10.12753/2284-9378-20-60

LIDAR APPLICATIONS FOR EARTH OBSERVATION MISSIONS

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Active remote sensing is a method of detecting bodies and phenomena and includes a wide range of active sensors, able to provide the data required to create images or electronic models of the monitored area, with multiple civilian and military applications. LIDAR is an important technology, with high impact on the development of robotics, automation of the manufacturing process and the development of fully automated and autonomous means of land, air and sea. LIDAR, as an active sensor, determines the distance of an object on the Earth’s surface and ensures the high-resolution mapping of the terrestrial surface, the obtained image having higher spatial resolution. Data provided by this sensor ensures the creation of high-precision digital maps, providing the information support for military and civilian activities.

Keywords: air surveillance; LIDAR; LADAR; active sensors; air threats; aerial surveillance systems.

The beginning of World War II marked the beginning of air active military confrontation on an unprecedented scale, characterized by the use in combat of an advanced aerial attack force representing the latest achievements in science and technology existing at the time. The radar played a major role during the air active military confrontations. The conduct of air military operations during the war confirmed the importance of this communication means for air defence, emphasizing its importance in providing the necessary information to the belligerent powers to track and identify the potential airborne threat, as well as ensuring the time required for the subsequent response aimed at fighting and destroying them.

The end of World War II emphasized the ideological contradictions between the URSS and the states of Western Europe and the US, leading to the emergence of the two military blocs: NATO and the Warsaw Pact. The establishment of the two military blocs marked the beginning of a competition that aimed to gain military superiority. This competition has engaged scientific and technological research in order to develop types of air attack, ballistic missiles and cruise missiles as carriers of nuclear warheads. The danger of these aircraft missile vectors has had a significant impact on political and military decision makers, with the effect of making special efforts to design solutions to detect and neutralize these threats. Thus, the design and development of air surveillance systems in order to neutralize advanced types of air attack was targeted. The purpose of political and military decision-makers was to include these air surveillance systems in radar sensor networks designed to detect aircrafts at maximum distance and to develop an airspace surveillance system with a complex architecture, able to provide the necessary information to neutralize potential threats from the air. In this regard, the actions carried out by the air force aimed both to defend against the threats of the opponent and to provide the appropriate framework in carrying out actions needed to neutralize offensive capabilities and destroying military targets that reside in its territory.

The diversification of air threats intensified scientific research conducted to identify new principles and methods of detection. Scientific research contributed to the development of new technologies that improved data quality through the ability to identify characteristics of the target. Another aspect of the scientific and technical achievements was the appearance of a wide range of radars that could fulfill various civilian or military missions, based on new principles and methods for detecting potential targets. The civilian use of these new principles and methods of detection has contributed to the emergence of a ”complex system of techniques used for the remote data processing of objects or phenomena”[1], later known to the scientific community as active remote sensing. Active remote sensing, as a method, has developed rapidly, incorporating a wide range of active and passive sensors capable of providing detailed information about the monitored area.

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Scientific and technological evolution has created the optimal framework for the development of new categories of sensors that have offered new opportunities for surveillance of the area of interest, able to offer new perspectives on the detection and identification of specific objectives. In this study I will pay special attention to and present in detail the active sensors used in active remote sensing, highlighting its military and scientific importance from the perspective of the possibilities of monitoring various bodies, phenomena, etc. Active sensors are instruments that explore, through generated electromagnetic radiation that is artificially created, phenomena and objects existing on the Earth's surface. The information obtained is stored as image data and used in the analysis of the explored environment, constituting complementary information to the images taken by photography techniques. The active sensors used in active remote sensing are the following: radar, sonar and LIDAR[2].

In this article I will discuss in detail the LIDAR, as the technical method capable of delivering relevant and detailed information on the battlefield.

In practice, used two names are: LIDAR[3] and LADAR[4], both referring to same detection device, the term LADAR being used mainly in the military field. As regards the use of these devices in practice, the term LIDAR is used in the civil applications of monitoring and mapping the terrestrial surfaces. At the same time, this term is used in the military applications for the precise determination of targets distances, hence the similarity of the name with the radar.

