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REMOTE SENSING TOOLS FOR ANALYZING STATE AND CONDITION OF VEGETATION

NARZĘDZIA TELEDETEKCYJNE W ANALIZIE STANU ROŚLINNOŚCI

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Introduction

Hyperspectral data, which are characterized by very high spectral, spatial and radiometric resolutions, allow the analysis of the biometric properties of plants in different wavelengths of the electromagnetic spectrum. This kind of data can be applied to interpretation of vegetation, land cover forecast biomass and crops and also for analyzing plant condition, because vegetation cover is a very good indicator of environmental condition.

All the spectral characteristics of plants can be measured and analyzed quantitatively using different vegetation indices, which are a mathematical combination of various bands. The most frequently used regions of the spectrum are visible, red-near infrared edge, near and middle infrared. In these regions it is possible to measure chlorophyll, carotenoids and other pigment content, fresh and dry biomass, water and nutrient content, internal leaf structure, soil moisture and plant surface temperature.

In this study, four of the vegetation indices have been analysed: Normalized Difference Vegetation Index (Rouse et al., 1973; Griffith et al., 2002), Soil Adjusted Vegetation Index (Huete, 1988), Leaf Area Index (Surlock, 2001; Haboudane et al., 2004) and fAPAR – fraction of Absorbed Photosynthetically Active Radiation (Moreau, Li, 1996). These indices measure the condition of plants and estimate the quantity of biomass. Correctly calculated indices offer much information about the functionality of an ecosystem. Such vegetation indices are broadly used for vegetation monitoring.

The main purpose of the research was an analysis of plant condition using remote sensing methods. Maps of spatial distribution of the NDVI, SAVI, LAI and fAPAR were prepared using ground and airborne measurements (DAIS 7915 products were corrected and verified by field measurements). Indices from airborne and ground level measurements were also correlated.

The studies took place in the Low Beskid Mountains., which constitute one of the most natural parts of the Polish Carpathian Mountains (Fig. 3). The area extends from 49°34'–49°41'N to 21°01'–21°09'E, with an altitude range of 400–750 m. The study area focuses on the Bystrzanka catchment around the town of Szymbark. This catchment has an area of around 13.5 km^2. The largest part of the area, 40%, is covered by forest. Meadows and pasture comprise 28% of the area. A small fragment of the area is covered by arable land. The area is defined as a natural and seminatural environment. The human influence is relatively low and natural processes are not disturbed, so that vegetation can be used here as an indicator of other ecosystem components (soils, microclimate etc.).

Materials and methods

The research methodology had few stages: measurements from ground level were compared to values from an image, images of vegetation indices were transformed using statistical analysis and maps were made.

Ground measurements consist of spectrometric and biometric measurements of LAI and fAPAR. During these measurements, which were made in July and August 2002, data from 47 polygons were collected. They represent different kinds of land use: meadows, corn, stubble, clover and potatoes. Values were collected by facilities analysing precise intervals of the spectrum using: a field spectrometer, ASD FieldSpec Pro (NDVI, SAVI), LAI-2000, Plant Canopy Analyzer (LAI) and AccuPAR 80 (fAPAR). The ASD FieldSpec Pro spectrometer has a spectral range from 325 do 2500 nm and spectral resolution from 3 do 10 nm. It is designed to record measurements of solar reflectance, radiance and irradiance. Correction was made before all measurements and measurements were made in natural light. Two vegetation indices were calculated from the collected spectra – Normalized Difference Vegetation Index and Soil Adjusted Vegetation Index. Leaf Area Index was measured using the LAI-2000 Plant Canopy Analyzer. The amount of foliage in a vegetative canopy can be deduced from measurements of how quickly radiation is attenuated as it passes through the canopy. The LAI-2000 measures the probability of seeing the sky looking up through a vegetative canopy in different directions. The measurements are non-contact, indirect and not destructive. The remaining index – fAPAR, was measured using an AccuPAR 80. The photodiodes measure PAR in the 400–700 nanometres and the fraction was calculated from the formula. The results of the field measurements were collected and saved in MS Excel worksheets.

