LIDARs Usage in Maritime Operations and ECO – Autonomous Shipping, for Protection, Safety and Navigation for NATO allies Awareness

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ABSTRACT

LIght Detection And Ranging (LIDARs) are cutting edge technological devices and are widely used in atmospheric science, in order to examine the optical and chemical properties of the present atmosphere, in mapping and topography and nowadays their participation in autonomous driving is evolving. In this work a presentation is been made on how LIDARs can be used in the benefit of shipping for navigation and also, autonomous navigation, present weather measurements and detection / self-protection against Unmanned Aerial Systems (UASs), Maritime Unmanned Systems (MUSs), small and radio-undetected boats and also Chemical Biological Radioactive Nuclear (CBRN) agents detection and partially neutralization. The scope of this work is to present the multiple usages that LIDARs can commit in shipping together with a total proposed solution in the all the above, in order for the NATO naval forces to gain their benefit by usage.

Keywords: LIDAR, shipping, autonomous, safety, UAS, MUS, chemical, biological.

1. INTRODUCTION

There are a lot of considerations for military camps, civilian gathering areas as well as for marine environment and shipping, that are not being covered in terms of drones and Unmanned Aerial Systems (UASs) in general and/or Combat UASs (CUASs), Maritime Unmanned Systems (MUSs), Unmanned Ground Systems (UGSs) threats as well as from Chemical and Bio Warfare (CBW) and Radioactive and Nuclear particles. These considerations became a problem especially with the rise of terrorism around the world. In most cases, over 90%, there is no total coverage availability in those areas of safety. In this work, there is a presentation been made with a novel well-established, overall proposal for detection and neutralization - avoidance of all the above, based mainly on LIght Detection And Ranging (LIDAR) and LASER emitting devices, but also working together with other systems forming most effective novel hybrid systems. Another main topic of this work is the well-known efforts been made globally in the Autonomous Shipping (AS) and how could this been provided safely and effectively, also by LIDARs.

2. LIDAR

LIDAR technique have the potential to detect particulate aerosols, incoming CBW agents as well as Radioactive and Nuclear particles after an event like this occurs, with different Lidar techniques and also detect low observable targets like UASs / CUASs, MUSs, UGSs remotely at distances of many kilometers[1 p. vii]. They can provide spatially resolved measurements in ‘real-time’ at ranges of several kilometers to several tens of kilometers dependent upon several factors such as wavelength, laser power transmittance, ambient conditions and the optical configuration. The ‘Laser Radar’ is as an effective tool with high temporal and spatial resolution and has been extensively employed to measure the atmospheric and environmental parameters and also applied for military and civilian purposes in many cases such as ‘LASER Weapons’ or LASER emitting devices.

The detection part depends upon present weather elastic scattering, which is when the scattering frequency is the same as the frequency of the incident light of the LIDAR (like Rayleigh and Mie scattering), or, inelastic scattering which is when there is a change in the frequency[1 pp. 47-58] like Raman scattering. The types of LASERs used by LIDARs are based upon the type of operation like Continues Waved (CW) or pulsed, the mechanism at which population inversion achieved and most important, the state of the active medium it stimulates. The "Free Electron LASERs" which is the most recent type of LASER like behavior, will be using a different kind of procedure for the LASER production and active medium. The application of this particular type of LASER belongs to the upcoming future and could be used mainly as a 'LASER Gun' or 'LASER Weapon'.

