Capabilities analysis of lidar and passive optical methods for remote vegetation monitoring

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Abstract. We have conducted a comparative analysis of efficiency to detect vegetation under adverse conditions by remote lidar and passive optical methods. The paper shows that a lidar method for monitoring at 1.65 and 2.03 μm wavelengths allows us to detect vegetation plots under adverse conditions with a probability of correct detection close to one and a probability of false alarm ~ second decimal places. A laser method that uses two eye-safe sensing wavelengths in the NIR spectral band can lie at the core of the airborne vegetation monitoring method.

1. Introduction

One of the promising aerospace applications is vegetation monitoring.

Adverse environment conditions and pollution, plant pests and deceases, etc. may make normal development of plants impossible. Therefore, development of vegetation monitoring methods is of relevance.

A laser-induced fluorescence technique [1-3] holds considerable promise for remote vegetation monitoring method. However, a sensing range (aircraft altitude, when used) of most fluorescent lidars, as a rule, is 100 - 150 m, at most. Low-altitude sensing leads to a small swath and, consequently, to the low efficiency of this method. Methods, based on the spectral analysis of vegetation-reflected radiation, allow high-altitude aerospace monitoring (from the satellite or aircraft), thereby providing a wide swath. Currently, these methods are, as a rule, passive [4-5].

To estimate vegetation condition, complex parameters called vegetation indices [6-8] are used. Most vegetation indices are based on the values of vegetation reflection coefficients in the visible (especially, red of 0.6 – 0.75 μm) and in the near infrared (NIR) spectral bands (mainly, of 0.75 – 1.3 μm). However, a shortcoming of passive optical sensing systems is that it is impossible to monitor in the dusk and at nighttime, and there is a heavy reliance on the optical state of the earth atmosphere. The lidar method that allows remote high-altitude airborne monitoring of vegetation (thereby providing a wide swath) despite the time of day in a variety of atmospheric conditions is substantially free of these shortcomings. The paper concentrates on the comparative analysis of efficiency to detect vegetation under adverse conditions by remote lidar and passive optical methods.

2. Problem description

Using laser radiation to solve the problems of remote sensing of environmental parameters always involves a potential hazard to the human eyes. The hazard, however, can be minimized.
Radiation in the NIR spectral band with the wavelengths above 1.4 μm and in the UV spectral band with the wavelengths of 0.2 – 0.38 μm is safer (it affects the anterior ocular media) than radiation in the 0.38 – 1.4 μm band, which acts on amphibolestrodes. Moreover, the NIR spectral band with the wavelengths above 1.4 μm is more eye-safe than the UV spectral one with 0.2 – 0.38 μm wavelengths.

Today, there are available spectral libraries of reflection coefficients of a variety of plants (and other natural and human-made objects) [9]. The typical examples of spectral dependence of vegetation reflection coefficients are shown in figure 1 [9].

![Figure 1](image)

**Figure 1.** The typical examples of spectral dependence of vegetation reflection coefficients. a - spurge leaves and b - oak leaves. 1 - live green plants, 2 - dried plants, plants in the fall period.

Figure 1a shows reflection spectra of spurge leaves in July (curve 1) and in October (curve 2). Reflection spectra of live (curve 1) and dry (curve 2) oak leaves are given in figure 1b. The crevasses in the reflection spectra curves mean the absence of measurement data for respective wavelengths.

It is seen from figure 1 that in the NIR spectral band (at the wavelengths above 0.75 μm) the reflection coefficient of live green plants under normal development conditions reaches a maximum value. For vegetation under adverse development conditions (with changing growth season, for dry leaves), with transition to the NIR band, maximum “drop” in the reflection coefficient becomes less.

Reflection spectra variations of plants are a basis for the optical methods to monitor vegetation condition.

The most common NDVI vegetation index uses reflection coefficient values in the red and NIR spectral bands and can be calculated from data of sensors, which have spectral channels in these bands [10], [11]. For instance, an ETM+ (Enhanced Thematic Mapper Plus) radiometer has a red channel of 0.63-0.69 μm and an IR channel of 0.76-0.9 μm. An ASTER (Advanced Space-borne Thermal Emission and Reflection) radiometer has the near 0.63-0.69 μm red and 0.76-0.86 μm IR spectral channels. An ALI (Advanced Land Imager) radiometer has a red channel of 0.63-0.69 μm and an IR channel of 0.845-0.89 μm. A MODIS (Moderate Resolution Imaging Spectroradiometer) has the near 0.62-0.67 μm red and 0.841-0.876 μm IR spectral channels.

An AVHRR (Advanced Very High Resolution Radiometer) has the near 0.58-0.68 μm red and 0.72-1.0 μm IR spectral channels. The MSU-MR (Multichannel Low Resolution Scanner) radiometer channels are of 0.5-0.7 μm and 0.7-1.1 μm, respectively, while those of the KMSS VIS Scanning Imager channels are of 0.58-0.69 μm and 0.63-0.68 μm and 0.76-0.9 μm.

