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Theoretical and applicative considerations regarding LIDAR

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Abstract: LIDAR is a mature method of data acquisition based on the use of light pulses, usually the system is airborne, but there are also terrestrial mobile systems used to map restricted areas or objects. This data acquisition technique is used in the field of topography, engineering, and related fields. LIDAR technique is capable of producing high-precision three-dimensional scalability of scanned objects. LIDAR technique is used to perform atmospheric measurements: determination of the types of pollutants; monitoring atmospheric conditions; determining dust dispersion; permanent monitoring of ozone; measurements of the wind; tracing pollutants from chimneys, etc. This article provides information about theoretical references and a LIDAR application.

1. Introduction. LIDAR monitoring technique for atmospheric pollutants

The first remote sensing systems were used in the US since the 1960s, and in 1972, the first terrestrial observation satellite to be launched in space; Landsat-1 was equipped with remote sensing equipment. In the paper [1] are presented the principles of passive detection (principle of multispectral scanning, principle of radiometry, principle of satellite television, and principle of thermo vision) and principles of active detection (radar principle, sonar principle, leader principle). It also analyzes a series of image interpretation elements, as well as the main features of aerial and satellite imagery, such as image scale, contrast, resolution, geometric properties, colour tone, brightness, detection capability, etc.

For atmospheric measurements (determination of the types of pollutants, monitoring of atmospheric conditions, determination of dust dispersion, permanent monitoring of ozone, wind measurements, smoke draft pollutants etc.), the most used remote sensing methods are methods laser (LIDAR), due to some advantages over classical methods:

- Unlike classical sources of electromagnetic energy, the lasers allow to obtain monochromatic pulses of high intensity;
- LIDAR systems are extremely precise, with great sensitivity;
-because of the specific properties of laser radiation (coherence, mono-chromaticity, directionality, etc.), there are systems of high selectivity;
- allow for remote, fast and real-time measurements;
- provide real-time spatial information on polluted areas;
-allow the use of several measuring techniques (retro diffusion, absorption, fluorescence, resonance, etc.) at the same time, thus allowing for the analysis of several types of atmospheric pollutants;
- can be coupled with weather surveillance systems, with alarm and / or pollution alarm systems;
- ensures the possibility of obtaining information on: range, amplitude, thickness, concentration, type and speed of displacement of chemicals, etc.

LIDAR detection methods are also used in a number of military applications [1]: detecting the presence of chemical and biological weapons in the atmosphere, determining by scanning with a pulsed laser the three-dimensional images of the targets, etc.

There are several types of LIDAR systems, a criterion for classifying them as the measurement principle of that system. Thus, the following systems [2, 3, 4, 5, 6 and 7] can be listed: Differential absorption (DIAL); Disparate Spreader (DISC); Fluorescence Leader; Lean with resonant scattering; Lidar Raman; Coherent Leader (heterodyne detection).

2. Atmospheric impact on propagation of the laser fascicle.

In the LIDAR technique, the laser beam, which is optical wavelength electromagnetic radiation, traverses the atmosphere twice: for the first time, incident radiation from the light source (laser) to the analyzed area (object) and, respectively, reflected radiation from the object to the photo detector. Due to the effects that take place with the passage of the atmospheric layers, the laser radiation changes some of the initial characteristics, these transformations being due in particular to phenomena underlying the propagation of light waves through unguided environments (reflection, refraction, dispersion, diffraction, absorption, diffusion, etc.). The laser radiation reflected from the particles in the analyzed area, which contains information about the atmospheric layer, is captured by the photosensitive surface of the photo detector and converted into an electrical signal from which the information / images is relating to the amphiphilic layers covered by the laser beam.

The laser is an optical device [8, 9, 10, 11], which by its mode of generating emission power in all radiating a light beam of high intensity, well collimated. The direction of a laser beam is primarily influenced by the angle of divergence, which depends on the transverse distribution of laser beam intensity, oscillation mode, distribution and spectral band, etc. (there is also an intrinsic low value divergence, which is due to the light diffraction phenomenon).

To achieve optimal collimation of the laser beam, a convergent optical system is placed at the laser beam output of the resonant cavity. Thus, on Rayleigh's distance (D^2/λ), the laser beam propagates parallel, and then begins to spread linearly with increasing propagation distance due to the diffraction phenomenon. The solid laser beam spreading angle [10] is proportional to the square of the beam divergence, the angular scattering of the α_d beam in the distant field, depending on the diameter D of the beam at the exit of the laser tube, and the wavelength of the laser radiationλ, equation 1:

$$\alpha_d = 1,22 \cdot \frac{\lambda}{D} \tag{1}$$

The atmosphere is a heterogeneous gaseous medium (mixture of gaseous, liquid and solid particles) is not crossed identically by laser radiation, which differs primarily in the way of generation, intensity, wavelength and spectral band.