The basic elastic LIDAR equation (Eq. 1) is given by the following equation[2, 3]:

$$P(\lambda,R)=P_{OL}\cdot\frac{A_0}{R^2}\cdot\beta(\lambda,R)\cdot\eta(\lambda)\cdot\xi(R)\cdot\Delta R\cdot\exp^{-2\int_0^R[\alpha_{aer}(\lambda,r)+\alpha_{Ray}(\lambda,r)]dr} \quad (1)$$

where, P(λ,R) is the received power in Watts, λ is the laser wavelength, R is distance in m, P_{0L} is the power of the transmitted laser pulse beam in Watts, A_0 is the diameter of the receiver's telescope in m^2, ΔR is the spatial resolution of the LIDAR (depending on the signal sampling frequency), ξ(R) is the geometrical form factor ($0\leq\xi(R)\leq1$) and is a pure number, η(R) is the LIDAR opto-electronic efficiency in %, while β(λ,R) is the backscattering and $\alpha_{aer}(\lambda,R)$, $\alpha_{Ray}(\lambda,R)$ are the extinction coefficients for Mie and Rayleigh scattering, accordingly in m^{-1}.

According to Klett[2, 3], the elastic LIDAR equation can be solved to provide the aerosol extinction coefficient ($\alpha_{aer}(\lambda,R)$) and aerosol backscattering coefficient ($\beta_{aer}(\lambda,R)$), assuming a relationship between these two coefficients, the so-called LIDAR ratio $C(\lambda,R)=\alpha_{aer}(\lambda,R)/\beta_{aer}(\lambda,R)$), So:

$$a_{aer}(\lambda,R)=\frac{\exp[S(R)-S(R_F)]}{\frac{1}{a(\lambda,R_F)}+2\int_R^{R_F}\exp[S(R')-S(R_F)]dR'}-a_{Ray}(\lambda,R) \quad (2)$$

and:

$$\beta_{aer}(\lambda,R)=\frac{\exp[S'(R)-S'(R_F)]}{\frac{1}{\beta(\lambda,R_F)}+2\int_R^{R_F}\frac{1}{C(R')}\exp[S'(R')-S'(R_F)]dR'}-\beta_{Ray}(\lambda,R) \quad (3)$$

where,

$$S'(R)-S'(R_F)=S(R)-S(R_F)-\frac{16\pi}{3}\int_R^{R_F}\beta_{Ray}(1-\frac{3}{8\pi\cdot C(R)})dR' \quad (4)$$

$$S(R)\equiv\ln[P'(\lambda,R)\cdot R^2]=\ln[RCS] \quad (5)$$

RCS is the Range-squared Corrected LIDAR Signal, R_F is a reference altitude for which a molecular atmosphere is assumed, in m, and P'(λ,R) is the received power after atmospheric and electronic noise Back-Ground (BG) correction:

$$P'(\lambda,R)=P(\lambda,R)-BG \quad (6)$$

In case of vertical or near vertical measurements, we can set a reference height at which the atmosphere is purely molecular. In this case, we are able to retrieve the values of $\beta_{aer}(\lambda,R)$ (and/or $\alpha_{aer}(\lambda,R)$) from that height and to the ground. These measurements are, thus, able to provide a clear view of the aerosol load located along the line of sight (LOS) of the LIDAR beam. The optical depth (τ) and total optical depth (τ_{total}) are given by Equations (7, 8) below:

$$\tau_{C_n}(0,R) = \int_0^R a_{C_n}(\lambda, R')dR' \quad (7)$$

$$\tau_{total}(0,R) = \tau_{C_1} + \tau_{C_2} + ... + \tau_{C_n} \quad (8)$$

where, R´ is the distance at which $\alpha_{aer}(\lambda,R)$ has been measured with a range resolution of 1 bin (i.e. 7.5 m), τ_{total} is the sum of τ_{Cn}, which is the individual optical depth (n=1,2,3,…) of the (n) prompted atmospheric layers.

The apparently most effective technique for slant pointing LIDAR measurements, for 3D scanning, in an operational environment and under any weather conditions without almost any assumptions, is the "3D stepping" or "LADDER" technique, in order for Klett technique[2, 3] or Raman techniques to be applicable (Fig. 1 - Left)[4, 5, 6, 7, 8].

