Challenges of Laser Range Finder Integration In Electro-Optical Surveillance System

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***Abstract*—In this paper we analyze integration challenges of an Electro-Optical device and a laser range finder into functional system. The laser rangefinder design and basic properties are reviewed. The key factors influencing reliability of the laser rangefinder based distance measurements are discussed using a simplified parametric performance model, fault tree analysis and failure mode error analysis we discuss possible sources of failures and their influence on field distance measurements capabilities in the multi sensor surveillance systems. Based on our practical experience, the recommendations for hardware and software integration and laser rangefinder selection are derived.**

***Index Terms*— laser range finder, electro-optical system, surveillance system.**

INTRODUCTION

During last few decades we have seen a constant increase in the number of camera based surveillance systems applications [1, 2]. The focal plane array technology development provides capability of application of the infrared image sensors in surveillance systems aimed for homeland security and border control [3,4,5]. The important role of multi sensor systems is in maritime control scenario (port and coastal control) [6]. In some particular application cases it is important to provide object of interest (target) distance data. In that case integration of the laser range finder - LRF in the multi sensor system is the best solution. The starting base for LRF selection is system task allocation, but LRF basic properties determines integration requirements and dictate proper technical solution.

Laser range finders have wide application in the military targeting systems and topographic measurements [7], and that applications are well known but there are poor open literature analysis of the application specificities. LRF cost can be limiting factor for application. On the other hand, surveillance systems are mainly applied in the urban environment where laser safety issues can introduce significant limitations. Because of that the LRF application limits and capabilities should be studied in more details to provide optimal application in security surveillance systems.

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LRF are used in the most of the Vlatacom multi-sensor surveillance systems to provide accurate target distance measurements. The example of multi-sensor imaging system with integrated LRF is given in Fig. 1.

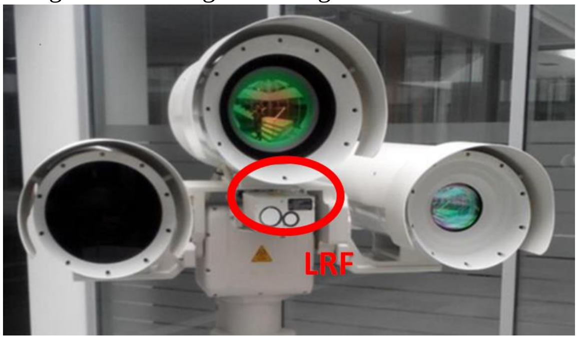

Fig. 1.Long Range Surveillance system structure

The particular LRF selection depends on the system purpose, distance measurements task allocation and target range measurement reliability and accuracy requirements.

The target goal of this paper is to provide good theoretical basis for LRF selection and follow on LRF application analysis and reliable troubleshooting during system exploitation.

The LRF principles of operation and basic LRF properties are reviewed followed by simplified laser range equitation derivation. LRF laser safety issues are discussed. LRF distance measurement fault tree analysis – FTA and failure mode error analysis - FMEA is performed to identify key limitation to LRF distance measurements errors. The atmospheric transmission and target reflection cross section influences on LRF maximal range measurements are analyzed. The LRF integration with electro-optical multi sensor systems defined requirements is defined.

LASER RANGE FINDER PRINCIPLE OF OPERATION

LRF is one of the useful optical methods object – target distance measurements [8]. In the case of long range surveillance systems the application of the time-of-flight method is the most appropriate [9]. This technique is based on a transmission of a short laser pulse of and the reception of backscattered signals from a target. The time between the transmission and the reception of the laser pulse or time of flight Δt is measured and the distance d is calculated on the basis of the relationship $d=c\Delta t/2$, where c is the velocity of light.