The hyperspectral images were acquired on 29 July 2002 by the airborne hyperspectral scanner DAIS 7915, which was installed on the Dornier Do-228 aircraft of the German Aerospace Centre (DLR). The images were acquired as part of the HySens PL02_05 campaign. The radiometric resolution of the imagery is 15 bit; it has 79 spectral bands from visible, near and middle infrared to thermal IR. The spatial resolution of the scanner is 3 meters. Three lines of image covered the key areas: Wiatrowki, Taborowka and Biesnik, but only two of them were used for these analyses. In January 2003 the pre-processing was performed at the DLR Oberpfaffenhoffen. The parametric geometric correction were made using the PARGE software, the atmospheric correction and creation of vegetation indices (SAVI, LAI and fAPAR) were made in the ATCOR 4 environment, developed by the DLR and ReSeL laboratories. The NDVI image was made using ENVI 4.3. The three index images: SAVI, LAI and fAPAR were validated against the ground measurements. Then, a vector layer with points and polygons for the measurement locations was created. Values for four vegetation indices were collected from the images and then saved in MS Excel.

Finally, statistical analysis of he vegetation indices from ground- and airborne- collections were performed. Correlations with regression equations were calculated for relationships between values of the same index (NDVI, SAVI, LAI and fAPAR) from ground and airborne measurements, and NDVI-LAI and NDVI-fAPAR relationships from ground and airborne measurements. Then the regression equation (describing the correlation between the same index from the: airborne and ground measurements) were calculated comparing values of the vegetation indices from ground and airborne data. The correlation equations of the same index were used to transform images of vegetation indices to get maps of spatial distribution of vegetation index in adequate units, using the BandMath function in ENVI 4.3. The maps were validated to each land cover unit by field collected data. This step used maps derived from the airborne images. Values on the maps and optimal ranges of biometrical indices were compared. Values of indices were divided into different state ranges, for NDVI: bad (less than 0), poor (0–0.19), rather good (0.2–0.39), good (0.4–0.59), very good (0.6–0.79), excellent (0.8–1); SAVI: bad (less than 0), poor (0–0.24), rather good (0.25–0.49), good (0.5–0.74), very good (0.75–0.99), excellent (above 1) and fAPAR: poor (less than 0), average (0–0.24), good (0.25–0.49), very good (0.5–0.74), excellent (0.75–1). Values of LAI were divided on ranges: no biomass (0–0.99), small quantity of biomass (1–2.99), rather big quantity of biomass (3–4.99), big quantity of biomass (5–6.99) and very big quantity of biomass (above 7).

The result was a map of plant condition including values for more than one vegetation index. The final map of the Bystrzanka catchment was prepared by multiplying all 3 layers of SAVI, LAI and fAPAR indices. Each legend unit had one value from 1 (for low values of index – the worst condition) to 5 (for high values of index – the best plant condition). Maps were prepared using ArcGIS. The new map was validated again creating 6 classes describing plant condition. This operation produced a map of plant condition based on plant canopy, amount of biomass and percentage of light, which is used for photosynthesis.

Correlations between vegetation indices from different level

The relationships for the four vegetation indices (NDVI, LAI, SAVI and fAPAR) measured from the ground and airborne levels were calculated (y – field measurement, x – airborne measurement). Some of the points characterized by a large standard deviation were eliminated. After this elimination, the relationships between ground and airborne measurements were strong; R^2 is above 0.8 for all indices; every point is an average from 10 measurements.

Closer dependence was noticed for spectrometric indices; the equations were: NDVI: $y=1.2769x–0.1968$ with $R^2=0.91$ and SAVI: $y=0.0027x–0.1596$ and $R^2=0.91$. Less strong correlations were for the other two indices: LAI – $y=0.0044x+0.5738$ and $R^2=0.80$; fAPAR – $y=0.0038x–0.2081$ and $R^2=0.80$ (Jarocińska, Zagajewski, 2008). Weak relationships can be caused by several factiors. Firstly, the data are from different kinds of measurements (instruments on the ground measure radiation on small area, while airborne DAIS 7915 measures radiation from 9 m^2 area, that can be very heterogeneous); secondly, ground measurements take longer than taking airborne pictures; values of vegetation indices can be variable due to different phenological stages and human activity for plants, which can influence the measurements; and stronger relationships for spectrometric indices – NDVI and SAVI can be caused by using the same instrument to make the ground measurements – here the FieldSpec Pro spectrometer.

The correlation between NDVI and LAI on ground level was very poor, the equation of correlation was: y=4.9691×x+1.2376 with R^2=0.37 (Fig. 1a). The relationship should be stronger, because the indices are connected. The relationship for airborne measurements is much more stronger with R^2=0.87 for y=2078.8×x–365.54 (Fig. 1b). The strongest correlation was for stubbles and meadows.