3. AUTONOMOUS SHIPPING

The shipping and maritime industry is often characterized as being highly conservative and slow to adapt to change, particularly a change as totemic as unmanned shipping. In recent years, the maritime world has been increasingly interested in exploring the benefits of autonomous maritime vessels for freight transportation. This has resulted in a number of exploratory projects including the Advanced Autonomous Waterborne Applications Initiative (AAWA), an AS concept from Rolls-Royce Marine at 2016, AS from Skredderberget at 2018, a Japanese Trans-Pacific test named by Cooper and Matsuda at 2017, the MUNIN research project at 2016, a Chinese AS test location named by Jennings at 2018, an autonomous military ship named by Mizokami at 2018, the DIMECC 'One Sea' Consortium named by Haikkola, 2017 and a start-up company retrofitting old ships to be autonomous named by Constine at 2018.

Many of these efforts focus on the expected benefits of AS, including reduced operational costs, reduced manning, increased operational times, reduced fuel consumption, data analytics[9] and intercommunication also with 5G Networks[10], improved lifestyles for the seafarers and increased maritime shipping capacity named by Kobyliński at 2018 among others. Else have shown more skepticism toward the proposed benefits and have pointed out many challenges that have not yet been solved including legal named by Karlis at 2018, commercial named by Willumsen at 2018 and Technical named by Kobyliński at 2018[9]. One additional benefit that could be brought about by AS is an increased technological and ECO improvement rate in the maritime shipping industry. This higher improvement rate is facilitated by increased potential for upgrading via software named by Greengard at 2015, rapidly improving energy technologies for propulsion named by van Biert et al at 2016 and 'Big Data' driven learning to continuously improve efficiency of transport named by Perera and Mo at 2016.

A ship's ability to monitor its own "health", establish and communicate with what is around it and make decisions based on that information is vital to the development of autonomous operations[6]. The need is to develop a set of electronic senses that informs an "electronic brain" and allow the vessel to navigate safely and avoid collisions. The areas of importance are Sensor Fusion, Sea state, Meteorology, Control Algorithms, Communication and connectivity[6]. Looking at different types of radars, high definition visual cameras, thermal imaging and LIDAR the project AAWA has concluded fusing multiple sensor inputs provides the best results. LIDAR systems (sensors) are high quality state of the art remote sensing systems that are able to monitor environmental parameters, important not only as an environmental baseline, but also for improving the quality and accuracy of measurements which will be mostly helpful for the accurate knowledge of the surrounding weather and sea conditions in real time, in terms of best trajectory calculation, reducing the risk of cruising[6] but also for feeding weather forecasting models for the future transportation planning.

Visibility, Fog and various other atmospheric conditions heading towards the ship, can be detected and measured, along with their calculated time of arrival even with the single wavelength LIDAR[4, 5, 6, 7] making the usage of the latter cost effective. LIDARs already work with the atmospheric conditions detection and measurement for years and accurate algorithms have been created in globally certified eye safe conditions[(1 pp. 203-204), 4, 5, 6, 7]. Ships in this case will be, in parallel, mobile high-performance remote sensing meteorological stations, contributing also to the work of National Meteorological Services or other Meteorological Organizations and through that, to the global Weather Meteorological Organization (WMO), clearly maximizing the accuracy of present weather and sea state measurements and contributing the most, in the weather forecasting models. A novel type of cooperation can be achieved in this way by forwarding the gathered weather and sea state data of each LIDAR capable, ship, to Meteorological Organizations around the globe in real time, which is also beneficial for the needs of marine units to acquire for future arrangements of cruising in warfare and trade conditions.

