ACQUIRING REFLECTION COEFFICIENTS USING HYPERSPECTRAL VIDEO IMAGERY

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ABSTRACT:

Remote sensing uses many different types of imagery for interpretational purposes. Multispectral photography has shown to be of especially high interpretational value. During remote sensing studies which are done "in situ", determining spectral reflectance coefficients of any given object is crucial. Spectrometers are usually used in acquiring such data. The authors of such a study have used an equipment set consisting of a digital video camera and an electronically tunable filter. The set is designed to work in the visible range 400-720nm. The matrix in this camera has a resolution of 1392 x 1040Px. It is capable of binning (the joining of pixels) 2x2, 4x4 and 8x8, which allows for the increase in sensitivity at the loss of resolution. Monochromatic images acquired by the camera have a radiometric resolution of 12bits. The images are saved into the controlling computers memory by means of the IEEE-1394 FireWire interface. The camera has a fully automated exposure mechanism together with an ROI function. The electronically tunable filter allows for the acquisition of images of a 10nm band, with a 0.1nm step, within the given spectral range. Special software had been designed to control the set (the camera and filter), which allows for the acquisition of any chosen sequence of images within the entire visible range of the electromagnetic spectrum, as well as their primary processing. On the basis of a sequence of images, the spectral reflection coefficient can be determined for any objects within the scene. The image sequences can be acquired in laboratory conditions, as well as during fieldwork.

The article describes the methodology in acquiring imagery using the video camera and the electronically tunable filter, as well as the determining of the spectral reflection coefficients. Additionally a comparison will be made between the reflection coefficients obtained by means of a spectroradiometer and those derived from the registered imagery.

1. INTRODUCE

In field measurements of light reflectance play an increasingly important role in researching the environment using remote sensing techniques. These are essential in both determining an appropriate spectral band, which is to be registered, as well as in aiding in the correct interpretation of acquired multispectral imagery. Obtaining the maximum amount of imagery about the value, character and variations of the spectral reflection coefficients as well as their dependency on lighting conditions guarantees a more complete image interpretation. The measurements of the incident light and the radiation reflected by the object at the moment of registration are key. At the stage of planning a way for the acquisition of images for remote sensing purposes, it is essential to know the relationship which describes the contrast between the object and the background. The registering system should measure its maximum value. To ensure full remote detection it is recommended that an appropriate channel is found, in which there is a considerable difference between the reflection characteristics of the object and the background – in other words there is a high contrast between and object and the background. During "in situ" studies, different types of spectroradiometers are used to determine the reflectance characteristics of objects. This however requires the use of complicated procedures to obtain accurate results. Together with the appearance of electronically tunable filters on the market, the authors propose the use of a video camera with such a filter to obtain such information.

2. THE SET DESIGN

The hyperspectral set, designed and created at the Military University of Technology in Warsaw, consists of the following elements:

- An electronically tunable narrow banded optical filter
- A monochromatic digital camera
- Software used to operate the hyperspectral acquisition of images

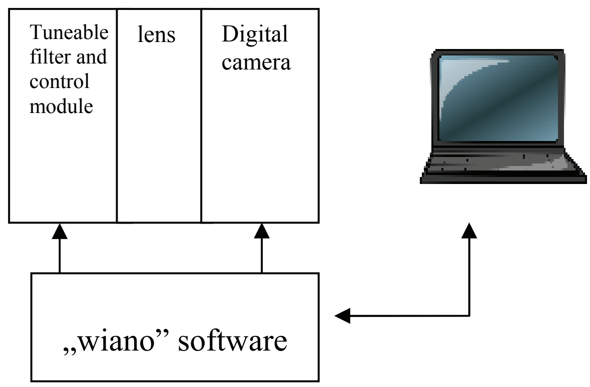


Fig no1. Draft of the hyperspectral set.

2.1 The electronically tunable narrow-band optical filter.

The use of liquid crystal filters is based on the phenomenon of wave polarization. In the part of the filter called the polarizer, any wave without a given direction is polarized, meaning, it is given a direction. When light is polarized, its vibration plane can be rotated in a process called involution by the angle $\Delta\varphi$. The aim of this process is being able to control the angle by which the wave is rotated with the use of electrical current.
One of the greatest disadvantages of using a tunable filter is the fall in the amount of transmitted waves when the wavelength is lowered. The transmission of the filter varies from 4% to 50%. The fall in transmission can be compensated by extending the time of exposure. This however can lead to an increase in the amount of noise on the resulting image.

