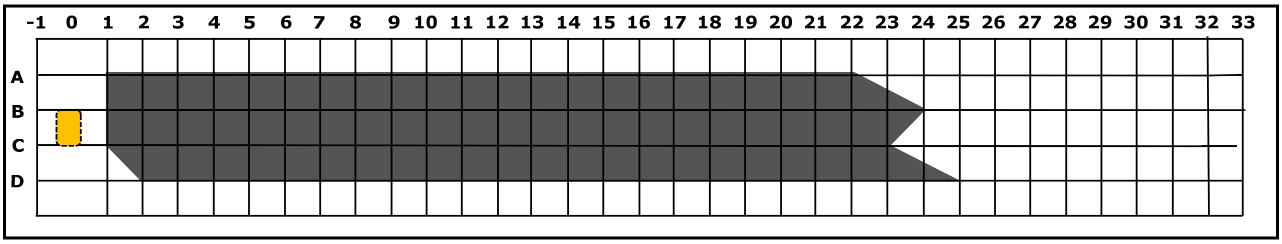

Figure 7 LMS511 "Fred" Lights On

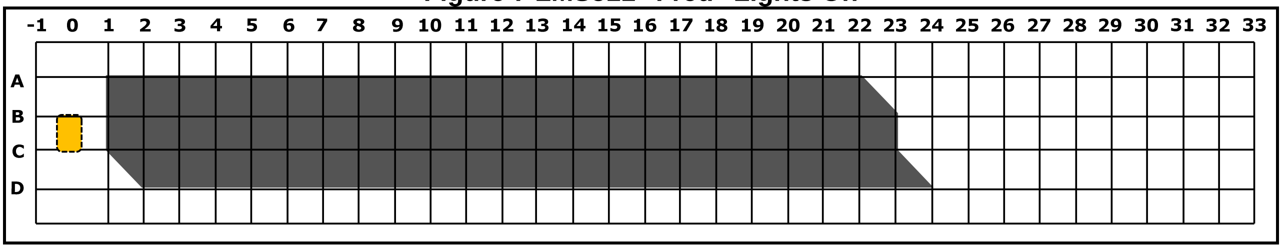

Figure 8 LMS511 "Fred" Lights Off

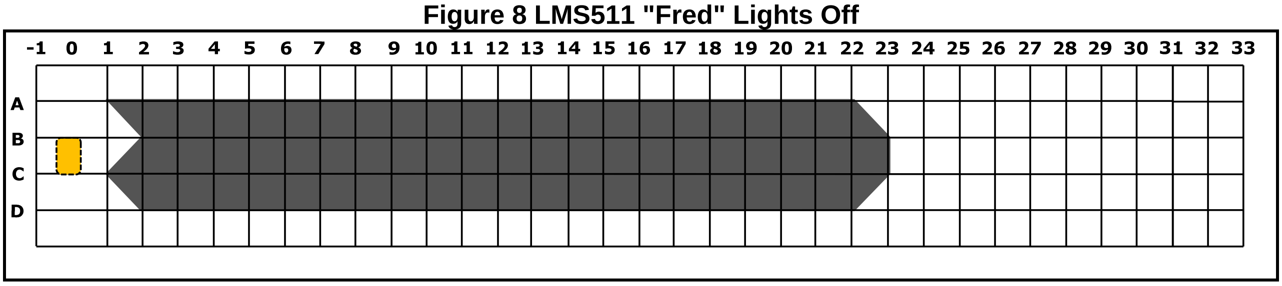

Figure 9 LMS511 "Rock" Lights On

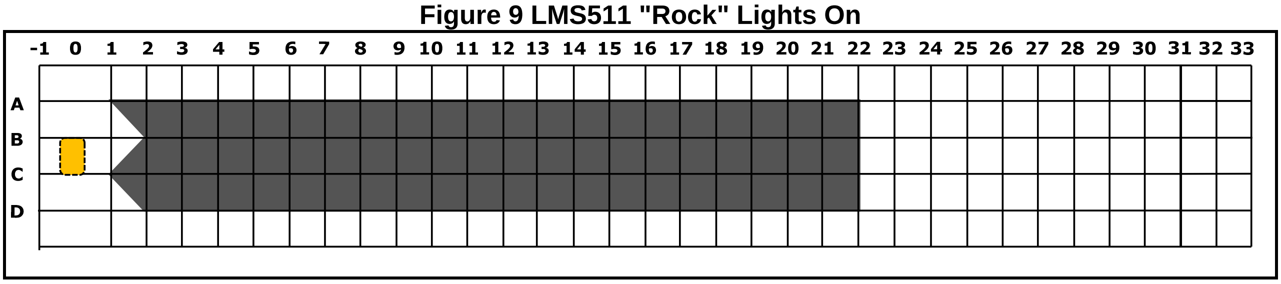

Figure 10 LMS 511 "Rock" Lights Off

The second series of tests in the shed was to determine the effect of "white" and "black" smoke on the performance of the different lasers. Results of the testing for the "Lights On" were used as the "reference" pattern for the smoke testing. Smoke, white and black was generated at one end of the shed. The smoke generation continued until the smoke started leaking from the opposite end of the shed. In addition the image from a video camera installed in the shed was used to determine the density of the smoke. The measurements was started when the video image was limited. Targets were moved along the tracks and the results recorded at 1 meter intervals.

The results for the LMS511 laser and "Fred" as target, are presented in Figure 11. The figure contains the reference (largest grey area), white smoke (light grey area) and black smoke (small dark grey area) results.

