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Impact of Reduced Visibility Conditions on Laser-Based DP Sensors

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Abstract

The traditional view of use of DP sensors in reduced visibility conditions is that radar and inertial based sensors work well in these environments and the laser based sensors do not. In extremely bad conditions this is true. In lightly to moderately reduced visibility we must understand the impact of the fog on the performance of a laser based DP sensor. With a variety of targets at 60m we demonstrate operation in heavily reduced visibility and we show the visual appearance of these environmental conditions. We have also modelled some specific use requirements and evaluated how a system will perform in those environmental conditions with differing types of targets. We consider extensions of this modelling to other adverse weather conditions. We will finish by evaluating prism targets on the basis that they are for use in reduced visibility environments rather than the more usual evaluation on the basis of extended range.

Introduction

In the DP industry, there is a widely held belief that laser sensors do not work in foggy conditions. Whilst other LIDAR sensors have had detailed studies on how they function in degraded visibility conditions [1] an equivalent work for laser based DP sensors is not available.

The meterological definition of foggy covers a wide range of visibilities (See table 1) This work was driven by the desire to properly understand the performance of a laser based DP sensor in fog so that users could better understand where their system should and should not work.

Visibility	**Description**
Less than 40m	Dense fog
40m to 200m	Thick fog
200m to 1000m	Fog
1km to 2km	Mist (if mainly due to water droplets) Haze (if mainly due to dust or smoke particles)
2km to 4km	Poor visibility
4km to 10 km	Moderate visibility
10km to 40km	Good visibility
Over 40km	Excellent visibility

Table 1 – Visibility descriptions

In order to test the effects of the differing means by which fog will interact with the range measurement the potential effect vectors were analysed individually.

Smoke release testing

A laser based position reference system comprises a sensor which is mounted on the vessel and retroreflectors which are mounted on the target installation. In operation the sensor monitors the distance to the retroreflectors.

To test over representative distances of close approach of a PSV (Platform Support Vessel) we utilised a large space in which we could generate and measure atmospheric attenuation. Generating atmospheric attenuation was accomplished by use of a smoke machine. Data gathered from is used to verify given models and predict performance at longer ranges.

Smoke machines operate by heating a chamber containing a volatile liquid which evaporates and is then pushed out into the atmosphere. The sudden change of temperature causes the formation of a fog. The liquid may be either glycerol based or oil based. Oil based systems produce a smaller particle size leading to a much lower settling velocity [2] and hence a more persistent smoke. In order to present an uniform atmospheric condition for the sensor system along the length of the beam, the smoke was released away from the measurement path and allowed to spread throughout the volume.

To quantify the fog level we are using a forward scatter technique to measure Meteorological Observable Range (MOR.) Measurements of this were taken on a Campbell Scientific CS120 [3]. This device has two arms angled at 42^{o} from one another. One of the arms contains a collimated LED. The other contains a photodiode collimated such that there can be no direct path from the LED to the detector. The only path is via scatter from something in the air between the arms.

Two types of reflective target were used. The distance to the targets is given in table 2 below.

The first type is a cylindrical tape target, physically 850mm long and 160mm diameter, with a 760mm long active area. This was chosen as it is representative of the lowest performing targets recommended for use in DP operations.

The second type was an 8-way fixed prism cluster. This consists of a number of corner cube prisms mounted in a fixed pattern. This is representative of the highest performing targets typically used in DP operations. In conjunction with the CyScan system this is capable of navigation at 2500m in best conditions with this target.

Target	Range
0.85m Cylinder	57.0m
Prism cluster (8 prisms)	56.7m
0.85m Cylinder	32.8m

Table 2 – Target distances

The laser based DP sensors were CyScan4 systems. A single sensor was operated normally. A second sensor was modified to operate without scanning and with the signals from the analog front end viewed on an oscilloscope. The modified sensor was pointed at the closest target.

Results

The sensor system was switched on and the automatic laser power control allowed settling time. In order to see all the reflectors in clear air the laser was run at 2% power.

The smoke machine was activated at the far side of the hangar and the smoke was allowed to spread through the volume of the building. As the smoke cleared the visibility readings were recorded along with the required laser power to see the scene and the signal intensity recorded by the CyScan. The results are recorded in table 3 below.