NDVI describes chlorophyll content and cell structure, which means it can measure plant condition. For plants under no stress the quantity of biomass measured by the LAI is high. That is why these two indices should be highly correlated. Poor correlation at ground level can be caused by heterogeneity of the fields and anthropogenic activity (Bochenek, 1990). The relationship is influenced by different type of land use: for example, potatoes grow in rows, the reflectance is from canopy and also soil, that is why values of LAI are small. Values of NDVI can be very high because plant are in good condition. The same situation can be described for stubbles, where biomass is removed by moving, so LAI is small but the condition of the plants is good and NDVI is very high. Better correlations for airborne level were noticed because images from scanner DAIS 7915 average values of indices from the one 3 meter pixel. The airborne measurements were also calculated from the same instruments whereas at ground level two different instruments were used.

In other research it was noticed, that NDVI is correlated with LAI, but stronger correlations are for LAI and SAVI (Epiphanio, Huete, 1995).

Correlation between NDVI and fAPAR for ground level were very weak. Correlation was described by the equation: y=0.6091×x+0.4458 with R^2=0.19, which indicates no relationship (Fig. 2a). The best correlation was for corns. For airborne level measurements the correlation was much better, R^2=0.86, which means good correlation. The equation was: y=535.07×x–32.657 (Fig. 2b). The strongest relationship was noticed for stubbles and meadows.

NDVI shows the condition of plants through their chlorophyll content. fAPAR estimates productivity and photosynthetic activity and also can be used to estimate condition of vegetation. Thus these two indices should be highly correlated, especially for natural ecosystems. The relation between indices has been analyzed by other authors (Di Bella et al., 2004). They discovered that it can be disturbed by many factors: the sensor angle, zenith angle, pixel heterogeneity, leaf surface, orientation and optical properties. No correlation on ground level can be also result from using different kind of instruments: ASD FieldSpec and AccuPAR. There were big differences between various kind of land use: for stubbles the values of the vegetation indices are completely different, from other farmlands. For natural ecosystems correlations were closer.

Evaluation of canopy condition of the Bystrzanka catchment

The analyses of vegetation were based on the spatial distribution of the four vegetation indices: NDVI, SAVI, LAI and fAPAR (Zagajewski, Jarocińska, 2008). All the vegetation indices had generally high values in the analysed area, which means that the plants are in good and very good condition.

The average value of NDVI was around 0.6, about 65% of area had good condition and 26.6% of the area had vegetation in average condition. Only 0.6% of area – mostly urbanized area or without plants at all, had small values. The average value of SAVI for the whole image was around 0.7, which means that most of the soil was covered by plants. Plants in good condition covered the biggest area. The small forest area had excellent conditions. The average value of LAI was around 3.9, maximum values were above 10 and minimum 0.6. The biggest area, about 61% had a small quantity of biomass. Less than 1% of the area (in forests) was covered by plants with very large quantity of biomass. Values of fAPAR were very high, the average value was around 0.75. About 80% of the area had very good or better condition and more than 40% was excellent.

The final product of the analysis was the map of multiplied values of the three indices: SAVI, LAI and fAPAR, which is shown on Figure 4. This map showed the quantity of biomass, coverage with plants and percentage of light, that is necessary for photosynthesis. The general plant condition can be based on these three factors. Pixels were divided to 6 classes: excellent, very good, good, rather good, average and poor. On 90% area the general plants conditions were defined at least as good. Only a very small area (only 2%) had bad plant conditions, mainly stubbles and urbanized areas. Average condition was mainly noticed on stubbles (about 8%). Rather good condition represented 28% of the catchment. Good conditions were noticed on 39% of area on all kinds of land use: anthropogenic, crops, stubbles and meadows. Very good conditions were on areas of forest, meadows and crops, which covered about 21% of the area. The best conditions – excellent, were only in forests in a small area (2%). Generally, the best conditions were in forests, where the quantity of biomass was very large. Crops were in good and very good condition, which mean good harvests. Worst conditions were noticed on stubbles, but in this case it was related to haymaking; the biomass was removed and values of LAI were small. Also, values of SAVI were getting smaller. At the same time values of fAPAR were high, because photosynthesis was still effective and plants grew well. Only 2% of area was in bad condition. About 85% had good or better condition.

Conclusion

The spatial condition of plants can be analyzed using remote sensing techniques. Vegetation indices give reliable information about plants (biomass, photosynthesis, pigments and estimate crops). The use of hyperspectral data gives more information about the plants than multispectral images, because a large number of biometrical input parameters, specific substances and adaptations of plants can be related to reflectance. It is also necessary to have support data. High values of analysed vegetation indices show the good condition of plants in the Bystrzanka catchment in July 2002.

Correlations of the four vegetation indices (NDVI, SAVI, LAI and fAPAR) calculated from ground and airborne measurements were strong, especially for spectrometric indices. The relationships between NDVI-LAI and NDVI-fAPAR were strong for airborne measurements and not very good for ground measurements. Relations were mainly influenced by the different types of land use.