Laser pulse is generated using solid state Q-switched laser (see illustration in Fig. 2.) [11-13]. Laser beam quality and radiation spatial distribution is determined by optical

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resonator. Laser wavelength is determined by laser active medium – crystal, and laser pulse duration and repetition rate is determined by Q-switch type and properties. Optical pumping source determines laser mean time between failure - MTBF expressed by number of pulses that could be generated. Xenon flash lamp is commonly used as a source for optical pumping. The key disadvantage is relatively low number of the pulses (several tens thousands). Modern LRF use optical pumping using semiconductor laser diodes providing much higher MTBF (several millions of pulses).

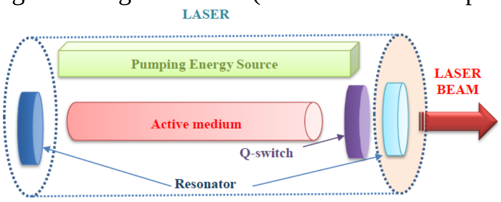

Fig.2.Solid State Laser Structure

The typical LRF [14-16] that is used for distance measurements is a single pulse electro-optical module used to measure the range of a selected target accurately and instantly. Such module consists of a laser transmitter, a laser receiver, power supply, control and signal processing electronics (as illustrated in Fig.3.). A pulse of infrared light is generated by the transmitter and directed at the target. This pulse of light (which is invisible to the human eye) strikes the target and is reflected back to the rangefinder. The time taken for the light to travel from the laser transmitter to the target and back is measured and automatically converted to distance.

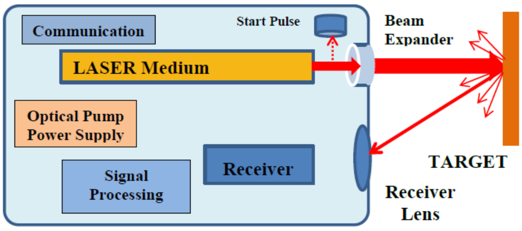

Fig.3. LRF based Distance Measurement Process

The parameters affecting distance measurement process can be divided into two groups:

- *LRF parameters*: laser wavelength, laser beam divergence, laser repetition rate, laser pulse duration, laser pulse energy and power,
- *Other parameters*: atmospheric transmission, object reflection properties

The meaning and importance of the influencing parameters are discussed in more details in the text below.

A. Laser wavelength

The most commonly used laser wavelength are 1.06 μm (Nd:YAG) and 1.54 μm (Er:glass). It is important to select eye safe laser wavelength in the case that LRF is considered for use multi sensor surveillance system aimed for application in urban environment. The wavelengths above 1.4 μm, are considered as eye safe, but eye safety should be assessed according with laser safety consideration defined in related standard. The laser safety will be considered in more details in separate chapter. In the case that LRF use eye safe laser it is called Eye Safe Laser Range Finder – **ESLRF.**

B. Laser Beam cross section and beam divergence

Laser beam do not have uniform intensity distribution across laser beam cross section but usually so called Gaussian distribution [14] as illustrated in Figure 4. Laser radiation beam is well known as collimated beam laser beam is spread inside, so called, divergence angle θ. In the case of Gaussian beam divergence angle is defined as angle at which intensity fall to $1/e^2$ peak value. Inside that angle about 86% laser energy is encircled.

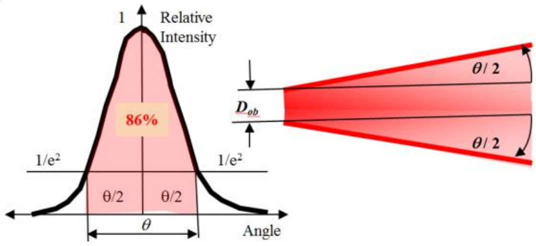

Fig.4. Gaussian laser beam parameters (diameter and divergence)

Another important parameter is laser beam output diameter D_{ob}, the value of laser beam cross section at transmitter optics exit aperture.

Laser beam diameter and divergence have a key influence on LRF distance measurement process energy balance determining maximal possible distance measurement range.