Whatever may be the practical use of these devices and structural differences between them, their principle of operation is similar to the operating principle of radar. The differences between LIDAR, LADAR and RADAR are due to the fact that LIDAR and LADAR can also provide, in addition to data on target distance, images of it, compared to radar that can determine only the distance. Another difference is that radar operates in the microwave region of the electromagnetic spectrum to detect targets, and LIDAR and LADAR most often use the laser light of the electromagnetic spectrum (including infrared and ultraviolet wavelengths). This difference provides a very good spatial resolution and very small detection errors, contributing to obtaining information about bodies and phenomena with very small size or with physical properties which are difficult to be detected by radar.

The principle of operation of LIDAR is similar to the principle of operation of radar. Similarly, LIDAR emits a short laser pulse which, when it encounters an obstacle, is reflected back to the LIDAR system, where the distance to the obstacle is determined by measuring the time between the moment of emission and the moment of reception of the reflected pulse.[5]

The LIDAR consists of:

- an emission system composed of a laser with the role of generating the probe laser pulses;
- a reception system composed of an optical device having a single lens or a telescope, depending on the destination of the LIDAR and optoelectronic devices composed of photodiodes and photomultipliers, with the role of detecting the light signal and creating the image corresponding to the monitored area;
- navigation system and global positioning system needed to determine more precisely the position and orientation of LIDAR so that the collected data may be used to create maps or images[6].

Therefore, I can say that the technical parameters of LIDAR or LADAR describe the characteristics of the devices in the composition of the transmission and reception systems, respectively the characteristics of the laser, optical devices and electronic devices.

The term laser is an acronym derived from English (LASER – Light Amplification by Stimulated Emission of Radiation) and refers to an optical device that emits light with different properties from the light coming from natural or artificial sources.

The first functional laser was built in July 1960, at Hughes Research Laboratories, Malibu (Southern California) by Theodore H. Maiman, using a synthetic ruby crystal as its gain medium[7]. The theoretical principles of the laser were formulated by Albert Einstein in 1916, when he brought to the attention of the scientific community the concepts of spontaneous emission and stimulated emission. According to this theory, the active environment receives energy from the outside, from a light source, which causes the excitation of atoms. Compared to the initial equilibrium state, the active environment will have more electrons on higher energy levels, phenomenon called population inversion in theory. The passage of a light beam through the absorbing medium will cause the stimulated de-excitation of atoms, having the effect of amplifying it by emitting photons that have the same properties (direction, wavelength, phase and polarization state) as the photons in the beam.[8] However, the implementation of the theories presented was carried out after World War II, when the studies of the great scientist were resumed and the first concrete results were obtained, respectively the achievement of the first MASERs.

Thus, the laser can be defined as a ”device for amplifying or generating electromagnetic waves in the optical field based on the effect of stimulated emission in atomic systems, which allows a concentration of energy corresponding to a temperature of tens of thousands of degrees”[9]. The light beam obtained is characterized by specific properties that differentiate it from natural light. The characteristics of the laser beam that are important for this study are the following:

- mono-chromaticity – a very narrow wavelength emission, resulting from the specific mode of operation, which multiplies the number of initial photons while maintaining their properties;
- coherence – the property of having the same wavelength and fixed phase differences at the same time;
- directivity – the property of propagating over long distances with a very small divergence and, subsequently, the ability to be concentrated in very small areas[10].

The optical device within the reception system has the role of capturing the light radiation reflected from an object Earth’s surface and directing it towards the optoelectronic detector. In order to acquire the best possible light signal, the choice of an optical device (lens, telescope) with the highest magnification power, resolution and aperture, corresponding to the technical requirements of LIDAR or LADAR is considered.