Variations in vegetation reflection spectra (with changing growth season or with plants being under adverse development conditions) in the NIR band at the wavelengths above 1.4 μm are not so apparent.
Based on experimental data of the spectral library of vegetation reflection coefficients, the paper conducts a capability analysis of the laser reflection method for vegetation cover monitoring, which uses two eye-safe sensing wavelengths in the NIR spectral band.

3. **Statistical simulation of correct detection and false alarm probabilities for monitoring of vegetation condition**

In statistical simulation, spectral library data of vegetation reflection coefficients of various plants were used [9]. As an information index (a plant under normal or adverse development conditions), was used a ratio of R reflection coefficients of plants at the wavelengths of 1.65 and 2.03 μm. These wavelengths have been selected in the “atmospheric windows” in the eye-safe spectral band according to spectral features of vegetation reflection in the IR band.

Values of this information index for the plants from the database, created on the basis of the library of spectral reflection coefficients [9], are shown in figure 2.

The Y-axis shows information index R- values for a number of plants data on which are available in the NIR spectral region while the X-axis represents the number of reflection spectrum of the plant in the database created (figure 2).

The item numbers 1-24 are green plants, broad-leaved or needle-leaved trees in the normal condition (1,2,22 – aspen from various plots, 3 – oak, 4 – Russian olive, 5 – blue spruce, 6 – Engelmann spruce, 7 – fir-tree, 8 – juniper, 9-15 – spurge from various plots, 16 – lodge-pole pine, 17 – walnut, 18,19 - lawn grass of various type, 20 – willow, 21 – maple, 23 – pine, 24 – needle-leaved trees and meadow). The item numbers 25-38 are dried plants, plants in the fall period, etc. (25 - dried sagebrush leaves, 26,37,38 – dried grass, 27 – dried oak leaf, 28,29,34 - spurge with flame-colored leaves in the fall period, 30 – lodge-pole pine, dried green needles, 31 – lodge-pole pine, dried brown needles; 32 - dried long brown grass; 33,36 - dried willow leaves, 35 – dried tumble-weed).

![Figure 2](image.png)

**Figure 2.** R values for 1.65 and 2.03 μm sounding wavelengths.

It is seen from figure 2 that for green plants in the normal condition (item numbers are from 1 to 24) information R index values are more than those of for dried plants, plants in the fall period, etc. (item numbers are from 25 to 38).

Figures 3-5 show similar calculated R values of reflection coefficients of plants in the IR and red spectral bands: 0.76-0.9 μm and 0.63-0.69 μm (ETM+ radiometer) - figure 3; 0.845-0.89 μm and 0.63-0.69 μm (ALI radiometer) – figure 4; 0.76-0.9 μm and 0.63-0.68 μm (KMSS VIS Scanning Imager) – figure 5.

Figures 3 – 5 show that for the spectral channels of ETM+, ALI, and KMSS radiometers (and their similar channels of other radiometers), the information index R values for the green plants in normal condition are, in most cases, more than those of for dried plants, plants in the fall period, etc.
Moreover, figures 2-5 show that there is no significant difference in data between the lidar monitoring method of vegetation condition in the NIR spectral band and passive optical method.

**Figure 3.** $R$ values for channels of 0.76-0.9 and 0.63-0.69 μm.

**Figure 4.** $R$ values for channels of 0.845-0.89 and 0.63-0.69 μm.

**Figure 5.** $R$ values for channels of 0.76-0.9 and 0.63-0.68 μm.

To conduct a quantitative comparison of efficiency between the lidar method for monitoring vegetation condition in the NIR spectral band at the wavelengths of 1.65 and 2.03 μm and the passive optical methods with using spectral channels of ETM+, ALI, and KMSS radiometers, mathematical modelling has been performed.

A probability of correct detection (probability to subsume vegetation, being under adverse development conditions, exactly under this category of plants) and a probability of false alarm
(probability to subsume vegetation, being in normal development conditions, under category of plants 
under adverse conditions) have been estimated for abovementioned methods.

A decision on vegetation detection under adverse conditions has been taken provided that the 
following conditions are 
fulfilled: the information index $R$ -value is less than a threshold value of the 
information index. The threshold value of the information index was chosen between the least value of 
the information index $R$ for the live green vegetation under normal conditi 
ions and the most value of 
the information index for the vegetation under adverse conditions.

The mathematical modeling results given below are obtained for the following threshold values of 
the information index: 2.66 – for the sensing wavelengths of 1.65 and 2.03 μm; 5.52 - for the spectral 
channels of 0.76-0.9 μm and 0.63-0.69 μm; 5.69 - for the spectral channels of 0.845-0.89 μm and 0.63- 
0.69 μm; 4.84 - for the spectral channels of 0.76-0.9 μm and 0.63-0.68 μm.