Atmospheric behaviour relative to laser radiation is described by two important notions, namely: the rate of atmospheric transmission (the percentage at which laser radiation with a certain frequency of vibration propagates over the entire height of the earth's atmosphere) and the window atmospheric transmission (laser wavelength range for which the transmission rate is very high, almost 100%).

The main considerations regarding the propagation of laser radiation through the atmosphere are the following [12, 13, and 15]: molecular absorption, which defines atmospheric windows at wavelengths favourable to laser transmissions; molecular scattering and aerosol (Rayleigh and Mie), which depends on particle size and wavelength of laser radiation; atmospheric turbulence or scintillation; refraction of light and reflection of light; aerosol absorption - determines the local change of the refractive index along the propagation pathway as well as local heating.

The fundamental physical processes that attenuate the propagation of laser radiation through the atmosphere are detailed in the paper [12]:

- Resonance absorption due to the rotational and vibrational movements of the diatomic and tri-atomic molecules composing the atmosphere;
- Rayleigh scattering due to molecules in the atmosphere much smaller than the wavelength of incident laser radiation;
- My scattering due to particles in the atmosphere with dimensions comparable to the incident wavelength of incident laser radiation.

Mathematical models have been developed [12, 14] that estimate the transmission of electromagnetic radiation through the atmosphere: the Lowtran model, the Modtran model, the Fascode (laser) model, is used for the calculation of electromagnetic radiation propagation with very narrow bandwidth as the laser line.

Particles that make up the atmosphere, especially water vapour, cause laser radiation attenuation. This effect depends on the humidity value and increases with the frequency of electromagnetic radiation. There results a maximum attenuation in the vicinity of the spectral absorption lines for each atmospheric molecule. Selective absorption results in the appearance of atmospheric transmission windows. Optical transmissions are carried out inside the air transmission windows.

Figure 1 represents the atmospheric transmission for the spectral domain $0,3 \div 14 \mu m$, determined by applying the Lowtran model [14] and Table 1 summarizes the atmospheric optical transmission windows in the same spectral range (the wavelengths at the beginning and end of each window are given in μm).

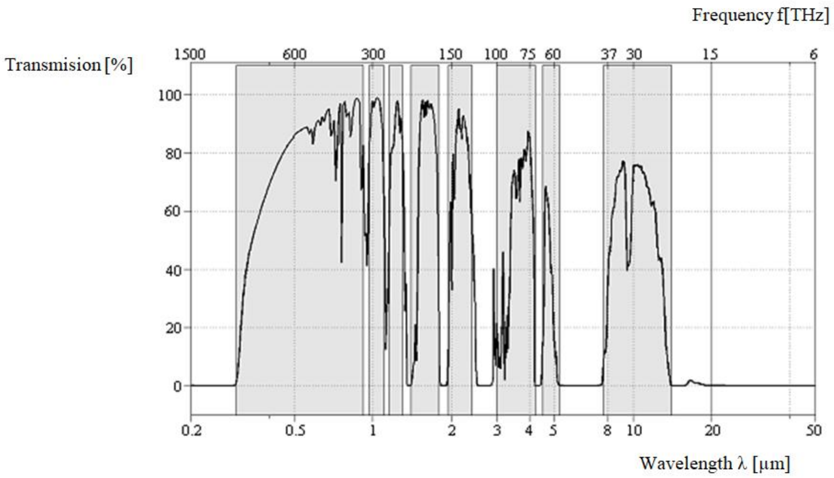


Figure. 1 Airborne transmission determined by LOWTRAN analysis [14]

Table1. Atmospheric Optical transmission windows

I	II	III	IV	V	VI	VII	VIII
0,30	0,97	1,16	1,40	1,95	3,00	4,50	7,70
0,92	1,10	1,30	1,80	2,40	4,20	5,20	14,0

A significant attenuation of electromagnetic radiation in the optical range is produced by very small liquid ($1 \div 100 \mu m$), water droplets and sub micrometric (Rayleigh dispersion) dust particles comparable to the wavelength of electromagnetic radiation. Using the Kruse relationship (equation 2) one can estimate the effects of the atmosphere on the propagation of the laser radiation:

$$A_e \, [dB/km] = \frac{17}{V\,[km]} \cdot \left(\frac{0,55}{\lambda\,[\mu m]} \right)^q \geq 0 \qquad (2)$$

Where V: is the meteorological visibility parameter.

