Acquisition of spectral reflectance characteristics of land cover features based on hyperspectral images.

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The advantage of hyperspectral sensors lies in their ability to derive a high spectral resolution reflectance profile for each pixel within its field of view from a set of recorded images. The data can reveal important information about the chemical composition and physical properties of materials being studied. Skillful interpretation of these characteristics and appropriate visualization of acquired data can be used for surface material identification, evaluation, and analysis of internal processes. The data is entered into a spectral library and can then be used in automated land cover and land use classifications.

Research described in this paper had been conducted in both laboratory and field conditions, using a monochromatic CCD camera with two tunable electrooptical filters – one in the visible range (VIS 400 – 720nm) and the other in the infrared range (SNIR 650 – 1100nm). In stable lighting conditions, a series of images is recorded by the sensor. Each image represents the amount of energy being emitted by the targeted features in narrow 10nm bands within the filters range. The acquired reflectance values are compared with data obtained by means of a spectroradiometer in order to confirm the validity of our methodology. A spectral profile can therefore be plotted for each object visible on the image.

Using the differences in proportions of reflected, absorbed and transmitted energy, we are able to distinguish objects on the ground. Because images acquired by means of hyperspectral technology are constructed using data acquired in different wavelengths, we can see that even objects within the same class (e.g. deciduous trees) differ from one another in the proportions of energy which they absorb, reflect and transmit depending on the wavelength.

1 Remote sensing data

Humans acquire information about the environment surrounding them by means of their senses. The sense of sight allows us to attain information without direct contact with our surroundings. The human eye can be compared to a sensor which detects only a small amount of electromagnetic radiation within the visible range of the electromagnetic spectrum (400-700nm). Radiation outside of this range is not visible to the human eye. Remote sensing techniques enable detection and registration of information, which is otherwise inaccessible to our senses.

2 Spectral reflectance characteristics

A spectral reflectance curve represents the amount of electromagnetic energy reflected or emitted by a given object. Because each object has a unique ability of reflecting incident radiation in all bands of the electromagnetic spectrum, it is possible to identify these objects based on their reflectance curves. If a given object does not reflect any energy in the chosen wavelength, its reflectance is equal to 0, however if all the energy is reflected, it is equal to 1.

The spectral response of objects is determined by a number of factors.
For example, the spectral response curves of certain plants can differ from one another in different phases of the vegetative cycle. This is very useful in remote sensing studies, as it may allow us to

identify a sick or malnourished plant at any point of its growth. The spectral response of soils is determined by moisture content, chemical composition, physical properties etc.

