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Laser Proximity Sensor for Fuel-air Explosive Bomb

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ABSTRACT

Present study deals with design and development aspects of a diode laser proximity sensor based on principle of optical triangulation. This sensor incorporates a laser transmitter and an optical receiver. The beam divergence of laser transmitter and look angle of receiver are oriented in such a way that they intersect at a predetermined measuring segment. The sensor can be set to give signal output at predetermined distance from the target. Theoretical studies have been carried out to determine the minimum power required for transmitter with a trade-off between S/N ratio, aperture of receiver optics, reflectivity of target and range requirement. The scattered laser radiation from the target in this segment is utilised in deriving a signal output to detonate the bomb at a predetermined distance from the target. The laser proximity sensor has been developed for 3 ± 0.5 m operational range and has qualified various environmental tests and live fuel-air explosive bomb trials.

Keywords: Laser proximity sensors, optical triangulation, fuel-air explosive bomb, laser-based triangulation sensors, photodiodes

1. INTRODUCTION

The introduction of laser-based triangulation sensor has revolutionalised the approach to the non-contact measurements. A well-defined divergence of laser radiation and field of view (FOV) of optical receiver makes the laser proximity sensors very difficult to jam. This type of sensor determines the position of a target by measuring the laser radiation reflected from its surface. A transmitter consisting of laser diode projects an infrared laser spot onto the target. The optical system receives and focuses the reflected laser radiation onto a light-sensitive device (avalanche photodiode) and the processing electronics gives an audio-visual/ pulse signal, if the target reaches within the preset range of the sensor.The present study deals with design aspects of an electro-optical proximity sensor, comprising a laser transmitter and optical receiver. A semiconductor diode laser constitutes the heart of the laser transmitter. The transmitter and optical receiver are oriented in such a way that the divergence angle of laser transmitter and FOV of the optical receiver interact at a predetermined fixed measuring section. The radiation reflected by target in this section is collected at receiver end for deriving the firing pulse. This principle, on which the laser proximity sensor works is called the optical triangulation approach (Fig. 1). Figure 2 shows the laser proximity sensor (LPS) developed at Instruments Research & Development Establishment (IRDE), Dehradun.

In optical triangulation technique, the laser transmitter, the optical receiver, and the target are

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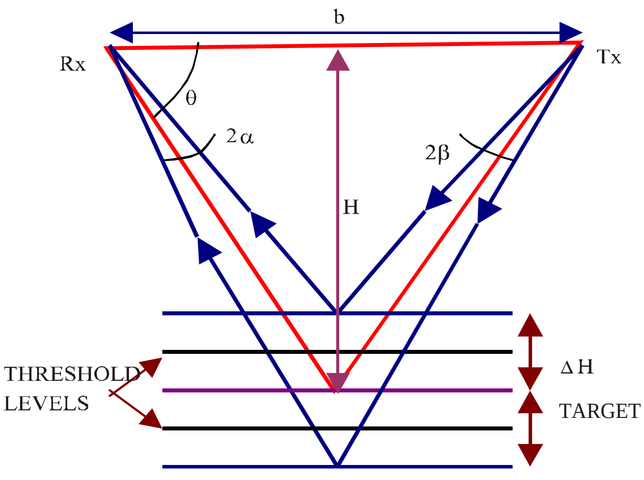


Figure 1. Principle of optical triangulation.

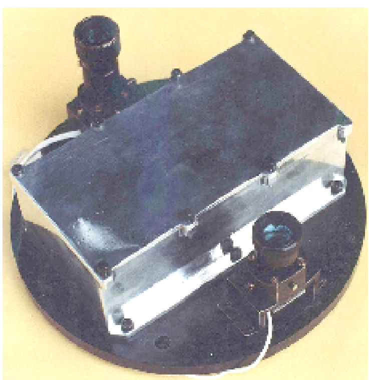


Figure 2. Laser proximity sensor developed for 3 ± 0.5 m range.

taken as situated on the three vertices of a triangle (Fig. 1). The divergence of laser transmitter and FOV of optical receiver are optimised in such a way that the receiver registers the signal only within a fixed predetermined range[3].