Exponent q depends on the meteorological visibility, thus

$$q = \begin{cases} 1{,}6\ if\ V > 50km \\ 1{,}3\ if\ 6km \leq V \leq 50km \\ 0{,}585 \cdot V^{\frac{1}{3}}\ if\ V < 6km \end{cases} \tag{3}$$

Both scintillation and laser beam refraction, caused by atmospheric turbulence, propagation environment properties, atmospheric temperature variation along the propagation path, increase laser beam divergence and make it difficult to orientate.

3. Fields use of the LIDAR system

The main areas of use of LIDAR can be synthesized as follows:

a. CPL - Leader for cloud physics: the wavelengths at which it works: 355nm; 532nm; 1064; the leader of retrospection; allows images of sections of clouds and aerosols to be obtained [18];

b. GLA - Geosciences Altimeter: It is on board the ICES satellite, being used for continuous observations on the Earth; allows climatic estimations through a series of atmospheric measurements (thicknesses and heights of clouds, composition and atmospheric properties, topography of glaciers, etc.), [22, 23];

c. CALIPSO Lidar (Lidar system on board the Calypso satellite): allows to obtain performance images of sections of clouds and aerosols [21];

d. Ceilometers - Small-sized LEDs that use pulsed pulsed light-emitting diode light sources and are used in particular to measure the height of the cloud ceiling (eg Plessey Radar in England), [16,19];

e. The mESYLIDAR system [17] - is used for applications in noxious environments, in vibration environments (aircraft) and in low gravity environments (spacecraft, satellites) respectively;

f. Sun, Sky, Lunar CE 318TDP9 (solar photometer monthly) - is used to continuously monitor the optical properties of aerosols forming in air columns [1];

g. PANDORA 2S - Sciglob UV-NIR 2S Sun & Sky Photometer - double spectrometer for monitoring nitrogen dioxide, ozone and aerosols, [1];

h. ACSM (Aerosol Chemical Speciation Monitor) - spectrometer for the continuous monitoring of aerosol chemical species, [20].

4. LIDAR weather application

The LIDAR application has as a sensor ceilometers used to calculate the cloud ceiling (see figure 3), operating at a VAISALA tactical weather station within our faculty, see Figure 4.

Fig. 2 Ceilometers CL 31, [25]

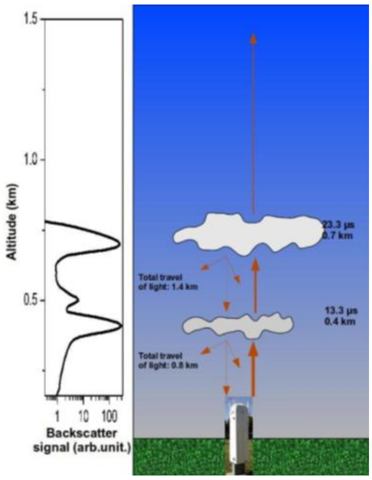


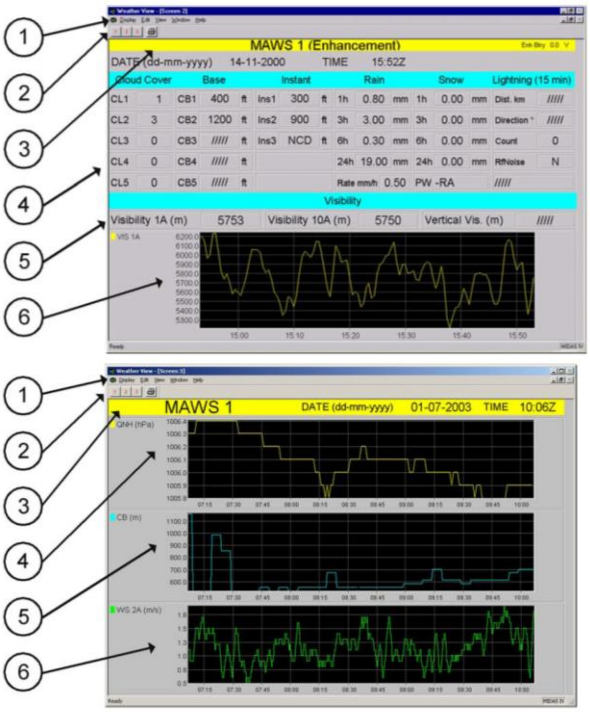
Fig. 3 Ceilometers detection

Fig. 4 VAISALA MAWS 201M, [25]

The ceilometers CL 31 (Figure 2) is a cloud base measurement tool and vertical visibility, it can detect three layers of clouds simultaneously and the cloud profile (see Figure 5). CL 31 uses pulsed diode laser, see Table 2, ceilings are detected under fog and precipitation conditions. These sets of measurements are taken by the diagnostic software and detection algorithm for maximum reliability and easy operation.