Results along the "D" track, for the white smoke test, could not be recorded as the connection to the laser was damaged when moving the sled from the "C" track to the "D" track. With the shed filled with white smoke the detection range of the LMS511 laser (light grey area) slightly reduced compared to the reference range. Black smoke, (small dark grey area) however, considerably reduced the detection distance of the LMS511 sensor. The distance was reduced from 24 meters to approximately 5 meters.

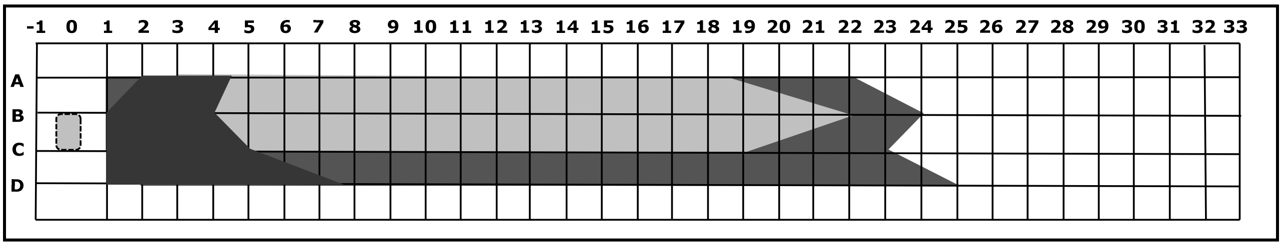

Figure 11 LMS511 "Fred" Reference Test, White Smoke, Black Smoke

The results for the LMS511 laser and the "Rock" as target, are presented in Figure 12. In the figure the reference, white smoke and black smoke are presented.

The detection range of the LMS511 laser (light grey area) slightly reduced a few meters compared to the reference range. Black smoke, (small dark grey area) however, considerably reduced the detection distance of the LMS511 sensor. The distance was reduced from 23 meters to approximately 4 meters.