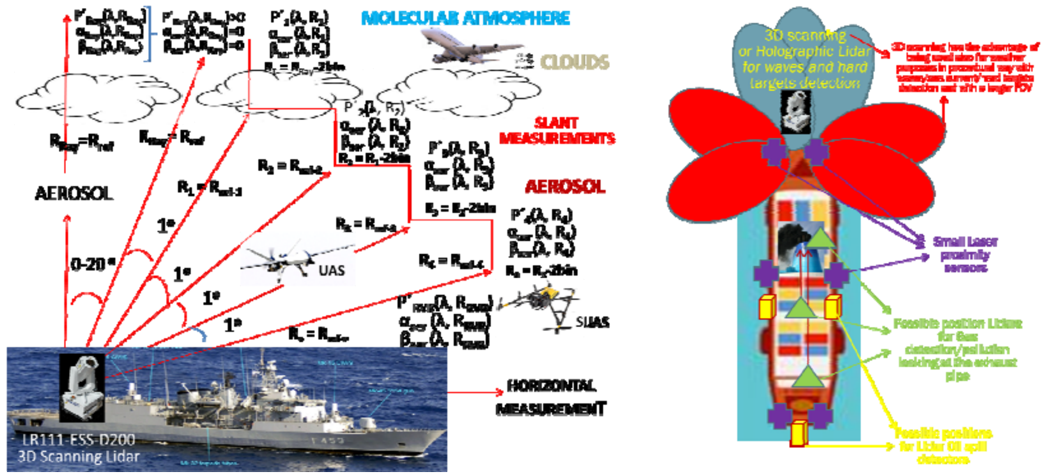

Figure 1. (Left) Visualization of "3D Stepping" or "LADDER" technique[4, 5, 6, 7] with Airplanes and UASs or CUASs detection with 3D LIDAR from a warship. (Right) Proposed LIDARs positioning on ships.

Algorithms developed in[4, 5, 6, 7, 8] can also add to the detection of hard targets and their separation from waves, measuring hard targets and waves velocity and time of arrival and contributing again in ship's safety from crashing – collision, cruising it also away from terroristic attacks in "operational" open or close seas. In particular, specific choice of laser beam wavelengths carries the ability of detecting submarines in some depth and/or surface or Subsurface – Submarine MUSs approaching, subsurface rocks and also measuring, in some depth, the affected for the ship sea current speeds, also through the measurement of the sea current energy spectra, contributing to the cost and fuel consumption effectiveness[9], as well as to safe cruising. LIDARs can also contribute to the accurate detection of oil spills (Fig. 1 – Right) and through that to the detection of earlier presence of ships and submarines in the area as well as their trajectory, even in situations where the 'naked' eye cannot detect.

So, the key measuring parameters of Visibility, Hard Targets detection over and under water, Incoming Fog – weather conditions – big sea waves and Oil spills can be achieved extremely accurately by LIDARs[6, 7, 8]. LIDAR measurements of wind, temperature and humidity 3D profiles as well as sea surface waves directional energy spectra, surface current air velocity and speed of the sea surface, can offer real time situational awareness. Safe alarms triggering can be achieved for approaching severe weather conditions detection and forecasting for optimal route planning, in terms of safe navigation, for fuel consumption and optimization[9] as well as for personnel comfort, providing for all crucial variables for ships in transit. Relatively, marine environment decision making is nowadays solely depended on the reliability and accuracy of weather and sea state prediction as well as personnel experience, but AI or AI – Man interaction with best hybrid sensor system availability and Algorithmic processing[6, 8] is about to "lift" the services provided.

Another area that LIDARs development can leave their fingerprint in shipping is the pollution that the latters create, especially inside harbors and their control by that means. LIDARs can be added near the pipes of the ships along with the stern side where the aerosol by the engines is produced and accurately measure the pollution and the effectiveness of those engines in different conditions and advice the controller of the ship through an AI – Man interaction system, to reduce the consumption when necessary, contributing to the cost effectiveness in terms of fuel consumption[8]. All the above mentioned usages and benefits can be used by autonomous and man handled ships and there will be needed[6]:

a). Fluorence and/or Raman LIDARs for detecting and accurate measurement of oil spill cases, fuel consumption, pollution, BIO and CHEMICAL agents detection of possible terroristic or other attacks and other marine or submarine systems existence by their own oil spills traces in the sea etc (Fig. 1 – Right, Fig. 2 – Left side).