Typical laser divergence values are in the range from 0.2 mRad to several mRad.

C. Laser repetition rate

Due to LRF design constraints connected with laser pumping source recovery capabilities and laser components (optical pumping source and laser crystal thermal management), laser based distance measurements have limited measurement repetition rate (usually about ten measurement in minute). Higher repetition rate could be required in surveillance systems using target distance data for tracking of the fast moving targets. Majority of the surveillance systems do not require high repetition rates

D. Laser Pulse duration (half width)

Laser pulse duration expressed as pulse half width. Typical values are about 10 ns to 20 ns. The shorter half-width, the higher is the distance measurement accuracy, but more demanding are design requirements for laser receiver circuitry. The shorter half-width, higher is the peak power.

E. Laser pulse energy and peak power

The lower laser pulse energy the easier is to fulfill laser safety requirements. Typical laser pulse energies are from several mJ to several tens of mJ.

F. LRF distance measurement accuracy

Modern LRF provide ±5 m, distance measurement accuracy. Some manufacturers provide ±3 m and even ±1 m, for distances of several kilometers.

G. LRF measurement range

LRF based distance measurement range is hard to define accurately because of significant influence of weather

condition and target reflection properties on measurement range. There are several definitions of the measurement range:
(1) Total measurement range (usually 0.1 to 20 km) determined by LRF counting electronics.
(2) Typical measurement range for predefined wide target with specified reflectivity and meteorological visibility.
(3) Measurement range for specified target (area and reflectivity) and meteorological visibility.
Using LRF manufacturer specified range and knowledge about measurement condition user could to estimate what measurement range is accountable for his application.

H. Built In Test - BIT

The data about LRF subsystem status (power supply readiness, start pulse detection, laser return detection etc.) could be detected using BIT procedures. BIT data could be transferred to host computer system and used for measurement process tracking and troubleshooting. LRF is designed to have communication with system host computer, and well defined BIT capabilities.

I. Advanced distance measurement results processing

LRF processing electronics could be designed to have advanced functions (detection of several targets and presenting distance measurement results for all of them, selecting range measurement gate, etc.)

J. LED projector in laser transmitter channel

Some manufacturers built in LED projector and align it with laser transmitter channel what is convenient and makes easier system bore sighting procedure in laboratory and field conditions.

K. Size and Weight

Overall LRF size and weight is important limitation factor for LRF physical integration in multi-sensor surveillance system. In our system design, we aim to achieve best performance by selecting system components and the most suitable LRF. In addition to basic LRF performances other factors as atmospheric transmission and target size and reflection properties should be considered, too.

L. Atmospheric Transmission

Atmospheric transmission τcould be calculated using Lambert-beer law:

$$\tau = e^{-\sigma \cdot R}, \qquad (1)$$

where:
σ extinction (absorption + scattering) coefficient and
R optical transmission path.

There are different model for extinction coefficient calculation for different atmospheric weather dependent conditions. In the visible spectral region it is convenient to define atmospheric transmission using meteorological visibility V [km] defined as distance at which apparent object contrast is reduced to 2 %.

Using meteorological visibility definition extinction coefficient, σ_V in the visible spectral region could be calculated using equitation (2).

$$\sigma_V = \frac{3.91}{V} \qquad (2)$$

Meteorological visibility parameter is measured and reported widely. It is convenient to establish connection between the extinction coefficient of the medium (atmosphere and aerosols) and the meteorological visibility V [km] at other wavelengths. A lot of efforts [18-20] are done to provide simplified model using modified Koschmieder relation:

$$\sigma_L = \frac{3.91}{V} \cdot \left(\frac{\lambda}{550nm}\right)^{-q}, \qquad (3)$$

where:
σ_L Extinction coefficient at selected wavelength,
V meteorological visibility (in km),
λ wavelength (in nm),
q representing the size distribution of the scattering particles (different for haze, fog, rain and snow) and having different values for different meteorological visibility values:
q = 1.6, high visibility, for V > 50 km,
q = 1.3, average visibility, for 6 km < V < 50 km,
q = 0.16 V+0.34, haze visibility, for 1 km < V < 6 km,
q = V - 0.5 mist visibility, for 0.5 km < V < 1 km, and
q = 0, fog visibility, for V < 0.5km.