Visibility	Laser power	Returned signal intensity

		Near cylinder	Far cylinder	Prism
20m	100%	94%	-	45%
25m	47%	90%	-	41%
31m	22%	92%	6%	72%
40m	11%	92%	7%	80%
45m	10%	90%	7%	85%
50m	9%	90%	8%	90%
60m	5.9%	85%	6%	80%

Table 3 – Laser power and intensity as a function of visibility

Comparison to attenuation model

There are various models for the attenuation due to fog. The Kruse model [4] is given by:

$$Attenuation = \frac{13}{V}\left(\frac{\lambda}{\lambda_0}\right)^{-q}$$

Where:

V = Visibility in km
λ_0= 550nm
q= $0.58V^{1/3}$ for V < 6km

The attenuation is given in dB/km

The Kim [5] model is a later extension to the Kruse model to improve the match to attenuation data at low visibilities and is given by:

$$Attenuation = \frac{13}{V}\left(\frac{\lambda}{\lambda_0}\right)^{-q}$$

Where:

V = Visibility in km
λ_0= 550nm

V	Q
1km < V < 6km	0.16V + 0.34
0.5km < V < 1km	V – 0.5
V < 0.5km	0

Table 4 – Kim attenuation model coefficients

The “French Telecom” model [6] is slightly more complicated as it provides two models for attenuation – one for advection fog and the second for radiation fogs. Advection fogs are formed by the movements of humid air interaction with masses of warmer air. These are typical of fogs in colder maritime regions. Radiative fogs are formed by ground cooling.

$$Attenuation_{ADV} = \frac{10}{ln(10)}\left(\frac{0.1148\lambda * 10^{-3} + 3.837}{V}\right)$$

$$Attenuation_{RAD} = \frac{10}{ln(10)}\left(\frac{0.1813\lambda^2 * 10^{-6} + 0.1371\lambda * 10^{-3} + 3.837}{V}\right)$$

Where:

V = Visibility in km
λ= Wavelength in nm

Key distances are the transition from fog to thick fog (at 200m visibility) and the transition from thick fog to dense fog (at 40m visibility)

Visibility	**Attenuation at 905nm Kim**	**Attenuation at 905nm, Kruse**	**Attenuation at 905nm, Naboulsi, advective**
200m	65 dB/km	63 dB/km	86 dB/km
100m	130 dB/km	129 dB/km	171 dB/km
40m	217 dB/km	215 dB/km	258 dB/km

Table 5 – Predicted laser beam attenuations for visibilities in the thick fog range

We can see that there are different attenuation values from the advective fog models compared to the Kruse and Kim models.

We can now consider validating the modes against the data. With a known distance to a target, we can estimate from the attenuation models what the power loss due to the fog should be and compare it to that which was found. Since we had a dry fog, we used the Kim attenuation model.