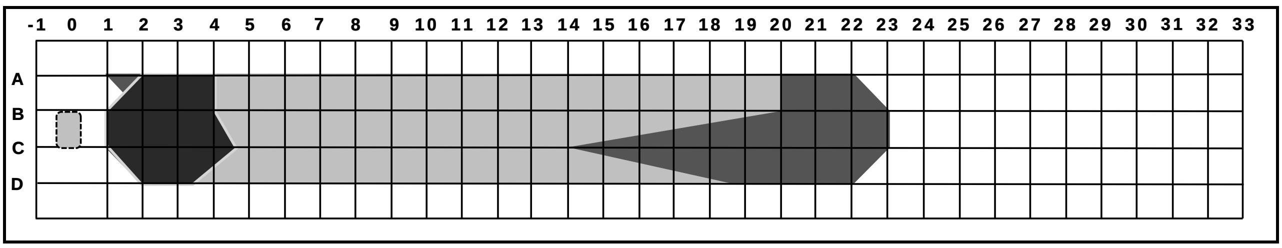

Figure 12 LMS511 "Rock" Reference Test, White Smoke, Black Smoke

Results obtained using " Fred" as a target and the LD-MRS laser is presented in Figure 13. With the large grey area as the reference, white smoke the light grey area and black smoke the small dark grey area. The detection range of the LD-MRS laser reduced from 30 meters down to 18 meters in the white smoke. With the black smoke the range reduced even further down to 4.5 meter. No results were recorded along the "D" track as the electrical connection to the laser was damaged when moving the skid from track "C" to track "D".

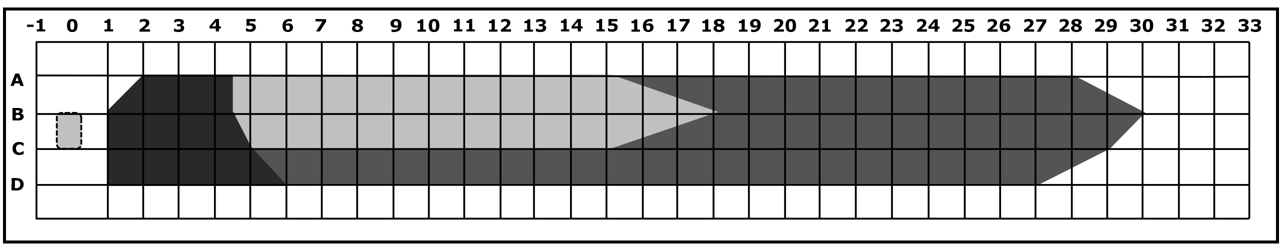

Figure 13 LDMRS "Fred" Reference Test, White Smoke, Black Smoke

The results for the LD-MRS laser and the "Rock" as target, are presented in Figure 14. In the figure the reference is presented by the large grey area, the white smoke by the light grey area and the black smoke is presented by the small dark grey area.

With the white smoke in the shed the detection range of the LD-MRS laser and the “Rock” as target (light grey area) reduced from 28 meters to about 14 meters. Black smoke, (small dark grey area) further reduced the detection distance of the LD-MRS laser to approximately 3 meters.

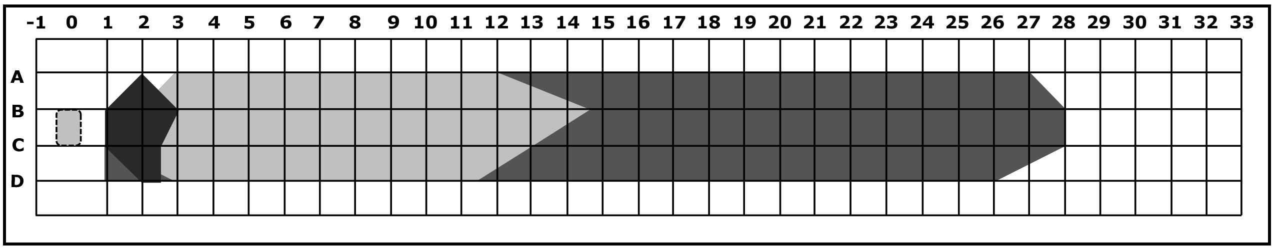

Figure 14 LD-MRS "Rock" Reference Test, White Smoke, Black Smoke

Containers

Testing of the lasers was conducted from behind the lexan window. As with the previous two series of tests a reference pattern was established for each laser type and the two targets, "Fred" and the "Rock". The targets were moved along the track on the floor and measurements recorded at 1 meter intervals. As a result of space limitations only one track was used in the containers.

Figure 15 is the reference obtained with the LD-MRS laser and “Fred" as the target and Figure 16 the reference with the “Rock” as the target.