Some selected values of extinction coefficient for different harsh weather conditions calculated using equitation (3) are presented in Table 1.

TABLE I
EXTINCTION COEFFICIENT FOR DIFFERENT WEATHER AND WAVELENGTHS

Weather conditions (Distribution type)	V [km]	σ [km^{-1}] (785 nm)	σ [km^{-1}] (1550 nm)	σ [km^{-1}] (4000 nm)
Heavy fog	0.1	37.7334	35.2517	39.10
Moderate fog	0.3	11.7140	9.5514	13.03
Chu & Hogg fog	0.5	6.5457	4.6582	7.82
Haze M (marine)	0.7	4.3544	2.7046	3.76
Haze L (continent)	2	0.9597	0.2462	0.53

In the case that video camera is used for observation LRF aiming it is clear that LRF can to measure target seen with camera. In all particular weather conditions atmospheric transmission could have influence to maximal range of LRF application and should to be considered.

M. Target size and reflection properties

Laser transmitter radiation backscattered (reflected) towards laser receiver depends on target material, shape and overall dimensions. The most critical is target material reflection properties, described by surface bidirectional reflectance function – BRDF showing the nature of surface reflection, which could be: diffusive, specular or mixed [27].

Laser Range Equation

The Generalized LRF based distance measurement process is illustrated in Fig. 5, showing basic components and processes involved.

LRF Properties that have a key influence on distance measurement process are:

- LRF Laser energy (power) value and stability
- Laser pumping source and Power supply reliability laser pulse emission.

- Receiver sensitivity threshold and signal processing accuracy.

The starting point for analysis of the LRF distance measurement range is so called laser range equitation. Some of factors influencing field distance measurements are usually not known accurately (atmospheric transmission and target reflectance properties). Also some LRF design parameters (receiver threshold detection signal to noise ratio and noise equivalent irradiation) so it is reasonable to apply reasonable approximations and simplification to provide accurate enough parametric analysis of the laser range equitation in order to determine limits in LRF maximal range.

The laser beam irradiation at target, denoted as M_T [J/m^2], is:

$$M_T \approx \frac{Q_L}{A_{LT}} \cdot e^{-\sigma_L \cdot R} \approx \frac{4 \cdot Q_L}{\pi \cdot (D_{oL} + \theta \cdot R)^2} \cdot e^{-\sigma_L \cdot R} . \quad (4)$$

In the case that target is wide and acts as Lambertian reflector, the radiance value towards receiver, denoted as L_T, is:

$$L_T \approx \frac{\rho_T \cdot M_T}{\pi} . \quad (5)$$

The irradiance of the receiver input aperture M_{rec} is

$$M_{rec} = L_T \cdot \frac{A_T}{R^2} \cdot e^{-\sigma_L \cdot R} = \frac{4 \cdot \rho_T \cdot A_T \cdot Q_L \cdot e^{-2 \cdot \sigma_L \cdot R}}{\pi \cdot (D_{ob} + \theta \cdot R)^2 \cdot R^2} , \quad (6)$$

where:

A_T target area (actual value or equal to laser beam cross section in the case of wide target),

ρ_T target reflectance,

Q_L laser pulse energy and

σ_L atmospheric extinction coefficient at laser wavelength.

Equitation (6) is so called LRF range equitation, and describes the influence of target and atmosphere.