The optoelectronic detector is designed to measure the amount of light energy reflected from objects or targets illuminated by the LIDAR device. The optoelectronic detector consists of photodiodes and photomultipliers that determine with high precision the low values of the light energy received by LIDAR through the optical device, thereby providing an electric current value directly proportional to the amount of light energy received. The photodiode has an important role in the functioning of the optoelectronic detector. The photodiode is an element of an electronic circuit with two electrodes, ”whose functioning depends on the intensity of the light flux falling onto it”[11]. This element is used in the detection of light radiation reflected from objects on the ground due to the following parameters: spectral sensitivity and absolute sensitivity to light[12]. Due to the listed parameters, LIDAR is a light detector with record-high sensitivity and a device that makes high-resolution images of the targets or the monitored area.

Navigation and positioning systems have to determine with high accuracy the trajectory of the mobile platforms on which the LIDAR sensors are mounted. The devices used to determine the position and orientation of the sensor include a receiver of the global positioning system (GPS, GLONASS) and an inertial measurement unit for determining orientation, the latter being replaced by an inertial navigation system[13]. The submitted systems have computers with high storage and processing power, which allow the processing of massive amounts of collected data. In order to determine the space positions recorded by the sensor, it is necessary that the data provided by the reception of laser light reflected from the objects on the ground (data from the global positioning system and those from the inertial measurement unit) be integrated and processed so that the obtained image will reflect as accurately as possible the reality on the ground. Therefore, it is necessary to know the correlation between these systems and the spatial relationship within the assembly formed by the laser, the global positioning system and the inertial measurement system.

Data provided by LIDAR technology include: different time modes of operation of laser, respectively the moment of laser emission and the moment of reception of the laser light reflected from the ground (distance to the target object), data on continuous representation of aircraft position obtained from a GPS receiver available on-board the aircraft and from another ground-based GPS receiver for correcting differences, aircraft altitude data and acceleration data provided by inertial measurement equipment. Obtaining the final product involves a complex process consisting of processing the above-mentioned raw data in various stages of data processing.

The stages of LIDAR data processing are:

• stage "0", *data and metadata*, which consists of raw data collected and stored on the mapping platform, including data obtained by laser measuring tools, GPS, inertial measurement system, as well as mapping data and other elements relating to coordinates, date, sensor type, sensor calibration data;

• stage "1", *the unfiltered 3D point cloud*, which consists in the representation of data, resulting from the measurement of objects, in the form of a 3D point cloud, obtained by using specific algorithms to transpose raw data into a three-dimensional space application; metadata from the previous stage is carried over to the current level;

• stage "2", *3D point cloud noise filtering*, consists in the fact that the unfiltered 3D point cloud from stage 1 was processed, using specialized algorithms for eliminating false data or the noise resulting from receiving laser radiation or anomaly data resulting from data processing; metadata from the previous stage is carried over to the current level;

• stage "3", *the registration of the 3D point cloud to a known geodetic database*, which consists in adjusting the processed data using the correlation between the identifiable objects in the database and data containing known geodetic coordinates, corresponding to the field objects, in order to improve the accuracy of the data collected from the LIDAR sensor;

• stage "4", *derived products* are obtained from the data in stage 1, 2 and 3 and the stage consists in the development of some standardized products by using standardized working methods or tools;

• stage "5", *intelligence products* are obtained from the data in stage 1, 2 and 3 and the stage consists in the development of community-based information products, that are obtained through domain-specific specialized tools or knowledge[14].

The main types of LIDAR are:

• topographic map – for landscape, infrastructure and vegetation measurements;

• bathymetric map – for measuring the depth of water, indicating the underwater relief and determining its profile, mapping of shallow waters, up to 50 meters, depending on water clarity;

• differential absorption LIDAR (DIAL[15]) – for measurement of atmospheric chemical composition[16].

LIDAR can be mounted on aerial and space platforms or ground based platforms. Compared to the ground-based LIDAR, the aerial LIDAR can monitor and map very large land areas in a very short time due to the advantages offered by altitude surveillance and the technical advantages of aerial systems. The aerial platforms that have LIDAR sensors mounted on-board are: airplanes, helicopters and drones. The space platforms with LIDAR sensors are: satellites, space shuttles and space stations.