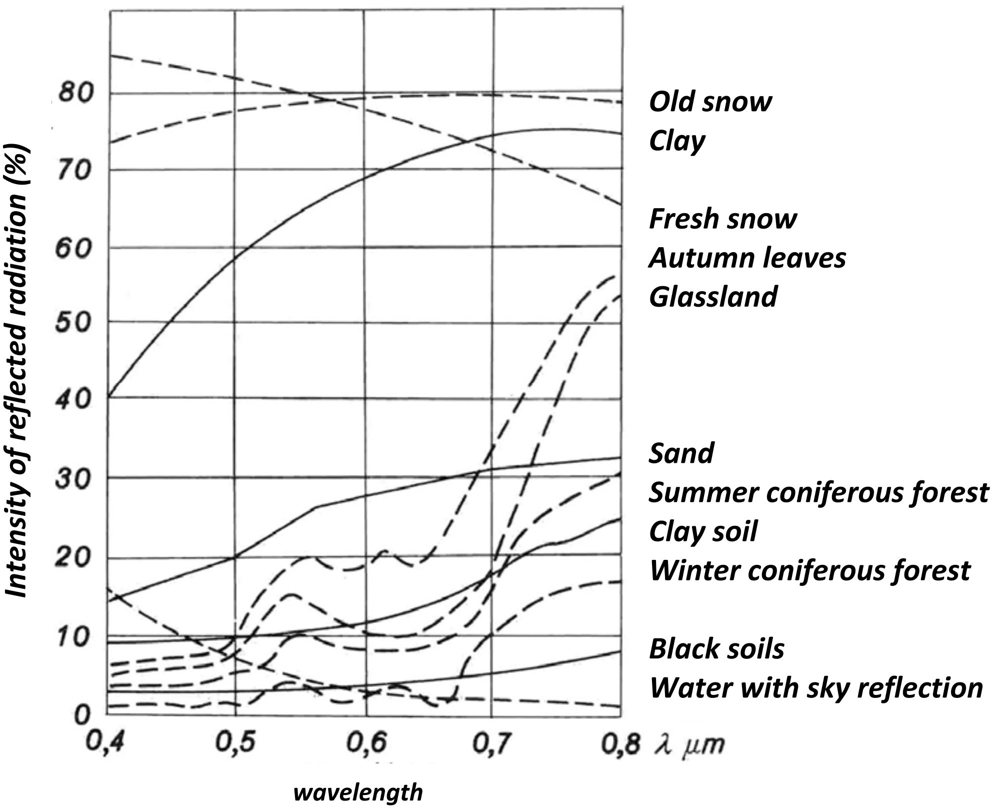

Fig. 1. Spectral response curves of selected natural materials. [6]

When analyzing spectral response curves of plants, soils and water (fig1) we should be able to notice that these materials are spectrally distinguishable. Our ability to separate two types of objects depends on which spectral range we analyze. Soils and plants may have a similar spectral response in the visible range, however in the near infrared range they will almost always differ. Even in relation to two very similar objects, it is possible to find a spectral band, in which these objects will be different.

Acquisition of spectral response curves of a range of objects allows us to determine optimal spectral bands to be registered or used in classification processes in order to guarantee that the selected objects will be distinguishable from one another.

3 Methods of acquiring spectral response curves

Reflectance characteristics of objects (materials, substances etc.) can be accurately determined in laboratory or field conditions using spectrometers.

Spectrophotometry is a spectrometric method based on a quantitative measurement of the absorption, emission or reflection of incident light. This technology differs from traditional photometry in that it enables the measurement of light intensity in narrow bands of the electromagnetic spectrum.

Spectrophotometry requires us to be in close range of the tested objects, therefore this method is time consuming, costly and sometimes impossible to conduct, if we do not have direct access to the objects. Multispectral and hyperspectral imaging systems can also be helpful in these spectral analyses.