Range of distance measurement depends on receiver design, sensitivity and threshold signal to noise ratio. These parameters are usually not reported, but using some of LRF known range (specified, declared) values and equitation (6) it is possible to make parametric analysis of measurement range in different measurement conditions, as illustrated in Fig. 5. Unknown system parameters are obtained by single point calibration, when measuring range to known target under known atmospheric conditions. Results on Fig. 5.show that measurement results and described mathematical model have good agreements.

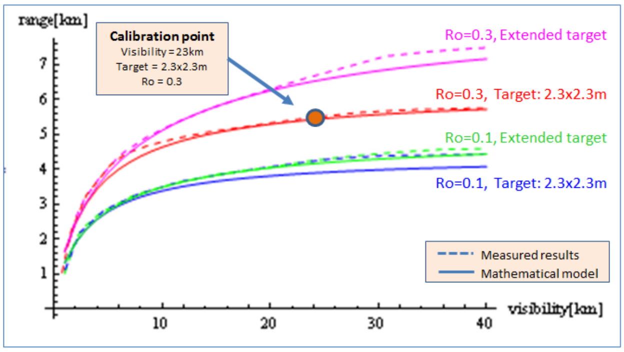

Fig.5. LRF range versus target size and meteorological visibility

Laser Range Finder Safety issues

The laser illumination spectrum at wavelengths greater than 1400nm is considered as eye safe, due to eye low transmission for named wavelength [21]. But, it is always necessary to provide detail assessment of the exposure levels for any laser system to compliance with standard defined acceptable levels [22.23].

The safety classification of the system at the system output and at the target is defined by the ANSI Z136 and IEC 60825 laser eye safety standards [24-26]. According with standard defined procedure [26] one need to access following parameters:

- Accessible Emission Limit - AEL,
- Maximum Permissible Exposure - MPE,
- Nominal Ocular Hazard Distance - NOHD and
- Extended Ocular Hazard Distance - EOHD,

that classify LRF in proper laser safety class: class1 – eye safe, or Class 1M safe at predefined distances.

Class 3B or 3R are un-safe and application of proper protection procedures and devices should be provided during operation. Safety standards define MPE levels for different lasers, as illustrated in Table II.

TABLE II
MPE values for different laser safety classes and laser operating mode

	Single pulse AEL	***Repetitive Pulse AEL***	***Average power AEL***
Class 1	8 mJ	2.53 mJ	10 mW
Class 3R	40 mJ	12.6 mJ	50 mW
Class 3B	125 mJ	39.5 mJ	500 mW

NOTE: Most LRF laser are classified as Class 1. 3R or 3B

Distance Measurements Channel Architecture

Distance measurements channel in the multi-sensor surveillance system is important as additional target data source. Implemented distance measurement functional structure is presented in Fig. 6.

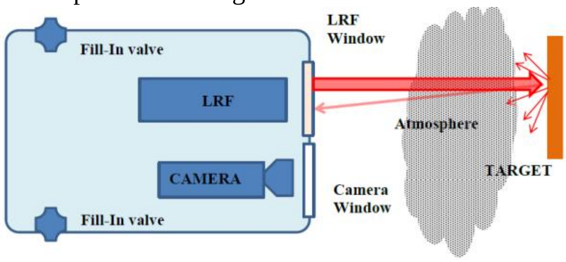

Fig.6: Distance Measurement sub-system structure

The influence of the LRF design parameters, environmental (weather) and target properties are already discussed.

A. LRF and system sealing

LRF contains components sensitive to humidity so LRF should be in hermetically sealed housing with dry atmosphere itself. Otherwise system designer should to provide that system housing have proper sealing.

B. LRF to camera line of sight - LoS boresighting

LRF laser beam is very narrow (usually less than 1mRad) providing laser beam diameter less than 1m at 1km distance.

LRF based distance measurement function require proper system aiming provided with camera with built in reticle defining aiming point. System bore sighting process should be done to assure that reticle position represents laser spot position. The most accurate bore sighting should be done in laboratory using collimator. Also, system should contain mechanical device suitable for fine position alignment.