2. DESIGN CRITERIA

2.1 Laser Power Evaluation

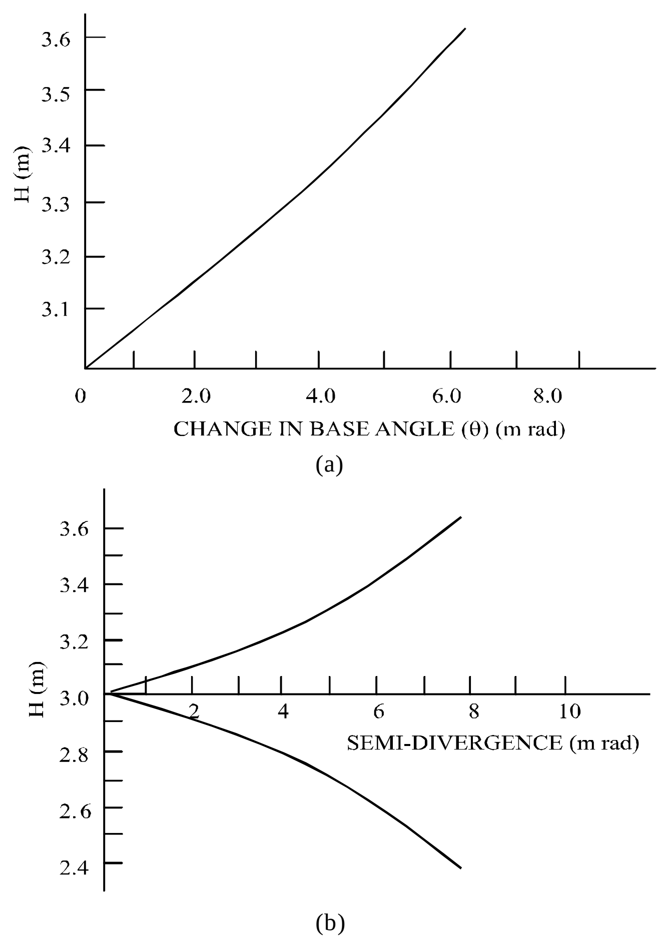
The choice of appropriate laser power plays significant role while designing the laser proximity sensor. The evaluation of required laser power is useful in the selection of a suitable laser diode for transmitter. Theoretical studies have been carried out to determine the minimum power required with a trade-off between S/N ratio, aperture of receiver optics, reflectivity of target for desired range.

The divergence of the *Tx* and FOV of *Rx* are mutually compatible such that the receiver receives a signal only within a predetermined range. The range *H*, base length *b*, FOV 2α, divergence 2β, base angle θ and variation in range Δ*H* are related by the expression

$$\pm \Delta H = \frac{b}{2}\left[\frac{2}{\cot(\theta \pm \alpha) + \cot(\theta \pm \beta)} - \tan\theta\right] \quad (1)$$

For a fixed base length *b*, the angle θ determines the optimal range *H*. The effect of variation in θ on the desired range has been worked out and is given in Fig. 3(a). Variation in the FOV/divergence angle (α/β) results in change in range of the LPF. The effect is shown in Fig. 3(b). The effect of change in base length on Δ*H* is shown in Fig. 3(c).

The formulation used to evaluate the required laser power[2] is



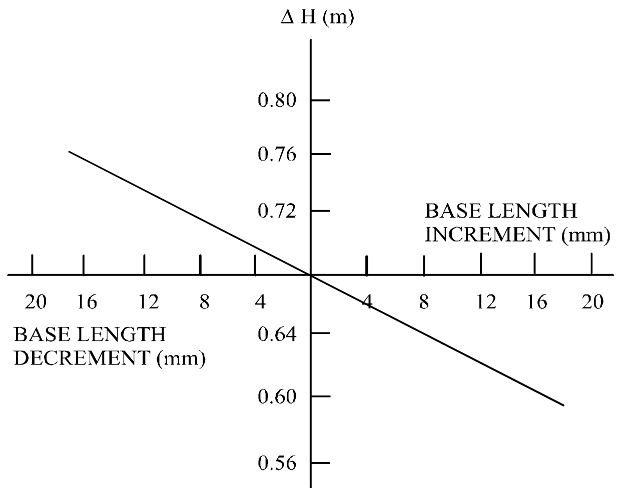


Figure 3. Variation in range with: (a) base angle, (b) divergence, and (c) base length.

$$P_L = \frac{4 P_S\, d^2\, e^{2\alpha d}}{T_t\, T_r\, T_x\, R_t\, D^2} \qquad (2)$$

Where,

P_s = Power received at detector surface (signal strength)

α = Atmospheric attenuation coefficient

D = Diameter of receiver optics

T_r = Transmission of receiver optics

T_t = Transmission of transmitter optics

T_x = Collection efficiency

R_t = Target reflectivity

d = Distance between target and transmitter

The signal strength is calculated using various factors such as S/N ratio and responsivity of detector at the receiver end.

