Laser airborne reflection method for remote sensing forest species composition

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Abstract. Statistical modelling of the correct detection and false alarm probabilities has been implemented to identify dominant (needle-leaved or broadleaved) tree species through laser sensing in the UV and NIR spectral bands. It is shown that the laser method of monitoring at 355 nm and 2100 nm wavelengths allows sensing dominant needle-leaved or broadleaved tree species with a probability of correct detection close to one and a probability of false alarm ~ second decimal places. The laser method using two eye-safe sensing wavelengths in the UV and NIR spectral bands can be used for airborne forest monitoring.

1. Introduction
Remote aerospace monitoring is the most promising method to monitor large forestlands [1-5].

Currently, forest monitoring, commonly, uses a variety of vegetation indices from data of passive multi- or hyper-spectral sensors in visible or near infrared (mostly, up to 1 μm) spectral bands. In forestry, a principal task to sense forest species composition [6-9] is solved by optical methods of aerospace monitoring.

Methods based on the spectral analysis of vegetation-reflected optical radiation allow high-altitude space or airborne monitoring thereby providing a large swath on the Earth’s surface.

Presently, these optical methods are passive, as a rule. However, a drawback of the passive optical sensing systems is that monitoring is impossible in the dusk and at night, and there is a heavy reliance on the optical state of the Earth’s atmosphere. A laser reflection method, which is free of these drawbacks, allows us to monitor forest species composition from a high-flying aircraft (thereby providing a large swath on the Earth’s surface) at any time of the day or night in a wide range of weathering conditions.

The paper analyses a capability of the laser reflection method for sensing the forest sites with dominant needle-leaved or broadleaved tree species.

2. Problem description
Up to date spectral libraries of reflection coefficients of various vegetation types (including a variety of forest species) are available [10,11].

Figure 1 shows typical examples of spectral dependences, representing reflection coefficients of broadleaved or needle-leaved tree species within the broad spectral band of 350 – 2500 nm.
Figure 1. Spectral reflection coefficients of tree species.

It is seen from the figure that, in the spectral band of 350 – 725 nm, the reflection coefficients of broadleaved and needle-leaved tree species are pretty much close to each other. In the spectral band of 725 – 1350 nm, the reflection spectra are unlike to some extent, but it is impossible to tell the needle-leaved tree species from the broadleaved ones.

The situation is a lot better in the spectral bands of 1500 – 1800 nm and 2050 – 2300 nm. It is much in evidence that reflection spectra of broadleaved tree species differ from those of the needle-leaved ones in these spectral bands.

Using the experimentally obtained reflection spectra of various needle-leaved and broadleaved tree species, the paper conducts mathematical simulation aimed at selecting the laser sensing wavelengths and analyse the laser reflection method capabilities to detect the forest sites with dominant broadleaved or needle-leaved tree species.

3. Laser sensing wavelength selection to detect forest sites with dominant broadleaved or needle-leaved tree species

Laser emission used to solve a task of remote sensing the environment parameters is always a potential eye hazard. However, this hazard can be minimized. Emission in the near infrared (NIR) spectral band with the wavelengths above 1400 nm and ultra-violet (UV) spectral band of 200 – 380 nm wavelengths is safer (it effects on anterior ocular media) than that of in the spectral band of 380 – 1400nm (it has impact on retina).

When selecting the laser sensing wavelengths to detect forest sites with dominant needle-leaved or broadleaved tree species, an eye safety has been taken into account, and spectral library data of reflection coefficients of various vegetation types have been used [10,11].

As an information index (needle-leaved or broadleaved tree species), a ratio $R(\lambda_1,\lambda_2)$ of the reflection coefficients of plants has been used at two $\lambda_1,\lambda_2$ wavelengths.

Modelling results show that the promising options of $\lambda_1,\lambda_2$ wavelengths are $\lambda_1$ in the UV spectral band of 355 nm and $\lambda_2$ in the NIR band of 2100 nm. These wavelengths were chosen in the eye-safe spectral band on the basis of spectral reflection features of the needle-leaved and broadleaved tree species and proceeding from the spectral dependence of atmospheric transmission.