b). 3D scanning LIDAR and/or holographic LIDARs with limited steady angle - position as it performs the on-going monitoring of the present sea status for hard targets detection, big waves, submarines, MUSs and incoming low level weather conditions (Fig 1, Fig. 2 - Right).

c). Smaller laser proximity sensors that will be activated during the mooring phase and during the ship's excursion phase and for safe Navigation inside harbors and narrow areas (Fig. 1 - Right).

d). Importing Navigation Data (Navigation App) and Satellite Communication (GNSS) based, also, in 5G Networks[11] (user dependable).

e). Importing Weather Data from App and from other vessels with corresponding systems.

f). AI Algorithms usage for LIDARs and hybrid system management in total for Data and decision making with an AI system or AI-Man interaction system (user dependable) after evaluation of current Weather / Sea status and other inputs.

g). 3D scanning or Holographic LIDAR, along with other Anti-UAS devices like Microwave radar, for UASs to be protected against possible terrorist or other attacks (Fig 1 - Left).

h). ‘Laser Gun’ or ‘Laser Emitting Device’ for self-protection of the ship after Tracking and ID of the incoming possible threat (Figs 2, 3).

i). TDL interoperability acting as Regular Networks with Shared info of all data available / Early warning for ship under attack / under emergency from nearby ships - Distress Call etc. Satellite communication (GNSS) and 5G Networks[11] could be beneficial for the above mentioned functions (Fig. 3 - Right).

j). LIDARs usage as an alternative way of Navigation via Sea Depth scanning (where able) in conjunction with sea depth maps availability and the further development of the latters, especially in narrow and shallow paths, when satellite communication is unavailable because of jamming or interference or any other reason like malfunction (Fig. 2 – Right).

A presentation of LIDARs usage is stated here for the needs of ECO - AS and protection and especially for warships and harbor to harbor or long routed trade ships. This occurred in order for NATO to be informed and perform in most effective way. Under the prism of the new upcoming ECO needs, like pollution control, especially inside harbors but also the threats developed lately like UASs and MUSs, LIDARs and hybrid systems supposed to feed an AI or AI – Man machine interactive navigation and protection device, which eventually will affect maritime patrol and control.

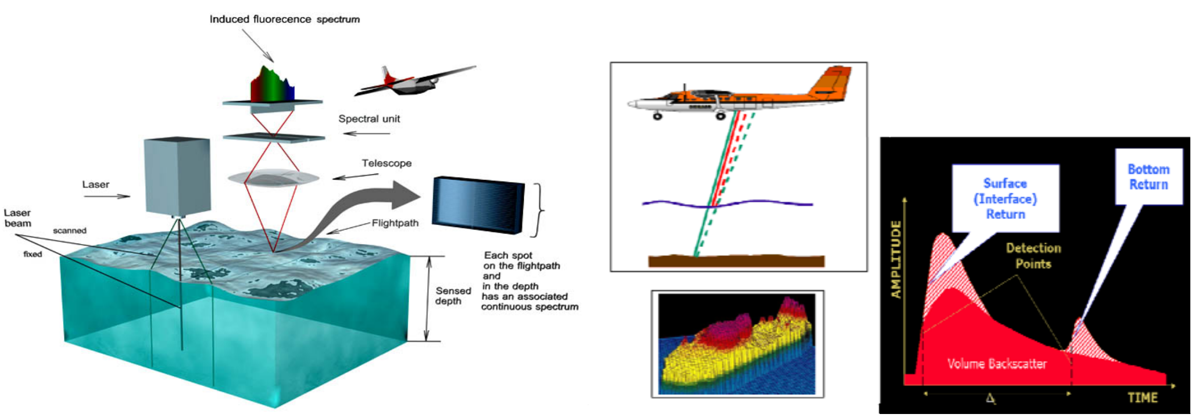

Figure 2. (Left) LIDAR for the detection of sea volumes like plankton, oil spills and through that the detection of early presence of ships – submarines in terms of oil traces in the sea surface. (Right) Aerial and Naval LIDAR και 3D presentation of a shipwreck which can also be used for 3D detection of mines presence Submarines, MUSs, inflatable boats etc in the areas of interest.