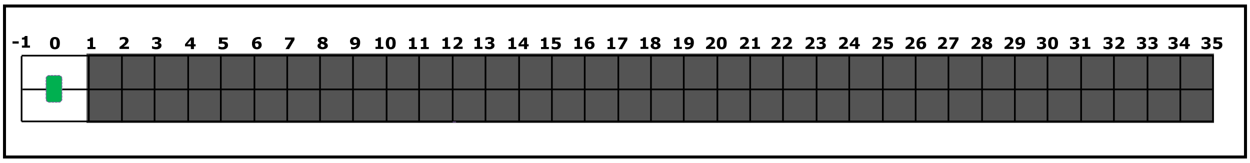

Figure 15 LD-MRS "Fred" Reference Test

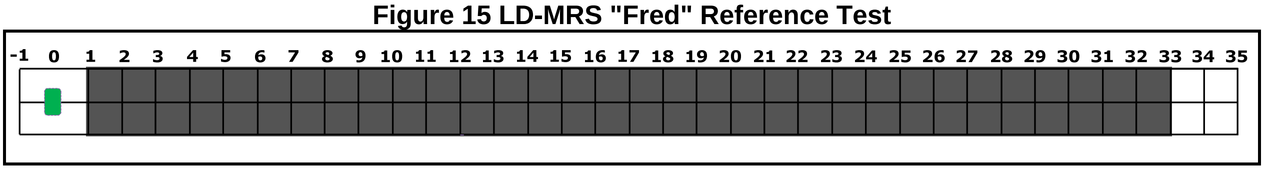

Figure 16 LD-MRS "Rock" Reference Test

References patterns measured with the LMS511 laser and the two targets are presented in Figure 17 and Figure 18.

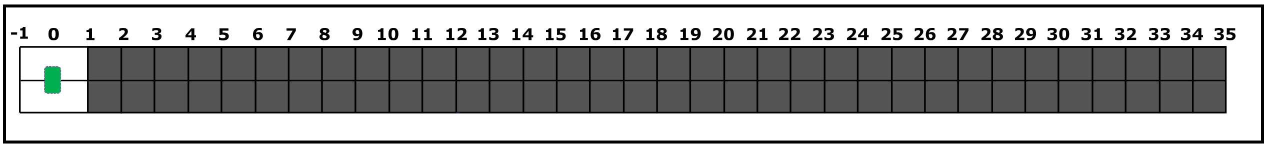

Figure 17 LMS511 "Fred" Reference Test

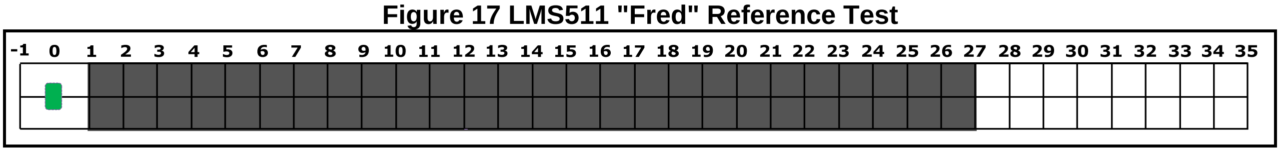

Figure 18 LMS511 "Rock" Reference Test

The same reference patterns, for both targets and lasers, were measured when the EXIT light and the illuminated "C" was installed at the end of the containers.

Measurements for test with the LMS511 laser and "Fred" as target in dust filled containers are presented in Figure 19. Results with the EXIT light and illuminated "C" is presented in Figure 20.