The terrestrial platforms used for specialized LIDAR applications can be fixed or mobile. LIDAR mounted on fixed terrestrial platforms is most common as a survey method, due to the relatively short time of obtaining the image, through a quick comparison with existing objects in the scanned area. Lidar applications are used in monitoring areas of interest, economic objectives, cultural heritage documentation, etc. LIDAR mounted on mobile terrestrial platforms presupposes the existence of satellite tracking devices and inertial measurement equipment. The products obtained by using LIDAR on a mobile terrestrial platform can represent 3D models able to make all the necessary measurements without being necessary a field presence. An example may be the surveillance of urban areas where it is necessary to make measurements on the height of bridges, power lines, trees, distances between buildings, etc.

LIDAR mounted on-board space platforms is used for both scientific research and navigation in space, development of planetary measurements or mapping the celestial bodies of our solar system. LIDAR has been used in scientific research to study the Earth's atmosphere, Earth's constituent elements, such as water droplets or industrial pollutants that would have been difficult to be detected with other measuring instruments. Another application of LIDAR mounted on space platforms is mapping the planets in the immediate vicinity of the Earth (Mars, Mercury) and the Moon, obtaining accurate and detailed 3D maps of the studied celestial bodies.

LIDAR mounted on aerial platforms consists of a laser scanning system designed to determine the distance by illuminating the target with laser light, a satellite tracking device and inertial measurement equipment. LIDAR mounted on aerial platforms creates a 3D point cloud model of the landscape, being the most precise and detailed method of making the digital elevation models, thus successfully replacing photogrammetry. Scanning in these conditions ensures the possibility to eliminate the influences of vegetation allowing the creation of digital maps of the landscapes or other places (rivers, archeological sites, etc.) that we sometimes cannot see because of the trees. An important aspect of LIDAR's use refers to the altitude from which the Earth's surface is scanned, having high-altitude and low-altitude applications. The differences in the final product, the digital image of the terrain, consist in a lower density of 3D points for high altitude scanning, so a lower accuracy of these digital terrain models compared to the accuracy obtained when scanning at low altitudes. There are some differences between high-altitude LIDAR system and low-altitude LIDAR that consists in a reduction in both accuracy and 3D point density of data acquired at higher altitudes

LIDAR mounted on aerial platforms can be used in bathymetry, for the development of digital bathymetric models for shallow waters, such as the study of lakes, rivers, seas near the shore, etc. Bathymetric LIDAR uses water-penetrating green light because of the penetrating power of this wavelength to up to 50 meters in depth. The technique is useful in mapping seabeds, lakes, etc. to create a digital model necessary for the study of underwater habitats, of the evolutions and transformations that occur in these environments, constituting a real support for the scientific community.

In conclusion, LIDAR is an active sensor that offers the possibility of mapping the Earth's surface with high precision, providing the necessary data to obtain images with a resolution of the order of centimeters. The sensor allows mapping natural phenomena with rapid evolution such as waves and coastal area tides, changes in physiognomy and evolution of riverbeds during floods, etc., providing the necessary data to develop predictive models that allow users to understand how the phenomena have occurred and evolved and to identify the best way to mitigate their impact on the environment and human communities.

Using LIDAR in the mapping Earth's surface has the following advantages:

- it allows the accurate measurement of the terrain morphology;
- it partially penetrates the vegetation, providing information on its type, size and impact on water runoff or landscape;
- it is a fast method of creating the Digital Terrain Model (DTM) that would be practically impossible to achieve with such precision by terrestrial measurements;
- it offers a complex image of the studied area by combining the data derived from aerial photographs;
- it obtains information quickly, compared to traditional methods."[17]

Using LIDAR has the following disadvantages:

- using LIDAR in certain projects of land area measurement or mapping might be expensive;
- inefficiency of LIDAR scanning in difficult weather conditions with heavy rains, heavy clouds, fog, in conditions of heavy smoke or surface of transparent media where there is no dispersion of the beam;
- time- and cost- intensive activity for processing large amount of data collected by LIDAR;
- certain wavelength range and intensity of the laser light might determine damage to the human eye;
- penetration with difficulty extremely dense matter[18].

