Analysing detection bands of two-spectral reflection method to identify forest species composition

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Abstract. The optical reflection method is considered for detection of the forest areas where coniferous or broadleaved trees are dominant. Statistical modelling of correct detection and false alarm probabilities for identifying dominant (coniferous or broadleaved) tree species by the two-spectral reflection method has been conducted. It has been shown that monitoring enables us to identify dominant (coniferous or broadleaved) tree species with correct detection probability close to 1 and false alarms probability ~ second decimal places for the temperate climate zone at the wavelengths of 532 and 1540 nm or 532 and 1480 nm. As to the subtropical climate zone, due to a great variety of reflection spectra of vegetation, a selection of the spectral detection bands for reliable identification of dominant coniferous or broadleaved tree species is possible only for specific forestlands where the number of evergreen broadleaved and coniferous tree species is relatively small.

1. Introduction
Forestland monitoring is a current challenge of environmental control. Reliable information on the forestland condition and species composition is needed to make an objective assessment of situation, predictions, and plans for sustainable use of forest resources.

Today, ground monitoring is a primary reliable data source to inform on the current condition of forestlands. It provides objective information on the forestlands, but makes it impossible to be promptly informed on the forest condition, especially if forest areas are large and in remote and uninhabited localities.

Optical aerospace sensing is a powerful method to monitor forest condition [1-4].

Methods, based on the spectral analysis of vegetation-reflected optical emission, enable high-altitude airborne monitoring (from a satellite or an aircraft) thereby ensuring a large swath on the ground surface.

Currently, one of the key tasks of remote forestland monitoring is to identify the forest species composition [5-9].

The paper is concerned with optical method development to detect the forest areas where coniferous or broadleaved trees are dominant.

2. Problem description
Databases of spectral reflectance of various broadleaved and coniferous trees are, currently, available [11,12].
Figure 1 [12,13] presents spectral reflectance of broadleaved and coniferous trees typical for a temperate climate zone in the broad spectral band from 350 to 2500 nm.

![Figure 1](image1.png)

**Figure 1.** Spectral reflectance of broadleaved. (a) typical trees (1 - beech, 2 – birch, 3 - oak) and coniferous (b) typical trees (1 – pine, 2 – spruce, 3 - cedrus) for a temperate climate zone.

Figure 1 shows that in the spectral bands of 1500 – 1800 nm and 2000 – 2500 nm there is clear distinction between reflection spectra of broadleaved and coniferous trees.

The paper [10] describes a two-spectral reflection method that uses two sensing wavelengths of 355 nm and 2100 nm to provide monitoring of forest species composition in a temperate climate zone. In the paper, based on experimental reflection spectra of deciduous and coniferous tree species, mathematical modeling is carried out in order to select the optimal recording spectral ranges and analyze the possibilities of a two-spectral reflectometric method for determining forest areas with a predominance of coniferous or deciduous tree species in different climatic zones.

### 3. Selection of spectral detection bands to identify forest species composition

A relationship \( R(\lambda_1, \lambda_2) = \frac{r(\lambda_2)}{r(\lambda_1)} \) of the spectral reflectance \( r(\lambda_1) \) and \( r(\lambda_2) \) at two wavelengths \( \lambda_1, \lambda_2 \) was used as an information index (broadleaved or coniferous trees).

Modelling was conducted at different wavelengths (355, 532, 850, 1480, 1540, 1935, 2030, 2100, and 2490 nm) for tree species, which are typical for a temperate climate zone (European and Asian part of the Russian Federation and North America) and a subtropical climate zone (California).

For a temperate climate zone, the calculated data values of the information index \( R(\lambda_1, \lambda_2) \) in the promising spectral bands are shown in figure 2 (a – d) for a database created on the basis of [12,13].

The vertical axis presents values of the information index \( R \), while the horizontal one depicts the number \( n \) of the reflection spectra of trees in the database created (figure 2). Species number 1-26: 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). Species 27-55: coniferous trees in summer season (27-32 – Pinus lambertiana, 33-38 – Pinus ponderosa, 39-41 - Pinus strobus, 42-44 – Gray Pine, 45 – Lodgepole Pine, 46 – Blue Spruce, 47 - Engelmann-Spruce, 48 – Juniper Bush, 49-52 – Cedrus atlantica, 53-55 - Abies concolor).

For figures 2-4 thick line is \( \lambda_2 = 1540 \) nm, thin line - \( \lambda_2 = 2100 \) nm, dashed line - \( \lambda_2 = 1480 \) nm, dashed dotted line - \( \lambda_2 = 2030 \) nm. Figures a - \( \lambda_1 = 355 \) nm, b - 380 nm, c - 532 nm, d - 850 nm.

It is seen form figure 2 that for green broadleaved tree species the values of the index \( R(\lambda_1, \lambda_2) \) are predominantly more than those of the information index for coniferous tree species.
The best option is the wavelengths $\lambda_1 = 532$ nm, $\lambda_2 = 1480; 1540; 2030; 2100$ nm. A slightly worse option of the wavelengths $\lambda_1 = 355$ nm, $\lambda_2 = 2030$ or 2100 nm can be used for a laser system.

Figure 2. Information index for coniferous and broadleaved tree species for a temperate climate zone.

Figure 3 (a – d) illustrates the calculated data values of the information index R at the same wavelengths as in figure 2 for the evergreen species of trees in a subtropical climate zone (California).
Figure 3. Information index for evergreen coniferous and broadleaved trees for a subtropical climate zone (California).