LRF to Camera Field based bore sighting process is illustrated in Fig. 7.and Fig. 8. The field based bore sighting procedure can have influence on the system sighting accuracy.so it should be done carefully and checked regularly.

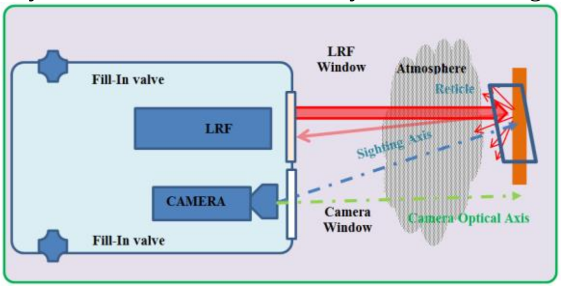

Fig.7.Field based System bore sighting definition and principles

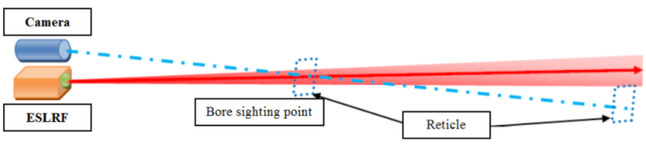

Fig.8. Reticle position during bore sighting and distance measurements

C. *Reticle*

Reticle shape and size should be accommodated to camera and LRF basic properties. One example is illustrated in Fig. 9. Value of parameter *A* (in pixels) in reticle shape is equal to 2 D_{ob} for maximal range for given camera in minimal zoom position. The parameter *B* corresponds to maximal zoom value, but even for lenses with higher zoom value than 10x it is not practical to have *B* higher than 10 *A*. Besides, since camera with continuous zoom lens changes optical axes due to lens mechanism tolerances, reticle position should be calibrated against lens optical axis position change during lens' focal length change.

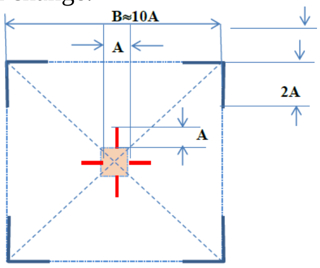

Fig.9.Proposed reticle shape

DISTANCE MEASUREMENT RELIABILITY ANALYSIS

LRF error sources analysis is presented in [15]. These errors are included into LRF distance measurement accuracy. In order to fulfill project requirements serious analysis of the LRF distance measurement channel should be done.

The range of the LRF depends on many factors. In order to determine expected measurement range limits, we must analyze the LRF range equation that comprises all parameters that affect measurement range. Also, one need to analyze the influence of

The key system components that have influence on distance measurement process are:

- LRF properties
- LRF protective window
- Atmosphere transmission properties
- Target reflection properties
- LRF to Camera bore sighting

The three key distance measurement fault are distinguished:

- LRF do not operate properly
- No distance measurement
- Not sufficient LRF range for distance measurements

After Fault Tree Analysis (**FTA)** and Failure Mode Error Analysis **(FMEA**) is performed it comes out that the most critical is proper system bore sighting, protective window selection and target reflection properties.

LRF failure is usually reported by BIT, and could be resolved through LRF replacement and maintenance process. Protective window and system bore sighting errors could be avoided through careful design and manufacturing process. But target reflection properties are out of control. Target reflection issues for non-cooperative targets could be partially overridden using repeating measurements aiming system to different area on target if possible.

LRF INTEGRATION RECOMMENDATIONS

In the short words, the recommendations for LRF integration in multi sensor surveillance system in design and manufacturing phase can be summarized as follows:

(1) Eye Safe Laser Range Finder (ESLRF) application in surveillance system is highly recommended. Otherwise, safety related additional procedures and limitations should be defined.

(2) Protective window should have proper spectral transmission at laser wavelength. In addition it should to provide easy and cleaning procedures safe application

(3) Protective window should be designed to provide easy replacement in the case of damage.