Values of this information index for 355 nm and 2100 nm from the database, created on the basis of the library of spectral reflection coefficients [10,11], are shown in figure 2. Y-axis shows $R$ information index values while along X – axis there is an item number n of the tree reflection spectrum in the database created.
Figure 2. R values at 355 and 2100 nm for the needle-leaved and broadleaved trees.

The item numbers 1-26 are broadleaved trees in summer season (1-3 – Aspen, 4 – Russian Olive, 5 – Walnut, 6 – Maple, 7,8 - Acer paxii, 9,10 – Acer pensylvanicum, 11-14 – Betula papyrifera, 15-18 – Quercus rubra, 19-22 - Quercus robur, 23, 24 - Fagus grandifolia, 25,26 - Fagus sylvatica).

The item numbers 27-55 are needle-leaved trees in summer season (27-32 – Pinus lambertiana, 33-38 – Pinus ponderosa, 39-41 - Pinus strobos, 42-44 – Gray Pine, 45 – Lodgepole Pine, 46 – Blue Spruce, 47 - Engelmann-Spruce, 48 – Juniper Bush, 49-52 – Cedrus atlantica, 53-55 - Abies concolor).

It is seen from figure 2 that the parameter R values at 355 and 2100 nm for the broadleaved tree species are more than values of the information parameter R for the needle-leaved ones.

Figure 3 (to compare with figure 2) shows the information parameter $R(\lambda_1,\lambda_2)$ values at $\lambda_1 = 355$ nm and $\lambda_2 = 1540$ nm.

Figure 3. R values at 355 and 1540 nm for needle-leaved and broadleaved trees.

It is evident that this option of the information parameter is worse than that of at $\lambda_1 = 355$ nm and $\lambda_2 = 2100$ nm.
For quantitative comparison of the laser reflection method efficiency at the sensing wavelengths \( \lambda_1 = 355 \text{ nm}, \lambda_2 = 2100 \text{ nm} \) and \( \lambda_1 = 355 \text{ nm}, \lambda_2 = 1540 \text{ nm} \), statistical simulation has been made. Probabilities of correct detection (properly identified forest species) and false alarm for abovementioned sensing wavelength pairs have been estimated. Noise was thought to be Gaussian random variable with zero-mean value and relative mean square deviation \( \delta=1–10\% \). The statistical simulation used \( 10^5 \) noise samples.

Decision on the dominance of needle-leaved or broadleaved tree species is made under following conditions: for broadleaved tree species, the information parameter \( R(\lambda_1, \lambda_2) \) value is more or equal to the threshold value of the information parameter, and for the needle-leaved tree species, the information parameter value is less than the threshold information parameter value. For the sensing wavelengths \( \lambda_1 = 355 \text{ nm} \) and \( \lambda_2 = 2100 \text{ nm} \), the threshold value is chosen to be equal to 2.32 while for the sensing wavelengths \( \lambda_1 = 355 \text{ nm} \) and \( \lambda_2 = 1540 \text{ nm} \), it is 4.21.

The probability values of correct detection and false alarm were found from the database for each spectrum and then were averaged throughout the database.

4. **Mathematical modelling results**

Tables 1 and 2 present mathematical modelling results of the correct detection probability \( P_d \) (proper identification of dominant forest species) and the false alarm probability \( P_a \) at the sensing wavelengths \( \lambda_1 = 355 \text{ nm}, \lambda_2 = 2100 \text{ nm} \) and \( \lambda_1 = 355 \text{ nm}, \lambda_2 = 1540 \text{ nm} \).