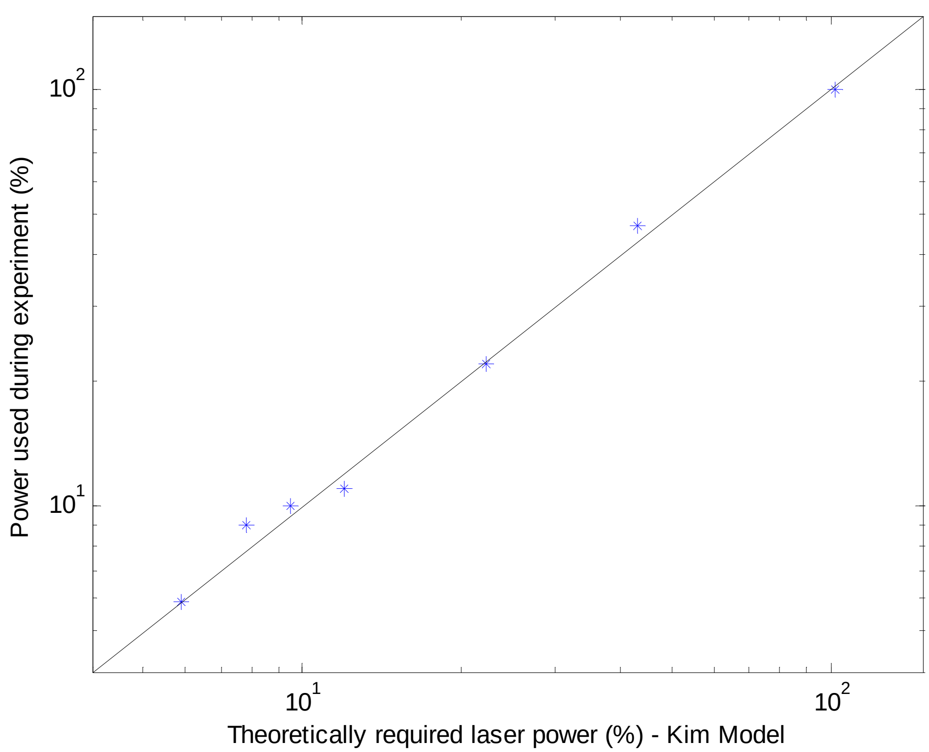

Figure 1 - Power used experimentally against model prediction

Performance limitation due to attenuation

A second system had been set up such that the electro-optical subsystem pointed permanently at one of the targets. The raw electronic signals from the system could then be monitored. The most relevant were the laser fire signal and the analog signal at the point where it enters the timing block

At the point where the system under test just lost the signal from the target our traces can be seen below. This comes from the closer (32.8m) small cylindrical target. The visibility at the point of losing the target was approximately 8m.

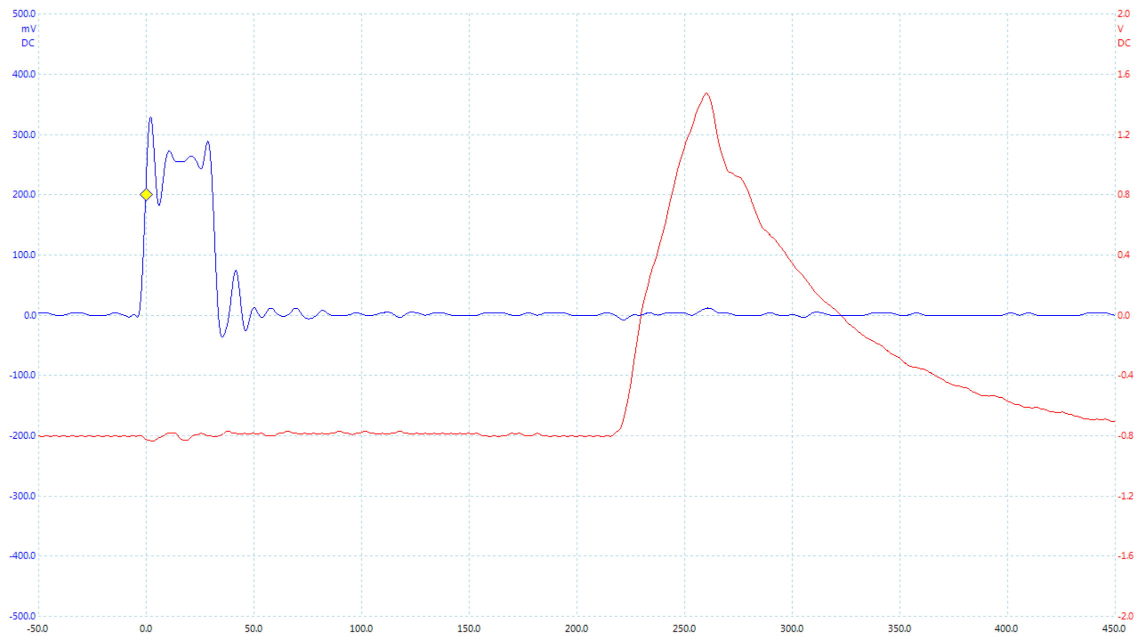

Figure 2 – Start pulse for laser pulse and returned analog pulse at the point of just losing reflector tracking on the closest target.

It is obvious that the returned signal is clear, with a high signal to noise ratio. However the system under test does not recognise this as a valid return. This is explained by looking at the clutter rejection systems of the system as a whole.

The CyScan system navigates on retroreflectors which have a high reflectivity. In order that returns from other objects are ignored there is pulse rejection based on distance and reflected power. Whilst we retained a signal that was obvious by eye as a return, it did not have sufficient power to be seen as a valid reflector signal. This validation of returns reduces the scene clutter which allows much better navigation in normal operation.

Rain

The effect of rain transmission of laser beams has been widely studied. [6] Rain produces much less attenuation in the visible and NIR region than fog effects. This is intuitively reasonable if one considers viewing distant objects on rainy days. Transmissions can be calculated for various conditions as showing in Table 6 [7]

Conditions	Rainfall (mm hr-1)	Transmittance of 1.8km path.
Light rain	2.5	0.88
Medium rain	12.5	0.74
Heavy rain	25	0.65
Cloudburst	100	0.38

Table 6 – Laser beam bulk transmittance through rain

Target wetting

In addition to bulk transmission effects in the atmosphere we must also take into account the surface effects which rain will cause on the surfaces which the laser beam is interacting with. We took a laser position reference system which was working in clear atmospheric conditions. Whilst the system was recording the returned power we applied a misting spray to the optical surfaces in turn.