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Streszczenie

Techniki teledetekcyjne umożliwiają prowadzenie monitoringu przyrodniczego roślinności, w tym dokładną analizę fizjologii oraz właściwości biometrycznych. W artykule przedstawiony jest sposób badania kondycji roślinności wykorzystujący teledetekcyjne wskaźniki roślinności oraz związki między wskaźnikami mierzonymi z poziomu naziemnego i pułapu lotniczego. Badania były prowadzone na terenach naturalnych i ekstensywnie wykorzystywanych rolniczo zlewni Bystrzanki w Beskidzie Niskim.

W badaniach wykorzystano dwa rodzaje danych: wartości wskaźników NDVI, SAVI, LAI i fAPAR pobranych na poziomie terenowym oraz obraz hiperspektralny ze skanera lotniczego DAIS 7915. Pobrano dane z poziomu terenowego. Następnie utworzono obrazy wskaźników w dwóch programach ATCOR i ENVI 4.3 (obraz wskaźnika NDVI). Obrazy wskaźników SAVI, LAI i fAPAR uzyskane z pierwszego programu były w jednostkach niezgodnych dla wskaźników, dlatego wymagały dalszych transformacji. Pobrano wartości wskaźników z obrazów. Następnie przeprowadzono analizy statystyczne porównując wartości z obrazów z danymi terenowymi, uzyskując równania regresji, których użyto do transformacji obrazów. Ostatnim etapem było utworzenie map przestrzennego rozkładu czterech wskaźników oraz mapy kondycji roślinności biorącej pod uwagę wartości wskaźników SAVI, LAI i fAPAR.

Stwierdzono, że użycie teledetekcyjnych wskaźników roślinności ułatwia pozyskiwanie informacji o stanie roślinności i obiektywizuje te dane. Zanotowano korelacje między wskaźnikami NDVI i LAI oraz NDVI i fAPAR, są one zdecydowanie silniejsze na poziomie lotniczym. Na ścisłość korelacji wpływa sposób pobierania danych oraz sposób użytkowania terenu. Techniki hiperspektralne stwarzają dodatkowe możliwości pozyskiwania informacji przez analizę krzywej odbicia spektralnego, a nie jedynie jej wycinków, tak jak w przypadku technik wielospektralnych. Wykorzystując tak utworzone wskaźniki możliwa jest dokładniejsza analiza roślinności. Stwierdzono, że na badanym terenie wskaźniki NDVI, SAVI, LAI i fAPAR mają wysokie wartości. Na podstawie mapy kondycji roślinności stwierdzono, że na przeważającym obszarze roślinność była w dobrym stanie.

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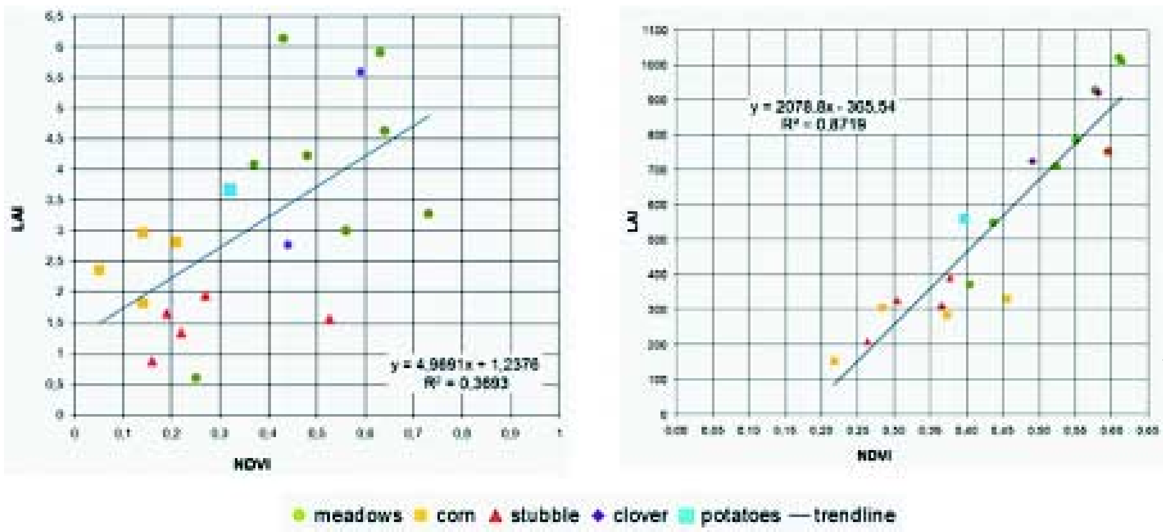