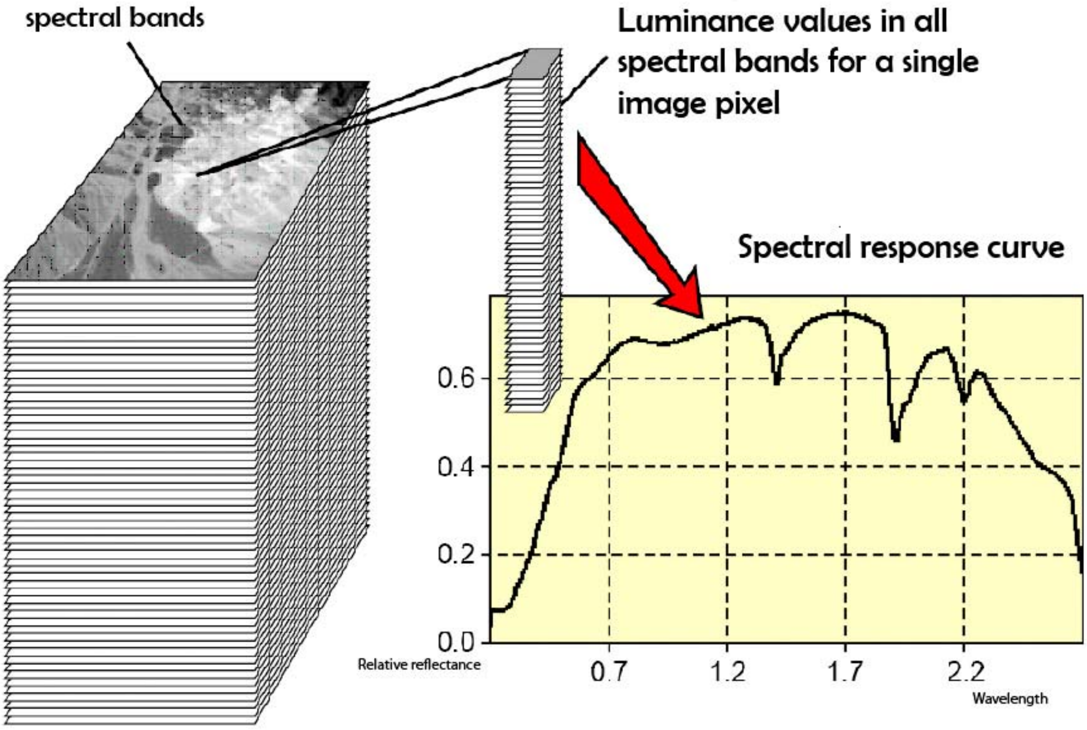

Fig. 2. Acquisition of spectral response curves using a hyperspectral method [5]

3.1 Multispectral and hyperspectral data

In recent years there have been major developments in multispectral techniques, which allow for simultaneous registration of the same scene in different bands of the electromagnetic spectrum. Both multispectral and hyperspectral techniques enable registering of a scene in many spectral bands, however the difference between these two techniques lies in the number and width of the acquired bands. Multispectral sensors acquire imagery in a small number of relatively wide bands. Hyperspectral sensors on the other hand, register a large number of very narrow, adjacent spectral bands, enabling detailed spectral analyses.

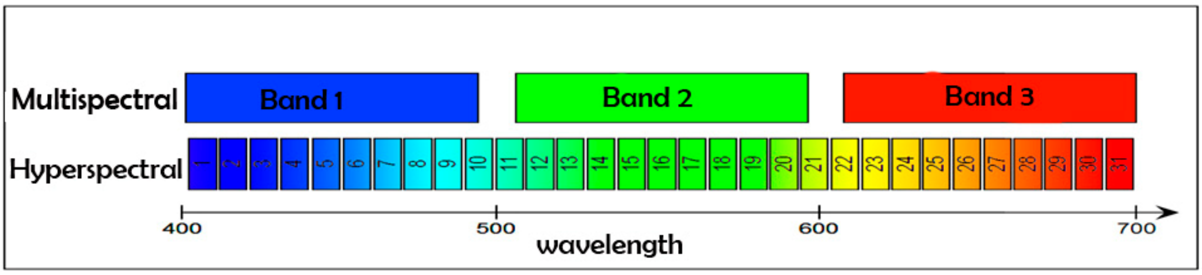

Fig. 3. A comparison of multispectral and hyperspectral bands

The more narrow spectral bands are acquired, the closer the hyperspectrally acquired spectral response curve is to the actual reflectance characteristic of the tested object.
At the Section of Remote Sensing and Photogrammetry of the Military University of Technology we have designed and assembled a hyperspectral set, which can be used for acquiring imagery in the 400-1100nm range.

3.2 Hyperspectral set

The hyperspectral set consists of the following elements:

- two interchangeable electronically tunable narrow band optical filters
- a monochromatic digital camera
- software used to operate the hyperspectral acquisition of images

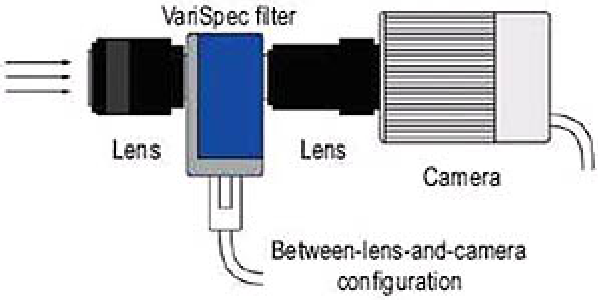

Fig. 4. Configuration of the hyperspectral set: camera, filter and lens

3.2.1 An electronically tunable narrow band optical filter

Liquid crystal filters polarize electromagnetic waves. Any wave entering the filter is polarized, i.e. its vibration plane is given a direction. The vibration plane of polarized light may be rotated in a process called involution. The aim of this process is to control the angle by which the wave is rotated. The set includes two interchangeable tunable filters – one enabling acquisition of imagery in the 400-750nm range, and the other operating in the 650-1100nm range.