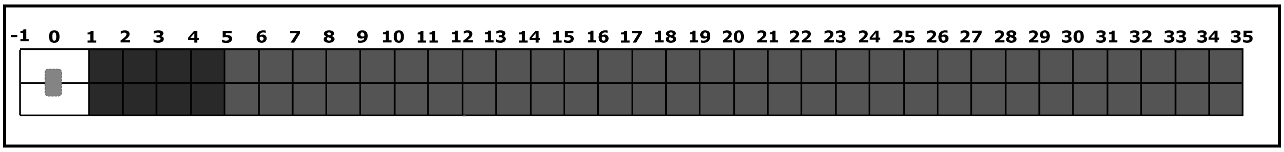

Figure 19 LMS511 "Fred" Reference Test and Dust

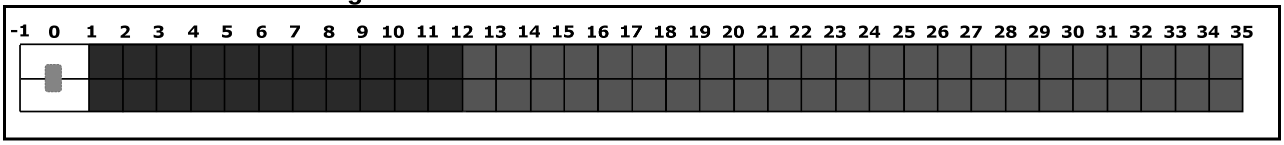

Figure 20 LMS511 "Fred" Reference Test, Dust, EXIT light +"C"

Results of testing the LD-MRS laser with "Fred" As target in the dust filled containers are presented in Figure 21 and Figure 22

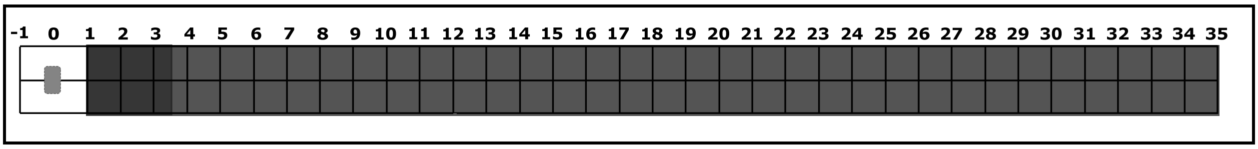

Figure 21 LD-MRS "Fred" Reference Test and Dust

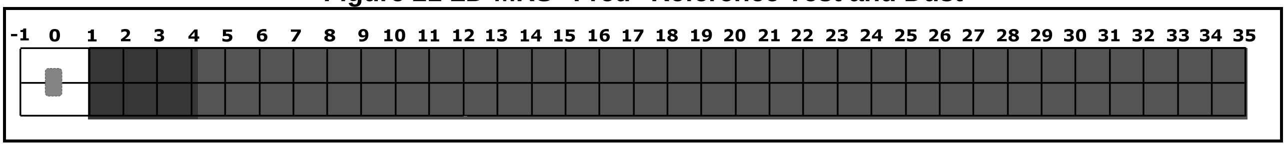

Figure 22 LD-MRS "Fred" Reference Test, Dust, EXIT light +"C"

Using the “Rock” as a target and the LMS511 in the dust filled containers the results in Figure 23 were measured. Adding the EXIT light and illuminated "C" resulted in the detection pattern presented in Figure 24. The results from tests under the same conditions but using the LD-MRS laser are presented in Figure 25 and Figure 26.

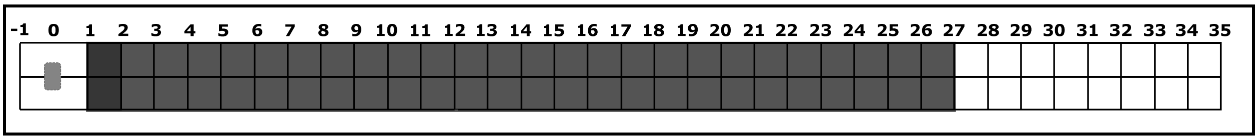

Figure 23 LMS511 "Rock" Reference Test, Dust

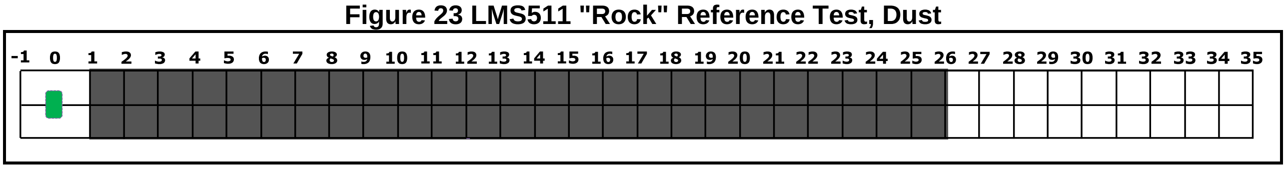

Figure 24 LMS511 "Rock" Reference Test, Dust, EXIT light +"C"