Figure 1. Correlations between NDVI and LAI indices on ground (a) and airborne (b) level

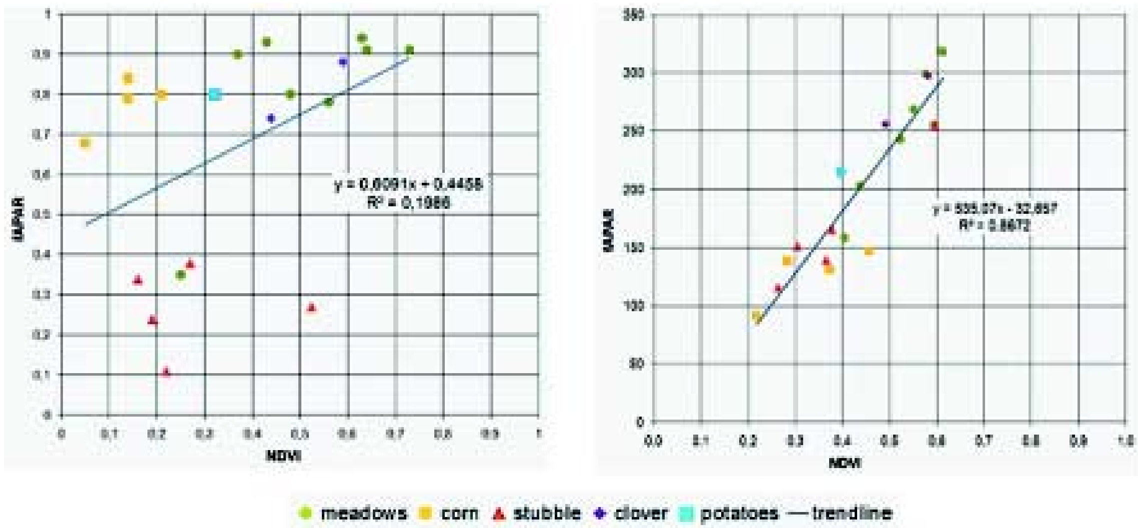

Figure 2. Correlations between NDVI and fAPAR indices on ground (a) and airborne (b) level

Figure 3. Area of Bystrzanka catchment

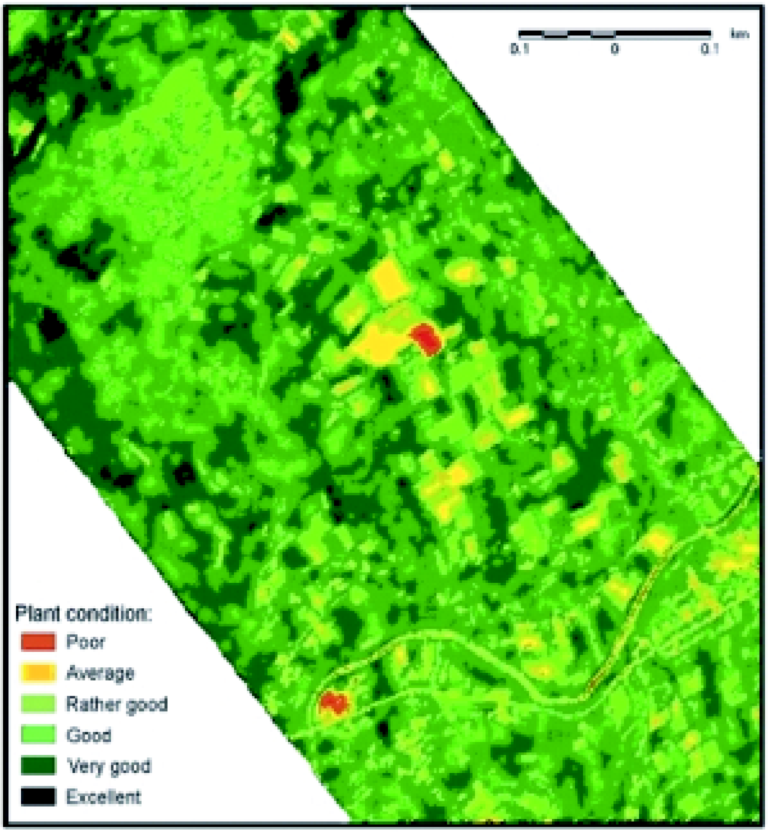

Figure 4. Condition of canopy based on values of three vegetation indices: SAVI, LAI and fAPAR