3.2.2 A monochromatic digital camera

The Qimaging QICAM is a digital camera which has been especially designed for high resolution experimental and industrial tasks. It is equipped with a monochromatic progressive CCD matrix (Sony ICX205 Progressive Scan Interline CCD Monochrome), which means that the image is registered on the matrix line by line, not every second line, as it is often the case. Contrary to traditional digital cameras, the matrix in this camera is monochromatic and does not contain the Bayer filter. According to the specification, the camera has a 12-bit grayscale, although analysis of the dynamic range of the matrix has shown that the proportion of the potential well (10 000e^-) to the noise (12e^-) is 834, so technically the image will have a 9.70-bit grayscale. The provided software makes it possible to register an 8-bit image. The camera uses a thermoelectric Peltier cooling system, which allows for cooling of up to 25˚C below the ambient temperature. The cooling system guarantees a constant level of noise on the matrix, which is essential for repeatability of results.

The QICAM video camera has an electronic shutter mechanism. This means that it contains no mechanical parts, and that its „opening” and „closing” takes place by applying electrical current to the matrix. The electronic shutter allows for integration of the exposure time with the software and additional hardware (for example with filters and lamps). The exposure time of the camera varies from 12ms to 17.9 minutes and may be controlled using the software. It is possible to automatically adjust the exposure time to a selected part of the image.

3.2.3 Software for operating the hyperspectral acquisition set

The acquisition set's specialized software „Wiano” has been designed and created for these tests and it is used to capture the hyperspectral images. The software controls functioning of the monochromatic camera coupled with the liquid crystal tunable filter. The main functions of the program include:

- interactive control of the camera,
- interactive control of the filter,
- direct preview of the camera image on the computer screen,
- automatic adjustment of the exposure time for a user selected area,

- the acquired camera image transfer into the computer's memory,
- saving the images to files automatically named using the spectral range in which the images were acquired and the date,
- automated acquisition of a sequence of images with the mid wavelength tuning by a user defined interval for each successive image.

3.3 A hyperspectral method of acquiring spectral response curves

Using the set, we acquire the spectral reflectance by capturing series of images of a given object in various spectral bands. The images are taken with a 10nm step in the VIS range of the spectrum at wavelengths from 400nm through 700nm and in the NIR range at wavelengths from 650 through 1100nm. The captured hyperspectral imagery is then used to create characteristic curves.
We conducted an experiment in which hyperspectral images of a test board (Fig. 5) were acquired. These images allowed us to generate spectral response curves for selected elements of the test.

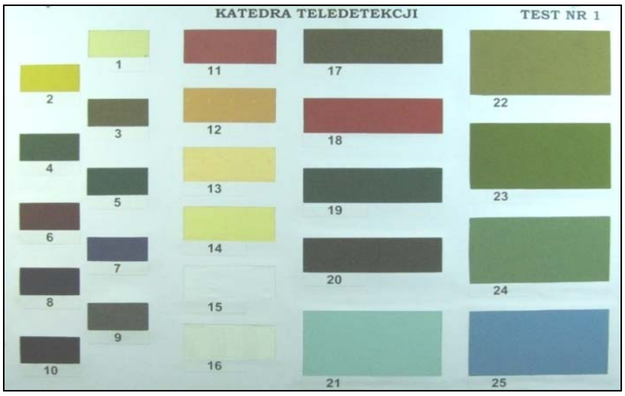

Fig. 5. Test board consisting of a number of different textiles on a white background

For each sample, in all bands in which images were acquired, statistical values such as the average, minimum and maximum pixel values and mean square error of the average were calculated. Based on these data, characteristic curves for the test samples were drawn. Furthermore, series of spectrophotometric measurements were taken by means of an additional spectrophotometer. Curves of a selected test sample with overlaid curves based on spectrophotometric measurements are shown below.