(4) Protective window should not disturb proper sealing of the system housing.

(5) Mechanical mechanism for bore sighting should be designed to provide easy and accurate alignment, and should provide proper fixing to keep adjustment after bore sighting is done. To provide proper field based bore sighting it is better to provide mechanical alignment mechanism on the camera channel.

(6) It is recommended to design system on such way to provide laser fixed position and bore sighting mechanism to control camera position.

(7) Fine – final bore sighting should be done by sighting reticle position change. Because of that sighting reticle position change during bore sighting procedure should be easy providing reticle fixed position after bore sighting is finished.

(8) In the case that camera use zoom objective it is necessary to provide calibration of the reticle

(9) It is extremely useful to provide continual LRF status and maintenance data reading and storing in separate file on system computer, easily accessible by authorized operator.

(10) Reticle design and position change with lens focus change require special care through system calibration process. At least camera optical axis stability during focal length changes in the case of zoom lens application should be well known.
(11) Reticle dimension should to represent laser beam angular size for selected system camera field of view - FOV.
(12) During bore sighting procedure system should to provide slowest pan/tilt motion.to provide system fine positioning.
(13) Capturing range measurement screen shots at operators request and storing them on defined place on system computer for documentation and further analysis should be provided in system control software package.
(14) Proper training and customer education regarding LRF range measurement capabilities is very important for achieving best results.

There are several recommendation related to LRF channel application during system field exploitation:

(15) Operator should be properly trained to provide good knowledge about distance channel usability.
(16) System protection window should be clean all the time
(17) Operator should track LRF operation regularly using BIT data generated.
(18) Operator should take care about meteorological visibility data to predict system usability for distance measurement.
(19) Operator should take care about target reflection properties. In the case of unsuccessful measurement repeat measurement using different part of target surface, if possible.
(20) Provide system regular maintenance to assure that system is in good condition.

CONCLUSION

Using systematic system engineering process and LRF design properties, through detail analysis we identified key issues for LRF integration with multi sensor surveillance system. In the same time we derived design recommendation for successful system integration and field operation. Relevant data are presented in the most cases, but selected sources for more detail studies and data extraction are referred.

This analysis is successfully applied for system design and field application. Also, it could be used for system distance measurement malfunction troubleshooting during system exploitation.

We are planning to continue our work on relevant data collection and more accurate analytical model models development to provide better understanding of our systems limitations.

REFERENCES

[1] J. Y. Dufour (Editor), *Intelligent Video Surveillance Systems*. ISTE Ltd. London and John Wiley & Sons Inc., New York, 2013

[2] G. L. Foresti, P. Mähönen, C. S. Regazzoni (Editors), *Multimedia video–based surveillance systems: Requirements. Issues and Solutions*, Springer Science+Business Media New York, 2000

[3] C. S. Regazzoni, G. Fabri, G. Vernazza (Editors), *Advanced video-based surveillance systems*, Springer Science+Business Media New York, 1999

[4] B. Javidi (Editor), *Optical Imaging Sensors and Systems For Security Applications*, Springer Science + Bussiness Media, New York, 2006

[5] G. L. Foresti, C. S. Regazzoni, P. K. Varshney, *Multi Sensor Surveillance Systems: The Fusion Perspective*, Springer Science + Bussiness Media, New York, 2003

[6] A. N. Ince, E. Topuz, E. Panayirci, C. Izik, *Principles of Integrated Maritime Surveillance Systems*, Springer Science+Business Media New York, 1988

[7] J. Shan, C. K. Toth (Editors), *Topographic laser ranging and scanning: Principles and processing*, Taylor & Francis Group LLC, Boca Raton, 2008

[8] M. C. Amann, T. Bosch, M. Lescure, R. Myllyla, M. Rioux, "Laser ranging: a critical review of usual techniques for distance measurement*"*, *Opt. Eng*. 40(1), pp. 10-19, 2001.