2.2 Transmitter and Receiver Design

2.2.1 Transmitter Design

The laser transmitter consists of a laser diode as source and a beam shaping optical system to reduce the divergence of raw beam emitted by laser diode. The main advantages of using laser diode are its compactness, and light weight. Laser diodes are miniature sized as compared to solid-state and gas laser. Semiconductor laser diodes in single chip are now commercially available with high peak power of several watts. A diode laser of 905 nm wavelength with 13 W peak power has been used to design the laser transmitter of laser proximity sensor.

Semiconductor laser diode has inherently large divergence along two mutually perpendicular axes. The divergence of transmitted laser beam is a critical parameter as it is one of the factors determining the accuracy of sensor. The *f* number of optical system is selected by making the trade-off between the requirements of divergence and the power collected from laser diode and the acceptable complexity in design. A suitable collimating optics has been designed to reduce the divergence to ~ 4.0 milliradians (m rad). A suitable laser collimator has been designed taking into consideration the laser power, divergence, and size. The important parameters to be considered in design of the collimating optics are clear aperture, *f* number and divergence. The accuracy of laser proximity sensor that decides the triggering range within ± 0.5 m depends solely upon the base length, the divergence of transmitter optics, and the FOV of the receiver optics.

2.2.2 Receiver Design

Receiver system in the present study consists of a silicon avalanche photodiode (APD) as detector and an optical system. The scattered radiation from the target is collected by the optical system and focussed on APD detector. For higher collection efficiency, a larger-aperture optics is required together with shorter focal length in conjunction with appropriate junction size of the laser diode. The detector then reports the signal to the processing electronics. The system is designed by considering the active area of APD, look angle, and S/N ratio.

A suitable interference filter has been used before the detector to minimise the background radiation. In case of laser diode, the central wavelength is changed by temperature variation. Therefore, a tradeoff analysis has to be done between filter bandwidth and transmission requirements. The signal thresholding technique has been used to discard the unwanted noise in the present sensor. The output signal is generated after proper validation of the signal.

Laser radiation from the sensor are diffusely reflected from the target and the receiver collects the reflected radiation to give the output signal. The signal strength received at the receiver depends on the diffused reflectivity of the target. This makes the measurement of the diffused reflectivity from the target imperative.

An experimental setup was rigged up to measure the diffuse reflectivity of intended targets. The measured values of diffused reflectivity for objects like rough concrete, metallic sheet and green leaves were found in good agreement with the available literature[3]. However, small variations may be because of the quality of sample. The diffused reflectivity from other surfaces of interest can also be evaluated. Table 1 highlights the measured diffused reflectivity values for a few likely targets.

Table 1. Typical diffused reflectivity values for likely targets

Target	Diffused reflectivity (%)
Olive green colour metal sheet	11
Rough concrete	19
Stone	21
Dry soil	33
Olive green colour cloth	58
Green leaves	77
Green grass	82

3. RESULTS AND DISCUSSION

A short range laser proximity sensor has been developed and tested for static and dynamic lab and field trials. The sensor was mounted on the front of a fast moving vehicle (60-90 kmph) and a thermocol target was placed in front of it to simulate the target (Fig. 4). The laser proximity sensor gave accurate audio/visual signals at 3 ± 0.5 m range. In laboratory conditions also the laser proximity sensor functioned satisfactorily.

Figure 4. Laser proximity sensor mounted on a vehicle for dynamic trials.

The laser proximity sensor has also been successfully tested at RTRS facility at TBRL, Chandigarh. The LPS was mounted in front of rocket assisted rail sledge and its output signal was observed for different velocities of rail sledge at various g values. Figure 5 shows the laser proximity sensor being tested on RTRS facility at TBRL, Chandigarh. Table 2 highlights some of the results achieved during simulated dynamic trials.