Species number (figure 3): 1-34 – evergreen broadleaved trees (1-7, 13-18, 25-27 - various species of Quercus; 8 - Umbellularia californica; 9, 10 - Lagerstroemia indica; 11, 12 - Macadamia integrifolia; 19-24 – various species of Eucalyptus; 28-34 – Manzanita), 35-55 - coniferous trees (35-40 – various species of Abies; 44-49 – various species of Pinus; 41-43, 50-52 - Calocedrus decurrens; 53-55 - various species of juniper).

It is seen from figure 3 that due to a great variety of reflection spectra of vegetation in a subtropical climate zone (California) none of given options of the wavelength pairs enables identifying the forest areas with dominant broadleaved or coniferous tree species.

Figure 3 shows that, in the general case, a selection of the spectral detection bands for forests of a subtropical zone is non-obvious. However, as to the specific forestlands of evergreen broadleaved and coniferous trees, the spectral detection bands can be easily selected.

Figure 4, for instance, present results for a special case concerned with mixed evergreen forests of California on the soils of Franciscan Association.

Figure 4. Information index for coniferous and broadleaved tree species for mixed evergreen forests of California on the soils of Franciscan Association.
Species number (figure 4): 1-14 – evergreen broadleaved trees (1-13 – various species of Quercus, 14 - Umbellularia californica), 15-26 - coniferous trees (15-20 – various species of Abies, 21-23 – various species of Pinus, 24-26 - Douglas fir). Information index zero values mean that at the wavelength of 355 nm no measurement data are available for certain tree species.

It is seen from figure 4 that the spectral detection bands can be easily selected. The best option is the wavelengths \( \lambda_1 = 850 \text{ nm} \), \( \lambda_2 = 1480; 1540; 2030; 2100 \text{ nm} \).

Statistical modelling was conducted to provide a quantitative estimate of the reflection method for various spectral detection bands. The correct detection (dominant tree species properly identified) and false alarm probabilities for the temperate and subtropical (mixed evergreen forests on the soils of Franciscan Association) climate zones were estimated.

It was thought that noise is Gaussian random variable with zero mean and relative mean square deviation \( \delta = 1 - 10 \% \). Statistical modeling was made for \( 10^5 \) noise samples.

Decision on dominance of coniferous or broadleaved tree species was made provided that the following requirements were fulfilled: the information index value was more or equal to the threshold value for broadleaved trees, and for coniferous ones the information index value was less than the threshold information index.

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

### 4. Mathematical modelling results

Tables 1 and 2 give the mathematical modelling results of the correct detection probability \( P_d \) (correct identification of dominant tree species) and the false alarm probability \( P_a \) at the wavelengths \( \lambda_1 = 532 \text{ nm} \), \( \lambda_2 = 1480 \text{ nm} \) (the threshold value of the information index was assumed to be equal to 1.571) and \( \lambda_1 = 532 \text{ nm} \), \( \lambda_2 = 1540 \text{ nm} \) (the threshold value of the information index was assumed to be equal to 2.094) for a temperate climate zone.

| \( \delta \) (%) | \( P_d \) | \( P_a \) |
|---------------|----------|----------|
| 1             | >0.99    | 0.07     |
| 3             | >0.99    | 0.08     |
| 5             | 0.98     | 0.08     |
| 10            | 0.97     | 0.09     |

| \( \delta \) (%) | \( P_d \) | \( P_a \) |
|---------------|----------|----------|
| 1             | >0.99    | 0.04     |
| 3             | 0.99     | 0.04     |
| 5             | 0.97     | 0.06     |
| 10            | 0.95     | 0.06     |

Tables 3 and 4 give the mathematical modelling results of the correct detection probability \( P_d \) and the false alarm probability \( P_a \) at the wavelengths \( \lambda_1 = 850 \text{ nm} \), \( \lambda_2 = 1480 \text{ nm} \) (the threshold value of the information index was assumed to be equal to 0.303) and \( \lambda_1 = 850 \text{ nm} \), \( \lambda_2 = 1540 \text{ nm} \) (the threshold value of the information index was assumed to be equal to 0.422) for a subtropical (mixed evergreen forests on the soils of Franciscan Association) climate zone.
Table 3. Correct detection and false alarm probabilities, $\lambda_1 = 850$ nm, $\lambda_2 = 1480$ nm.

| $\delta$ (%) | $P_d$ | $P_a$ |
|--------------|-------|-------|
| 1            | >0.99 | <0.01 |
| 3            | >0.99 | <0.01 |
| 5            | 0.99  | 0.01  |
| 10           | 0.98  | 0.03  |

Table 4. Correct detection and false alarm probabilities, $\lambda_1 = 850$ nm, $\lambda_2 = 1540$ nm.

| $\delta$ (%) | $P_d$ | $P_a$ |
|--------------|-------|-------|
| 1            | >0.99 | <0.01 |
| 3            | >0.99 | <0.01 |
| 5            | 0.99  | 0.01  |
| 10           | 0.99  | 0.1   |

The results (tables 1-4) demonstrate that the two-spectral reflection method is highly reliable (with correct detection probability close to 1 and false alarms probability ~ second decimal places) to identify dominant tree species in a temperate and subtropical climate zones.

5. Conclusion

Thus, statistical modelling of correct detection and false alarm probabilities for identifying dominant (coniferous or broadleaved) tree species by the two-spectral reflection method has been conducted. It has been shown that monitoring enables us to identify dominant (coniferous or broadleaved) tree species with correct detection probability close to 1 and false alarms probability ~ second decimal places for the temperate climate zone at the wavelengths of 532 and 1540 nm or 532 and 1480 nm. As to the subtropical climate zone, due to a great variety of reflection spectra of vegetation, a selection of the spectral detection bands for reliable identification of dominant coniferous or broadleaved tree species is possible only for specific forestlands where the number of evergreen broadleaved and coniferous tree species is relatively small.

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