Noise was thought to be Gaussian random variable with zero-mean value and relative mean square 
development $\delta=1 – 10 \%$. The statistical modeling used $10^5$ noise samples.

The correct detection and false alarm probability values for each plant were found in the database 
and then were averaged over all plants.

4. Statistical modelling results
Table 1 presents statistical modeling results of the correct detection probability (Pd) and the false 
alarm probability (Pa) for lidar method in the NIR band for the wavelengths of 1.65 and 2.03 μm.

| $\delta$ (%) | Pd (rel. units) | Pa (rel. units) |
|-------------|-----------------|----------------|
| 1           | >0.9999         | <0.0001        |
| 3           | 0.9995          | 0.0009         |
| 5           | 0.9940          | 0.0086         |
| 10          | 0.9750          | 0.0330         |

Tables 2 – 4 give statistical modelling results of the correct detection probability (Pd) and the false 
alarm probability (Pa) for the spectral channels of 0.76-0.9 μm and 0.63-0.69 μm (ETM+ radiometer); 
0.845-0.89 μm and 0.63-0.69 μm (ALI radiometer); 0.76-0.9 μm and 0.63-0.68 μm (KMSS VIS 
Scanning Imager).

| $\delta$ (%) | Pd (rel. units) | Pa (rel. units) |
|-------------|-----------------|----------------|
| 1           | >0.9999         | <0.0001        |
| 3           | 0.996           | 0.0034         |
| 5           | 0.987           | 0.010          |
| 10          | 0.968           | 0.032          |

| $\delta$ (%) | Pd (rel. units) | Pa (rel. units) |
|-------------|-----------------|----------------|
| 1           | >0.9999         | <0.0001        |
| 3           | 0.994           | 0.005          |
| 5           | 0.984           | 0.017          |
| 10          | 0.961           | 0.044          |

| $\delta$ (%) | Pd (rel. units) | Pa (rel. units) |
|-------------|-----------------|----------------|
| 1           | 0.997           | 0.0001         |
The results given in tables 1 - 4 show that lidar sensing of vegetation condition in the NIR spectral band proves to be more efficient than monitoring of vegetation condition by passive optical method using the multispectral ETM+, ALI, KMSS radiometers (and other sensors similar in spectral channels), which have spectral channels in the red and NIR (less than 1 μm) spectra.

The given results show that laser sensing at the wavelengths of 1.65 and 2.03 μm provides highly reliable (with a probability of correct detection close to one and a probability of false alarm ~ second decimal places) detection of vegetation plots under adverse conditions.

Thus, the lidar method using two eye-safe sensing wavelengths in the NIR spectral band can lie at the core of the airborne vegetation monitoring method.

5. Conclusion
The statistical simulation of correct detection and false alarm probabilities to monitor vegetation under adverse conditions has been performed for lidar reflection method at two eye-safe sensing wavelengths in the NIR band and for the passive optical methods. It is shown that the lidar method at the wavelengths of 1.65 and 2.03 μm allows detection of vegetation plots under adverse conditions with a probability of correct detection close to one and a probability of false alarm ~ second decimal places. The lidar method using two eye-safe sensing wavelengths in the NIR spectral band can lie at the core of the airborne vegetation monitoring method.

References
[1] Yanga J, Gonga W, Shia S, Dua L, Suna J and Songe S 2016 Spectroscopy letters 4 263
[2] Pandey J K and Gopal R 2011 Spectroscopy 26 129
[3] Hedimbil M, Singh S and Kent A 2012 Natural Science 4 395
[4] Zygielbaum A I, Gitelson A A, Arkebauer T J and Rundquist D C 2009 Geophysical research letters 36 1
[5] Gitelson A A, Kaufman Y J, Stark R and Rundquist D 2002 Remote Sensing of Environment 80 76
[6] Vina A, Gitelson A A, Nguy-Robertson A L and Peng Y 2011 Remote Sensing of Environment 115 3468
[7] Emangini E J, Blackburn G A and Theobald J C 2013 Research Journal of Applied Sciences 8 302
[8] Huete A, Didan K, Miura T, Rodriguez E P, Gao X and Ferreira L G 2002 Remote Sensing of Environment 83 195
[9] Clark R N, Swayne G A, Wise R, Livo K E, Hoefen T M, Kokaly R F and Sutley S J 2007 USGS Digital Spectral Library splib06a (U.S. Geological Survey) Available online: http://speclab.cr.usgs.gov/spectral.lib06
[10] Meteor-M-2 Meteorological Mission. Available online: https://directory.eoportal.org/web/eoportal/satellite-missions/m/meteor-m-2
[11] Kramer H 2002 Observation of the Earth and its Environment (Berlin: Springer Verlag) pp 329-553