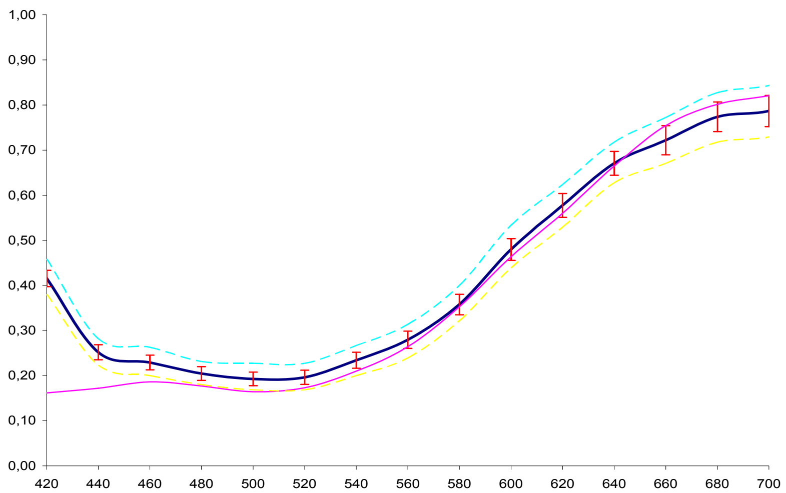

Fig. 6. Characteristic curves for the No 12 sample of the test board – actual values (pink) and hyperspectrally derived values (black). The blue and yellow lines denote the minimum and maximum values of the hyperspectral data.

3.4 Problems related to acquiring hyperspectral imagery

The “Wiano” software used to control the Qicam Fast camera offers the following options for setting the exposure time:

- manual setting of the exposure time,
- automatic setting of the exposure time for the entire imaged area,
- setting of the exposure time for a user selected area – a “Region of Interest”.

The results analysis showed that the first two options do not give required results. Manual setting of the exposure time is very difficult, because the properties of the light source and the way the objects are illuminated must be taken into account each time the image is acquired. For the automated methods of setting the exposure time for the whole scene, this parameter is set for a weighted average for the whole scene.

A certain pattern may be noticed when the third of the options is applied. With the ROI set on an area of a uniform shade of grey, the area will always be registered to have roughly the same shade of grey – with the digital number close to 230 on at 8-bit image, which is equivalent to 91% reflectance in the area. This means that by setting the ROI to an area of 91% reflectance (a reference plate), the camera will automatically select the correct exposure time so that the image will be correctly exposed. This method of calculating the exposure time has been used in all further experiments. In this case, the percentage values of reflectance calculated from average pixel values are closest to the values derived from spectrophotometric measurements.

One of the greatest disadvantages of using a tunable filter is the decrease in the amount of transmitted energy when the wavelength is lowered. The transmission of the used filters varies from 4% to 50%. The fall in transmission can be compensated by extending the time of exposure and adjusting the aperture. This however can lead to an increase in the amount of noise on the resulting image. Additionally, the optics of the hyperspectral set are causing vignetting (Fig 7) and chromatic aberrations. These effects could be eliminated by redesigning the optical system used with the camera and filters.

Fig. 7. The effects of vignetting on images acquired using f/4 (left) and f/8 (right) aperture settings.

When acquiring reflectance characteristics in laboratory conditions it is essential to use stable lighting which guarantees constant lighting conditions for all images in all spectral bands.

4 Conclusion

The error, with which the reflectance is determined, is dependent on the blend of paints used to create the reflecting plate. It is very difficult to create a paint, which reflects exactly 91% of the incident radiation. This affects the projection of the test samples as well as the reference plates.
There is only a slight difference between the obtained measurements results and the actual values. This confirms that the test plates used to examine the camera and filter work well, and may be used in further studies.

The laboratory tests results show that the method used to acquire spectral response curves by means of the hyperspectral set including a digital camera and a tunable filter is correct. Modifying the set by replacing some of the elements enables to use it in other spectral ranges. The speed of the cameras CCD matrix must be taken into account. When choosing a lens for the set, one must take into consideration the possibility of the occurrence of vignetting, which affects the final results. However, it is possible to eliminate the interference caused by vignetting and noise on the image by processing the images before analysis.

Reference

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