4. BIOLOGICAL AGENTS DETECTION

NATO has placed a survey through many kinds of LIDAR techniques and devices and their effectiveness in the detection of early Biological warfare through its RTO – Technical Report – SET 098/RTG-55[12], named “Laser Based Stand-off Detection of Biological Agents”, on February of 2010. Biological weapons have become an increasingly important potential threat in today's military and civilian arenas. They are relatively inexpensive to produce and can yield a significant impact as a terrorist and threaten weapon. Early warning of a biological attack, also with UASs, is essential to establish in a timely defense and to sustain operational tempo and freedom of action.

In addition, the mapping of a biological attack profile is needed to obtain intelligence on affected areas. For these reasons the need to develop methods to remotely detect and discriminate biological aerosols from background aerosols and ultimately, to discriminate biological warfare agents from naturally occurring aerosols, is paramount. The general conclusion was that LIDAR can provide the above mentioned task and also recommends the best kinds of LIDARs that this can be obtained[12]. In order to address these fundamental challenges, several stand-off technologies covering a broad region of the electromagnetic spectrum are being investigated under RTG-055. These technologies include spectrally resolved Ultra-Violet Laser Induced Fluorescence (UV-LIF) at several different excitation wavelengths[12,13], Infrared Depolarization and Long-Wave Infrared (LWIR) Differential Scattering (DISC)[12, 13].

The RTO committee suggested that, active techniques for detection of biological warfare agents may use infrared or ultraviolet Lasers, or both[12]. For Laser induced fluorescence, wavelengths in the ultraviolet are required. The most desired wavelengths are 260 to 300 nm for tryptophan excitation and ~350 nm for NADH excitation. Also excitation of different flavins, primarily riboflavin, is possible. A common excitation wavelength for riboflavin is ~450 nm, but due to the common radiation spectrum as the human visibility (400 to 700 nm) it may carry some limitations in its detection. To obtain good signal to noise ratio, the laser pulses need to be very intense – preferably in pulses of tens of nanoseconds duration with several milli-joule pulse energies. As averaging over many pulses often is required, high pulse repetition rates is also desirable. Continues Waved LIDARs could also do the job without the need of pulses usage[6, 8, 13].

Bio agents but also Chemical ones represent a great threat for marine environment and especially inside harbors in mooring. Opinions are divided as to which is the preferred wavelength: 266 nm UV excites fluorescence primarily from tryptophan, an amino acid present within the bacterial cell wall and tyrosine (also NADH and flavins to a lesser extent) while 355 nm UV excites fluorescence primarily from NADH, a coenzyme found in all living cells and also flavins but not tryptophan. The 266 nm is hence the most appropriate for tryptophan excitation and has a higher fluorescence cross section. In counterpart, 355 nm excitation of NADH may be related to bacterial spore viability. In addition, the attenuation of 266 nm light by atmospheric ozone is approximately 10 times greater than that of 355 nm and so 355 nm LIDAR systems may have a longer detection range. All of the above techniques UV and IR are all up leveling their effectiveness when combined with spectroscopy techniques (Fig. 1 – Right, Fig. 2 – Left, Fig. 3 - Left).