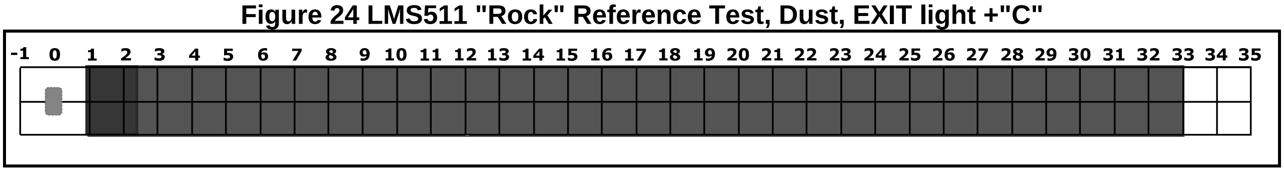

Figure 25 LD-MRS "Rock" dust

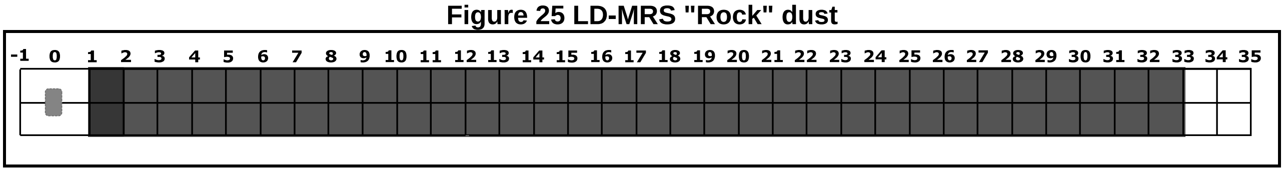

Figure 26 LD-MRS "Rock" Dust, EXIT light + "C"

Without any dust both the lasers could detect “Fred” at a distance of 35 m. With the "Rock" as target the reference distance reduced to 33 meters for the LD-MRS laser and 27 meters for the LMS511 laser. With "Fred" as the target and in the dust filled containers the detection range of the LMS511 laser reduced by 30 meters to only 5 meters and for the LD-MRS it reduced even more to only 3.5 meters. When the EXIT light and illuminated "C" was installed at the far end on the containers the detection distances were not as severely effected as the LMS511 reached a distance of 12 meters while the LD-MRS reached 4 meters. When the "Rock" was used as target the LMS511's detection range dropped down to 2 meters and 0 meters when the EXIT light and illuminated "C" was added. With the LD-MRS laser the detection distance reduced to 2.5 meters and when the EXIT light and illuminated "C" was added it reduced to 2 meters.

CONCLUSIONS

Open Air

- Both targets, “Fred” and the “Rock,” were detected with the lasers evaluated The distance of 30 m, as specified, were obtained from behind the lexan window. This would allow for the laser sensors to be mounted in a flameproof enclosure with a suitable lexan window.
- The LMS 151 laser had a area in front of the laser where it could not detect the targets, it is therefore not suitable for this application.
- The basic detection field of the lasers were “V” shaped with the viewing angle more than 90˚.

Shed

- The Lights in the shed did not influence the performance of the lasers.
- With no smoke generated in the shed the lasers could detect the targets at the maximum distance of 31.5 m.
- With the white smoke, using wood, the sensors detected the targets at a distance of approximately 18 m, with the lights having no effect on test results.
- In the black smoke the sensors could only detect the targets at a distance of approximately 5 m, the lights having no effect on the detecting capabilities of the lasers.

Container

- Without any dust in the container the lasers detected the targets at the specified length of 30 meters.
- The dust reduced the detection range of the laser to only a few meters.

ACKNOWLEDGEMENT

The authors would like to thank Tim Seymour, working for the SICK Australia, for his effort and assistance with the testing of the different lasers and providing information on the technologies used in the laser systems.