[9] C. Cooke, J. Cernius, A. La Rocca, „Ranging, communication and Simulation Systems". Ch.23 in *The Infrared Handbook*. (Editors: W. Wolfe, G. Zissis), Office of Naval Research. Department of Navy, Washington, 1978

[10] R. Byren: „Laser Rangefinders". Ch. 2 in *The Infrared and Electro-Optical Handbook. vol.6 – Active Electro-Optical Systems (Editor: Clifton Fox).* Infrared Information Analysis Center & SPIE Optical Engineering Press, Bellingham, USA, 1993

[11] A. K. Maini, *Lasers and Optoelectronics: Fundamentals.devices.and applications*, John Wiley and Sons, Chicheste,. UK, 2013

[12] Frank Träger (Ed.).*Springer Handbook of Optics and Lasers*. Springer Science+Business Media. LLC New York. 2007

[13] Walter Koechner.*Solid-State Laser Engineering*.6th edition.Springer Science+Business Media.Inc.. 2006

[14] H. N. Burns, C. G. Christodoulou, G. D. Boreman, "System design of a pulsed laser rangefinder".*Optical Engineering.*, March 1991, Vol. 30 No. 3, pp. 323 - 339, 1991

[15] K.C. Bahuguna, Prabhat Sharma. N.S. Vasan. and S.P. Gaba:"Laser Range Sensors"*.Defence Science Journal*. Vol. 57. No. 6. November 2007. pp. 881-890

[16] S. Kruapech, J. Widjaja: "Laser range finder using Gaussian beam range equation".*Optics & Laser Technology* 42 (2010) 749–754

[17] K. S. Hashemi, P. T. Hurst, J. N. Oliver, "Sources of error in a laser rangefinder".*Rev. Scl. Instrum*. 65, October, 1994, pp. 3165-3172

[18] Capt. R. Sabatini: "Tactical Laser Systems Performance Analysis in Various Weather Conditions". Symposium "Meteorological Conditions Considering Out-of-Area Operations", held at the Italian Air Force Academy, Naples. Italy. 16-19 March 1998. RTO MP-1

[19] O. Bouchet, H. Sizun, C. Boisrobert, F. de Fornel. P. N. Favennec, *Free Space Optics: Propagation and communication*, ISTE Ltd. London. 2006

[20] S. Arnon. D. Sadot& N.S. Kopeika (1994): "Simple Mathematical Models forTemporal. Spatial. Angular.and Attenuation Characteristics of Light Propagating Through theAtmosphere for Space Optical Communication:.*Journal of Modern Optics*. 41:10. 1955-1972Atm3

[21] D. Sliney, M. Wolbarsht, *Safety with Lasers and Other Optical Sources*. Springer Science+Business Media, New York, 1980

[22] B. Kenneth, *Laser safety management*, CRC Press. Taylor & Francis Group. Boca Raton. FL. USA, 2006

[23] L. Udovicic, *Keeping an eye on safety*: *Protection against laser radiation*, Federal Institute for Occupational Safety and Health, Dortmund, 1st edition. ISBN 978-3-88261-733-7, May 2013

[24] *Safety of laser products – Part 1: Equipment classification and requirements.* IEC 60825-1 – Ed. 2.0; International Electro technical Commission. Geneva, Switzerland, 2007

[25] *Safety of laser products- Application Guidelines and Explanatory Notes to IEC 60825*. IEC 60825-10; International Electro technical Commission. Geneva, Switzerland, 2001

[26] *American National Standard for Safe Use of Lasers*. ANSI Z136.1—2007. Laser Institute of America, Orlando, 2007

[27] D. E. Bowker, R. E. Davis. D. L. Myrick, K. Stacy, W. T. Jones, "Spectral Reflectance of Natural Targets for Use in Remote Sensing Studies", NASA Reference Publication 1139, 1985