5. CHEMICAL AGENTS DETECTION

CBW (Chemical and Biological Warfare) agents are more commonly delivered close to the ground or sea level, preferably within the altitude region of few hundred meters using the system like rocket shells, missile, UAS, etc. The prevailing atmospheric dynamic processes (wind speed) makes them to spread both vertically and horizontally to form stratified layers / clouds in the atmosphere. Lifetime of these clouds can be from an hour to a day depending upon its nature. In course of time, these clouds settle down and thereby cause health hazard to plants, animals, and human beings. Hence, it is emphasized that the continuous monitoring of the atmosphere nowadays is very important around military areas and marine environments together with civilian population.

LIDAR systems plays a vital role in detecting and identifying these clouds in the atmosphere. A backscattering LIDAR operating at 1064 nm based on Mie scattering principle can search the suspected atmospheric region to look for upcoming clouds, though it cannot identify its composition and concentration. A LIDAR system which contains multiwavelength laser source UV (266 nm and 355 nm), 1064 nm and mid-IR (3-4 μm) wavelengths), common transceiver and scanning gimbal, AI or computer controllers with Graphical User Interface (GUI) can perform the task. A LIDAR master controller or AI triggers IR or UV laser sources to transmit laser radiation into the specific direction for identification of cloud composition if any suspicion arises in the detected cloud signal[14].

In view of the importance of monitoring the atmosphere continuously, a stand-alone backscattering LIDAR system may operate at 1064 nm. Then for the possibly cloud detection and for Chemical agents a DIAL (DIfferential Absorption LIDAR) can be ordered to point the aerosol mass or cloud. Two laser pulses with different wavelengths are emitted into the atmosphere for detection of Chemical Warfare (CW) agents. One wavelength (λ) is tuned exactly to the center of the specific absorption line of the molecule of the interest. The second wavelength (λ_{off}) is detuned to the wing of this absorption line with no specific absorption. The absorption cross section of the molecule of interest at λ is very large as compared to that at λ_{off}. Knowledge of which wavelength has been absorbed (indicated by a highly depleted return signal as compared to that at other wavelengths) gives information about the specific constituent of the atmosphere. Ratio of the return signals at these wavelengths determines the concentration of the molecules of interest due to differential absorption.

A pulsed DIAL laser can always provide the exact range of the detected agents. Selecting the appropriate wavelengths for DIAL measurements involves consideration of factors such as the molecular absorption, interference from other molecular species, atmospheric transmission and scattering, laser transmitter characteristics (for example, gain factor and line width of the chosen wavelength), detector characteristics etc. The emitted laser line widths of these wavelengths should be narrower than the widths of molecular resonant transitions, which, in turn, should be less than the difference between the online wavelengths of two neighboring species. Spectral information on online and offline absorption wavelengths and their cross section values of potential CW agents are very much required for DIAL operation. Many of these agents have distinct absorption bands in the 3-4 μm and 9-11 μm regions[13, 14] and there is relatively less atmospheric attenuation in these spectral regions. No single laser source with the required level of high peak power at each of these wavelengths is used to detect these agents in the atmosphere. CO2 lasers (9 to 11 μm) have commonly been used for the detection of a majority of chemical agents[14]. The generation of 2 to 5 μm wavelengths can be done by various nonlinear techniques, like the Optical Parametric Oscillator (OPO) technique in solid-state lasers.

These LIDAR settings for Chemical agents detection could also be used at the positions of the ship where ECO - pollution measurements are made and for the detection of oil spill traces by other ships, submarines and/or MUSs providing early warning and self-fuel efficiency capabilities at the same time (Fig. 1 – Right, Fig. 2 – Left).