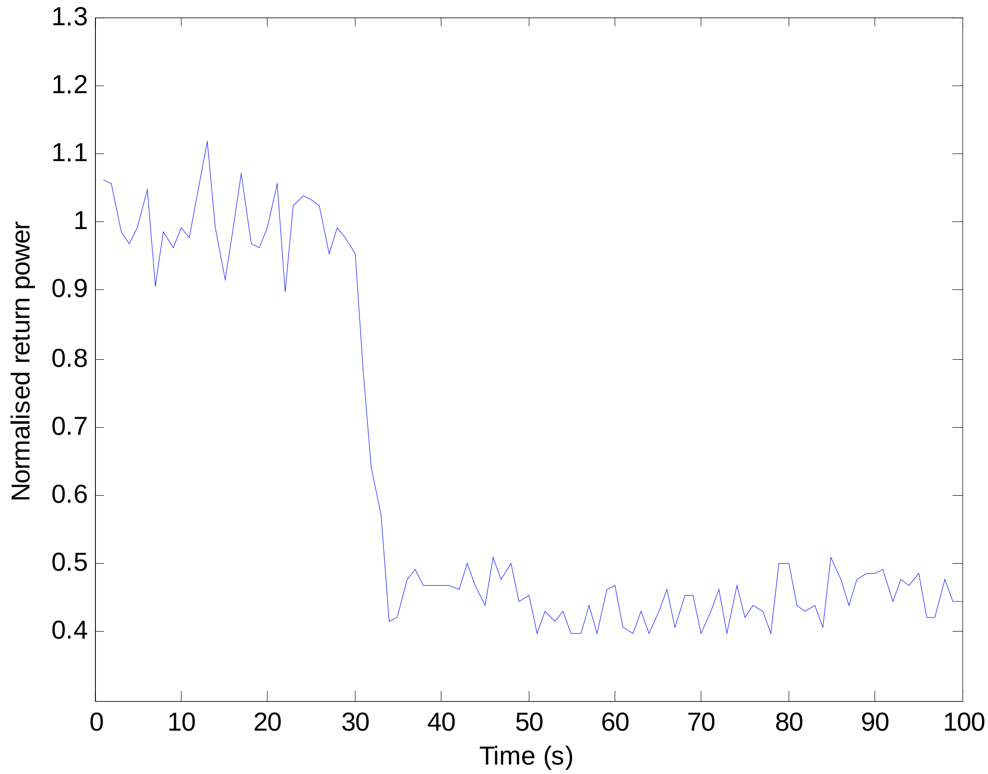

Figure 3 – Effect of wetting of the target

Loss due to target wetting = 55.3%, or 3.3dB

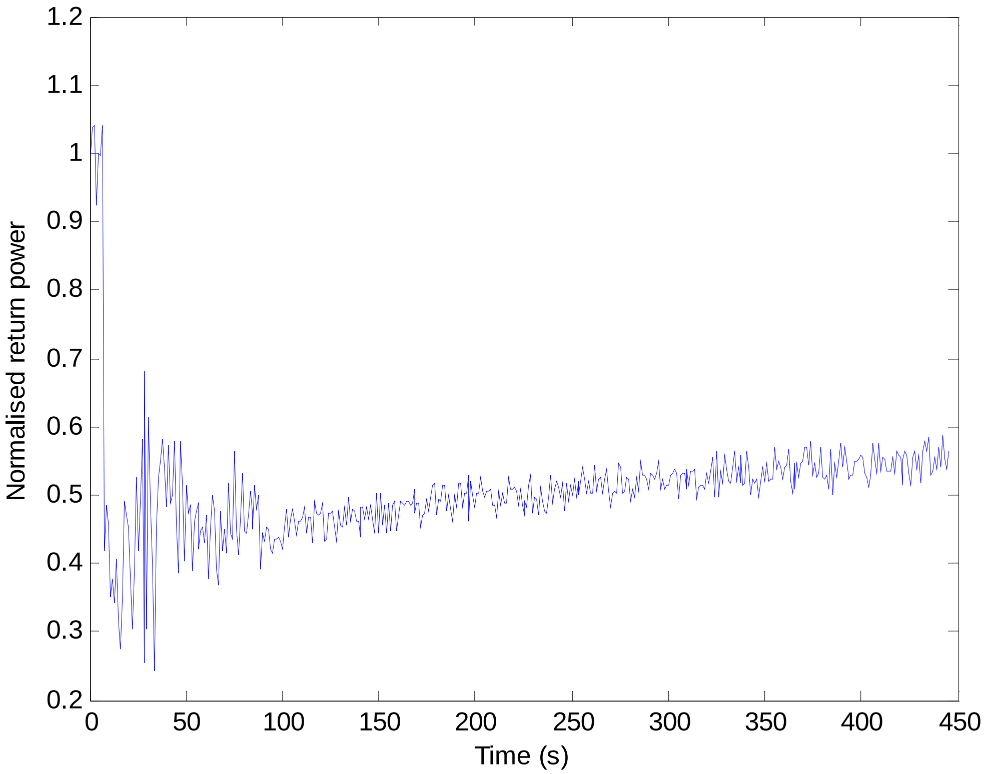

Figure 4 - Effect of wetting the sensor

Worst case power loss = 75.6%
Average loss during rain = 54.1%

Combining all these effects over a 1km target distance, we can estimate the total signal loss due to rain.

Condition	Worst case signal loss over 1km
Light rain	90.4%
Medium rain	91.9%
Heavy rain	92.9%
Cloudburst	95.9%

Table 7 – Signal loss in raining conditions including target and sensor effects

For a system with a reflector capable of maintaining 2.5km tracking in good conditions has a signal reserve of 2.5^4, and thus can continue to track at 1km with 97.44% additional loss.

Combined system performance

A crane operator on a rig should be able to see the full extent of the deck of the PSV that is holding position under the rig. In the event that this gives us a visibility of 100m, in the middle of the dense fog classification, then the CyScan system with a fully populated reflector cluster will see a reduced maximum range.

We also know the maximum ranges for our targets. At long range the returned signal drops with the 4th power of range. From this data we can work out what the effective range of the system is. At very close range this trend transitions to an r^3 dependence when the beam width undersamples the target.

We can calculate the expected range of the system by solving the equation

$$\left(\frac{r}{r_0}\right)^4 = \frac{P}{P_0}$$

$$4\,log_{10}\left(\frac{r}{r_0}\right) = log_{10}\left(\frac{P}{P_0}\right)$$

This is complicated as $\frac{P}{P_0}$ is a function of distance. Using the advective fog model, we have 171dB/km loss with a 100m visibility fog. We can insert this into the equation. Solving this equation numerically with a range in clear air of 2500m, we find an attenuated range of 240m. We can additionally modify this to include the effect of a wet target and a wet sensor, as shown in table 8.