**Table 1.** Probabilities \( P_d \) and \( P_a \) at \( \lambda_1 = 355 \text{ nm}, \lambda_2 = 2100 \text{ nm} \).

| \( \delta \) (%) | \( P_d \) | \( P_a \) |
|------------------|---------|---------|
| 1                | 0.99    | <0.01   |
| 3                | 0.96    | 0.06    |
| 5                | 0.94    | 0.07    |
| 10               | 0.89    | 0.12    |

**Table 2.** Probabilities \( P_d \) and \( P_a \) at \( \lambda_1 = 355 \text{ nm}, \lambda_2 = 1540 \text{ nm} \).

| \( \delta \) (%) | \( P_d \) | \( P_a \) |
|------------------|---------|---------|
| 1                | 0.90    | 0.14    |
| 3                | 0.89    | 0.14    |
| 5                | 0.88    | 0.14    |
| 10               | 0.85    | 0.17    |

The results given in tables 1,2 show that an option of the information parameter at wavelengths \( \lambda_1 = 355 \text{ nm}, \lambda_2 = 2100 \text{ nm} \) is essentially better than that of with \( \lambda_1 = 355 \text{ nm}, \lambda_2 = 1540 \text{ nm} \).

Spatial averaging of measurement data, perhaps, can improve results of sensing the dominant forest species at \( \lambda_1 = 355 \text{ nm}, \lambda_2 = 2100 \text{ nm} \). As an example, figure 4 shows the value of the information parameter \( R(\lambda_1, \lambda_2) \) at \( \lambda_1 = 355 \text{ nm}, \lambda_2 = 2100 \text{ nm} \) after averaging of data [10,11] from various measurements taken for each of the forest species.

Table 3 shows the mathematical modelling results of the correct detection probability \( P_d \) and false alarm probability \( P_a \) for data given in figure 4. The threshold information index value (table 3) was chosen midway between the least value of the information parameter \( R \) for broadleaved tree species and the most information parameter for needle-leaved ones.
Figure 4. R values at 355 and 2100 nm after averaging.

Table 3. Probabilities $P_d$ and $P_a$ at $\lambda_1 = 355$ nm, $\lambda_2 = 2100$ nm after averaging.

| $\delta$ (%) | $P_d$ | $P_a$ |
|--------------|-------|-------|
| 1            | 0     | 0     |
| 3            | 0.99  | <0.01 |
| 5            | 0.96  | 0.01  |
| 10           | 0.93  | 0.04  |

The given results show that laser sensing at the wavelengths of 355 nm and 2100 nm allows a highly reliable (with a probability of correct detection close to one and a probability of false alarm ~ second decimal places) detection of dominant needle-leaved or broadleaved tree species.

5. Conclusion

Statistical modelling of the correct detection and false alarm probabilities has been implemented to identify dominant (needle-leaved or broadleaved) tree species through laser sensing in the UV and NIR spectral bands. It is shown that the laser method of monitoring at eye-safe wavelengths 355 and 2100 nm wavelengths allows sensing dominant needle-leaved or broadleaved tree species with a probability of correct detection close to one and a probability of false alarm ~ second decimal places. The method using two eye-safe sensing wavelengths can be used for airborne forest monitoring.

References

[1] White J C, Coops N C, Wulder M A, Vastaranta M, Hilker T and Tompalski P 2016 Can. J. Remote Sens. 42 619
[2] Gini R, Passoni D, Pinto L and Sona G 2014 European Journal of Remote Sensing 47 251
[3] Puliti S., Ørka H O, Gobakken T and Næsset E 2015 Remote Sensing 7 9632
[4] Torresan C, Berton A, Carotenuto F, Filippo S, Gennaro B, Matese A, Miglietta F, Vagnoli C, Zaldei A and Wallace L 2017 International Journal of Remote Sensing 38 2427
[5] Immitzer M, Vuolo F and Atzberger C 2016 Remote Sensing 8 166
[6] Laurin G V, Puletti N, Hawthorne W, Liesenberg V, Corona P, Papale D, Chen Q and Valentini R 2016 Remote Sensing of Environment 176 163
[7] Michez A, Piégay H, Lisein J, Claessens H and Lejeune P 2016 Environmental Monitoring and Assessment 188 146
[8] Colgan M S, Baldeck CA, Féret J B and Asner G P 2012 Remote Sensing 4 3462
[9] ECOSTRESS Spectral Library - Version 1.0 Retrieved from: https://speclib.jpl.nasa.gov
[10] USGS Digital Spectral Library 06 Retrieved from: http://speclab.cr.usgs.gov/spectral.lib06