6. DRONE / UAS / CUAS / SUBS / MUS DETECTION WITH LIDAR

The main idea is for a LIDAR system to be made in order for low observable targets (UASs, MUSs) to be detected initially and also for the aerosol detection to be made and for the LIDARs of Fluorescence and DIAL ones to be engaged and detect their potential threats[14, 15]. In particular the idea is:

a). The detection of the target (UAS / CUASs / Drones / Mini Drones / SUBs / MUSs / Bio agents / Chemical agents) by a 3D LIDAR Continuous Waved (CW) or Pulsed with quasi-CW formation in 3 Dimensions (Fig. 3 – Left) and/or a Holographic Lidar. (The contribution of a millimeter Radar for the solid targets with metallic parts - equipment, detection, working in synergy with the LIDAR would be an asset)[15].

b). The Identification (ID) of that target (UAS / CUAS / Drone / Mini Drone / SUBs / MUS) by an Imaging IR (IIR) database (preferably long distance device) or Visual ID (preferably long distance visual camera).

c). The tracking and profile of that target (UAS / CUAS / Drone / Mini Drone / SUBs / MUSs / Bio agents / Chemical agents) by the same or other LIDAR device and also by the IR and Visual camera.

d). The termination - neutralization of that target (UAS / CUASs / Drones / MUSs / Mini Drones) by a 'Laser Gun', preferably, provided by the same LIDAR or other Laser device. It is preferable that the 'Laser Gun' device will be transmitting in a non-visible wavelength like in IR spectrum, avoiding the immediate geolocation of the 'Laser Gun' shooter and visual Early Warning 'proof" of ever shooting towards the target. CO2 LASER could handle this task!

It could also be accompanied by other sensors like:

e). A millimeter Radar for the solid targets with metallic parts - equipment, detection, working in synergy with the LIDAR, would be an asset.

f). Acoustic – Audio sensor tuned to the acoustic frequency made by a number of UAS / CUAS / Drone / Mini Drone / MUS for the alert of nearby targets presence, but avoiding the sound of the "whispering" wind blowing at the same time.

g). An InfraRed sensor (IR or Imaging IR) for "extra" (Thermal) detection of nearby targets and preferably from a respected distance like from few km away.

h). A visual camera especially for detecting moving objects scanning the perimeter of the ship, preferably from a respected distance like from few km away.

i). RF and WiFi seekers and jammers for the detection of radio guided UAS / CUASs / Drones / Mini Drones / MUS to detect and be able to intervene to their guidance.

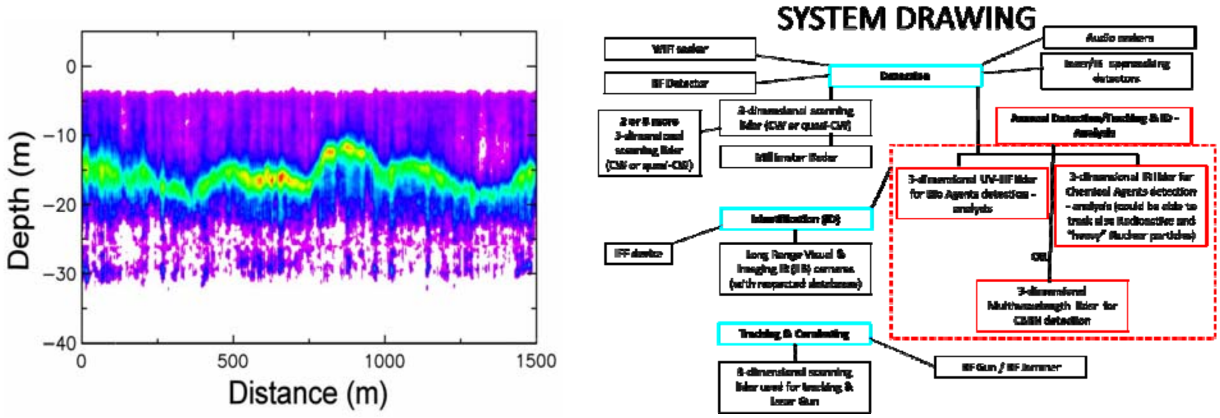

Figure 3. (Left) Vertical slice of thin plankton layer. Processed NOAA LIDAR return as a function of depth and distance along the track is encoded as color from violet -least return to red-highest return. (Right) Draw of the proposed system connected between different sensors[6].

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