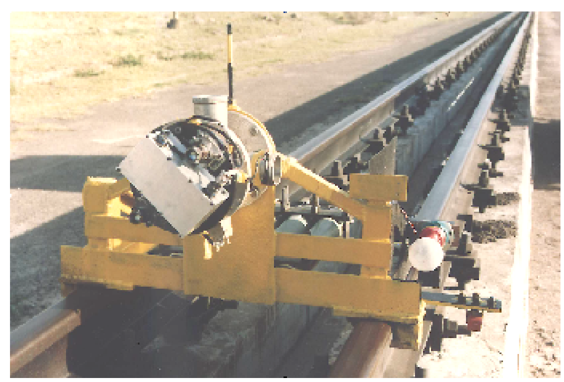
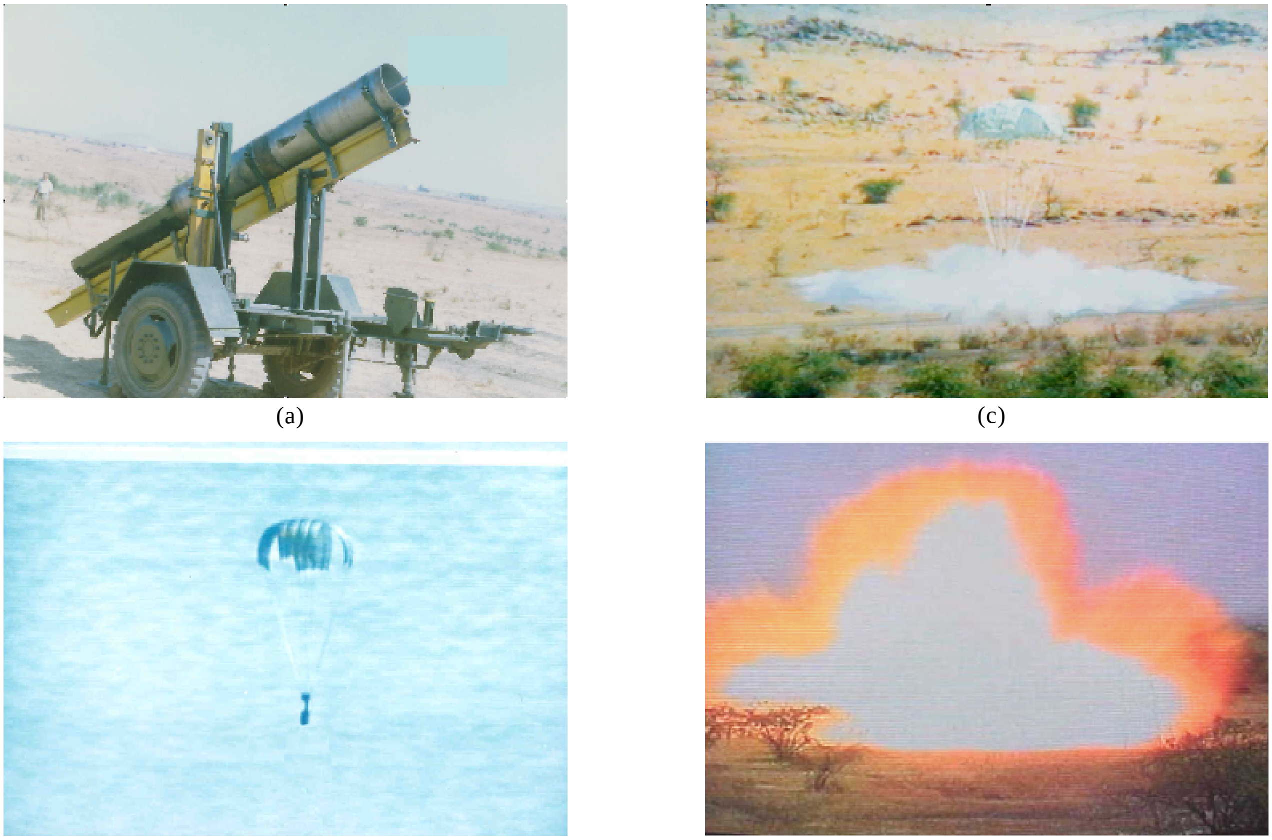


Figure 5. Dynamic trials of laser proximity sensor at RTRS facility.

Table 2. Ranges obtained by laser proximity sensor during simulated dynamic trials

Speed (kmph)	Design value (m)	Result (m)
60	3 ± 0.5	3.30
60	3 ± 0.5	3.30
80	3 ± 0.5	3.20
80	3 ± 0.5	3.30
90	3 ± 0.5	3.40



(a) (c)

(b) (d)

Figure 6. (a) Fuel-air explosive bomb with laser proximity sensor being fired, (b) fuel-air explosive bomb coming down on target area, (c) fuel cloud generated after receiving signal from laser proximity sensor, and (d) detonation of fuel-air explosive bomb at 3 ± 0.5 m from target.

Live fuel-air explosive bomb trials were also conducted at Dighi range, Pune. The laser proximity sensor was integrated in the nose cone of mine-clearing fuel-air explosive bomb. The bomb unit was launched using a rocket motor. The laser proximity sensor triggered the bomb at a desired range of ~3 m above the ground target (Fig. 6).

4. CONCLUSION

A laser diode based short range laser proximity sensor has been designed and developed. The sensor incorporates a laser transmitter and optical receiver. Various design parameters have been worked out and diffuse reflectance measurements have been performed for various likely targets. A prototype of the sensor has been developed and tested under lab and field conditions including live fuel-air explosive bomb trials. The developed laser proximity sensor performed satisfactorily under all desired conditions. The laser proximity sensor can be configured to suite various requirements depending on application.

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