LIDAR is used for multiple civilian or military applications because the information contained in digital images enables high-resolution map of the Earth's surface. Civil applications of LIDAR are used in the following fields:

- LIDAR is used in agriculture: to control and coordinate agricultural robots; make topographic maps of agricultural fields and classify them according to yield; to use the necessary fertilizers in order to improve soil fertility and to increase yield potential of the agricultural lands; to detect and monitor existing insects in the agricultural field, detecting their species and their movement behavior; to identify species of plants in order to apply weed control measures in agricultural crop production;
- LIDAR is used in archeology to create high-resolution digital models to detect archaeological sites obscured by dense vegetation;

• LIDAR is used in autonomous vehicles: to detect and avoid obstacles so that they can move safely;

• LIDAR is used in transportation: for development of driver-assistance systems for the safety of the vehicle and passengers;

• LIDAR is used in biology: to assess and measure the biodiversity of the scanned area, to take height measurements of trees, to observe change in biomass, etc.;

• LIDAR is used in geology and pedology: to detect topographic features such as river terraces, to measure vegetation height, etc. which allowed the understanding of the physical and chemical processes that shape Earth's landscapes; it is used in structural geology to study land elevation, slope change detection, water infiltration, etc.;

• LIDAR is used in study of the atmosphere: to perform measurements on cloud formations, air mass movement, to study aerosols, greenhouse gas emissions, fires, humidity, etc.; DIAL measures gas concentration in the atmosphere;

• LIDAR is used in mining: to monitor and scan periodically mineral extraction areas and to compute volume of extracted ore;

• LIDAR is used in law enforcement: to calculate speed of vehicles, within the forensic field, to precisely map and to record the crime scene in order to analyze the evidence at a later point in time;

• LIDAR is used in physics and astronomy: to find the location of the Moon in the sky and to conduct experimental tests of the general theory of relativity; snow detection in the atmosphere of Mars; to measure the density of certain constituents of the Earth's middle and upper atmosphere; nuclear fusion research; to provide three-dimensional maps for autonomous landing of unmanned aerial vehicles, etc.;

• LIDAR is used in optimizing wind farm performance: to measure wind speed, to provide wind-turbine blade information allowing wind turbine controls and blades to adjust appropriately to various conditions, to proactively adjust blades to protect components and increase power, to assess the wind power potential of an area, etc.;

• LIDAR is used in optimizing photovoltaic power plants performance: to determine the optimal placement of photovoltaic solar power plants and to analyze the influence of vegetation, land, buildings, etc. on the efficiency of the solar power plant;

• LIDAR has other uses such as: making videos in music industry, movie industry, etc.

In the military field, LIDAR is used in a broad range of military operations. It has the ability the position or movement of the objects and measure their speed, being used to measure the speed of cruise missiles. It has also the ability to scan and detect landmines, being used in the de-mining of former conflict areas. LIDAR plays an important role in detection of chemical and biological warfare agents, being able to detect artificial clouds containing chemicals or pathogens at a standoff distance of up to 30 kilometers. LIDAR sensors might contribute to the massive entrance of autonomous military robotics into the arsenals of armies and their increasing use in future military operations.

Militarily, LIDAR, regardless of its basic design, constitutes a data source that ensures the implementation of detailed and precise electronic battlefield. Detailed 3D images will ensure understanding the operational reality and will enhance the adaptability to the realities of the modern battlefield. LIDAR enables high-resolution maps of the areas of interest, the detection of the opponent's means of combat, of the cruise missiles, of chemical and bacterial contamination in various areas, etc.

In conclusion, LIDAR is an extremely useful tool for monitoring and mapping the Earth's surface. LIDAR is used in almost all areas of social life because of its multitude applications for civilian and military use or the ability to accurately detect the terrain morphology, to identify plant and animal species in the scanned areas or to detect buildings hidden among vegetation. The collected data contribute to the understanding of natural phenomena, the impact of human activity on the environment, providing the necessary information support for the constant development of three-dimensional electronic maps. Militarily, LIDAR will ensure an accurate three-dimensional image of battlefield terrain, enabling battlefield dominance by holding the initiative and maintaining freedom of actions in battle.

NOTES:

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