Table 2. Features CL 31, [24]

Features	Value	Features	Value
Dimensions	620x235x200 mm	Position	Vertical/12°
Total weight	31 kg	Temp	-40°÷60°C
Range	7,6 km	Resolution	5/10 m selectabilă
Acquisition interval	2÷120s	Wavelength	910 nm
Power consumption	310W	Voltage	110/220V
Connexion	RS 232/RS/modem/LAN	Back-up battery	2A



1 = Menu bar
2 = Toolbar
3 = Title of the screen
4 = Values of the cloud, rain, snow, and lightning data
5 = Visibility values
6 = Graphical display of the visibility

1 = Menu bar
2 = Toolbar
3 = Title of the screen
4 = QNH (altimeter setting) graph
5 = Cloud base graph (not available in Basic system)
6 = Wind speed 2-minute average graph

Fig. 5 Software interface with measured parameters, [25]

Data from sensors can be viewed in real time (fig. 5) or exported in ASCII format (fig. 6).

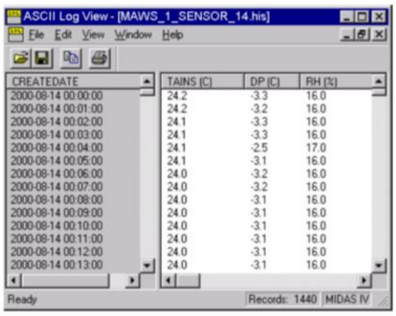


Fig. 6 ASCII log view data sensor, [25]

With the help of this instrument it is possible to analyze the attenuation of solar irradiance in the lower troposphere at a high spatial-temporal resolution through meteorological parameters such as backscatter coefficient and extinction coefficient, see figure 6, [26].

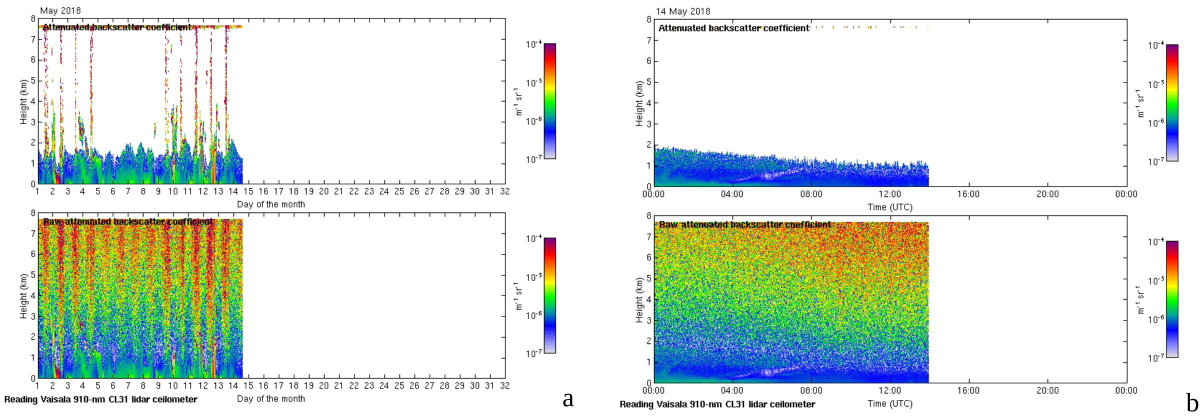


Fig. 10 Backscatter coefficient a. may 2019, b.14 may 2019, [26].

Conclusions

In laser remote sensing, data about an object is obtained by analyzing the electromagnetic radiation (laser beam) reflected or emitted by the object, since each object is unique in terms of emission or reflection of electromagnetic radiation, depending on the physical parameters of the environment.

Depending on the wavelength, the types of electromagnetic radiation used by remote sensing systems are mainly: microwaves (*1mm – 1m*), infrared radiation (*0,75 – 14μm*), visible radiation (*0,4 – 0,75μm*) and ultraviolet UV-A (*0,315 – 0,4μm*) due to the properties of these spectral domains both in terms of the propagation of electromagnetic waves (optical transmissions) and their emission-related influences tellurium and solar reflection. The sun is the main light source used in the fields of visible radiation and IR-A (near IR), with a maximum spectral emission of $\lambda = 0{,}5\mu m$. In the case of the remote IR domain, the radiant energy source is the object to be analyzed, the field of operation being in the spectral area $\lambda = 10\ \mu m$, where the radiation difference of the bodies according to their temperature difference is optimal.

In the case of atmospheric measurements, LIDAR systems have superior advantages over classical remote sensing systems (precision, sensitivity, fast and simultaneous measurements, etc.), the source of electromagnetic radiation being the laser. The main platforms for LIDAR systems are aircraft and satellites.

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