If we start with a weaker reflector, such as a 0.85m cylindrical tape reflector, then the 100m visibility sea fog reduces the maximum range from 250m to 95m

Environmental conditions	**Range to reflector in a sea fog**	
	Fully populated (8 prism) cluster	**0.85m tape cylinder**
Clear, dry	2500m	250m
100m visibility, dry	240m	95m
100m visibility, wet system	133m	54m

Table 8 – Range to reflectors in good and degraded conditions

For all these results we have assumed that the targets and the sensor are in good condition and clean.

Conclusion

Range specifications of laser DP sensor systems are quoted under favourable weather conditions. The environment in which they are used is, however, often subject to much worse conditions. Such poor environments will reduce the range but the use of a bright target such as a prism cluster will provide the user with additional signal reserve which will allow the sensor to remain working.

References

[1] Trickey, Church, Cao, Characterization of the OPAL obscurant penetrating LiDAR in various degraded visual environments, *Proc SPIE 8737*, Degraded Visual Environments: Enhanced, Synthetic and External Vision Solutions (2013)

[2] Berne & Pecora, Dynamic Light Scattering, Dover (2003)

[3] http://www.campbellsci.co.uk/cs120 (Downloaded August 2014)

[4]Kruse et. al. *Elements of Infrared Technologies: Generation, Transmission and Detection*, Wiley, (1962)

[5] Kim, Mcarthur & Korevaar, Comparison of laser beam propogation at 785 and 1550nm in fog and haze for optical wireless communications, *Proc SPIE*, (2001), 4124, pp26-37

[6]Chu & Hogg, Bell Syst. Tech. J, 47, 723, (1968)

[7] R. D Hudson, Infrared Systems Engineering, Wiley & Sons, (1969)