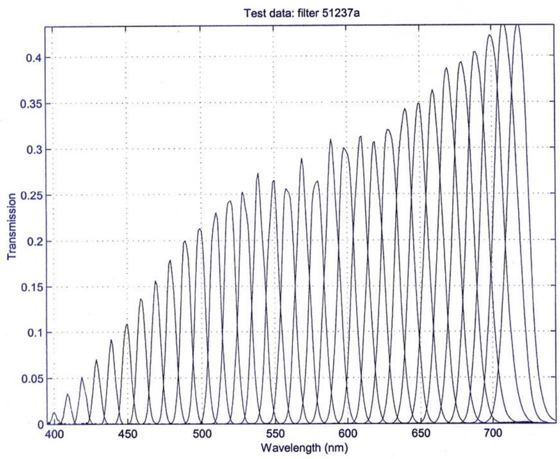


Fig no2. The filter transmission in relation to the light wavelength

2.2 The 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 is the often the case. In contrast to traditional digital cameras, the matrix in this camera is monochromatic and does not contain elements of the Bayer filter, by means of which colour images are created. According to the specification, the camera has a 12bit 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 9.70bit grayscale. The attached software makes it possible to register an 8bit image. The camera uses a thermoelectric Peltier cooling system, which allows for the cooling of up to 25˚C below the surrounding temperature. The cooling system guarantees a constant level of noise on the matrix, which is essential for the repeatability of results.
The QICAM video camera has an electronic shutter. This means that it contains no mechanical parts, and that its „opening" and „closing" takes place by applying a certain current into the matrix. Use of the electronic shutter allows for the integration of the exposure time with the software and additional hardware (for example with filters and lamps). The exposure times on the given camera can be from 12□m to 17.9 minutes and can be freely changed, according to the needs, with the given software. It is possible to automatically adjust the exposure time to a given part of the image.

2.3 Software used to operate the hyperspectral acquisition of images.

The specialized software - „Wiano" – created for these tests is used to capture hyperspectral images. The software controls the functioning of the monochromatic camera coupled with the liquid crystal tunable filter. The main functions of the program are:

a. The interactive control of the camera
b. The interactive control of the filter
c. A constant preview of the camera image on the computer screen
d. The acquisition of an image from the camera into the computers memory, with the possibility of an automatic adjustment of the exposure time for an area chosen by the user
e. Saving the image to file (the filename should automatically contain the range in which the image was creates, the date, etc.)
f. The automated registration of a sequence of n images with the tuning of the mid wavelength by a certain interval for each successive image
g. Compatibility with the Windows 2000 and XP operating systems

3. TESTING THE SET

3.1 Lens selection.

The camera equipment does not include a lens. The user can choose a lens for the camera depending on the photographed scene. For the purpose of this research, lenses with a focal length of 12.5mm, 25mm and 50mm were tested in order to examine the cameras capabilities. Because of the focal length of the tunable filter (20mm) the lens with a focal length of 50mm was used in further studies. The remaining lenses caused too much vignietting, which had a direct affect on the acquiring of image information.

3.2 Acquiring image information.

Research has shown that it is possible to automate the selection of the time of exposure on the basis of a chosen ROI area. It is also possible to select the exposure time manually, however this requires the user to take into account the way in which the objects are illuminated and with what type of lighting. Using the automatic method of exposure time selection for the entire scene, the exposure measurement is set based on a weighted average for the scene and is equal to 18% of its value. When setting the ROI area onto a white reference standard, the camera automatically sets the ROI do 91% of the maximum value in each spectral band. Therefore bright areas on the images will not be overexposed.
Test plates of different shades of grey were used in the research.

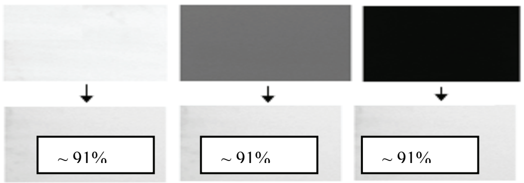


Fig no3. Test plates of different shades of grey

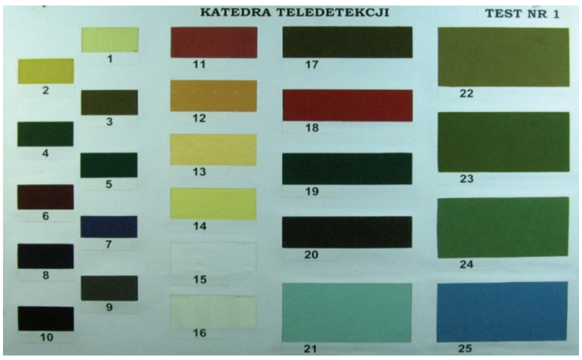
Tests carried out with analogue filters have shown that the sensitivity of the CCD matrix shown in the technical specification corresponds to its actual value. Its panchromatism allows for the acquisition of imagery within the 350nm to 950nm range. Therefore it is possible to use the Qicam Fast 1394 to attain images in the UV, RGB and NIR ranges.

4. ACQUIRING SPECTRAL REFLECTION COEFFICIENTS FROM HYPERSPECTRAL IMAGES

4.1 Designing a test for spectrometric experiments

Tests with different reflectance coefficients were created in order to examine the filter. Specifically chosen materials guarantee a change in the reflectance coefficient along with any change in the wavelength. The spectral ability of the set was analyzed based on such tests. Each area was measured with a spectrophotometer. The measured reflection coefficients create a reference standard. The spectrophotometric measurements were taken with the DATACOLOR 110P™ spectrophotometer with a viewing angle of 2°. The charts below show exemplary characteristic curves for two samples, based on spectrophotometer measurements.

Fig no.2 Tests used to examine spectral resolution



Spectral reflection coefficients have been acquired through obtaining a series of images of the object in different spectral bands with the use of the set. The images were taken in the visible range starting from a 420nm wavelength to 700nm with a 10nm step, which gave 29 images of each test. We can therefore say that, within the experiment, hyperspectral images were acquired, which were then used to create the characteristic curves.

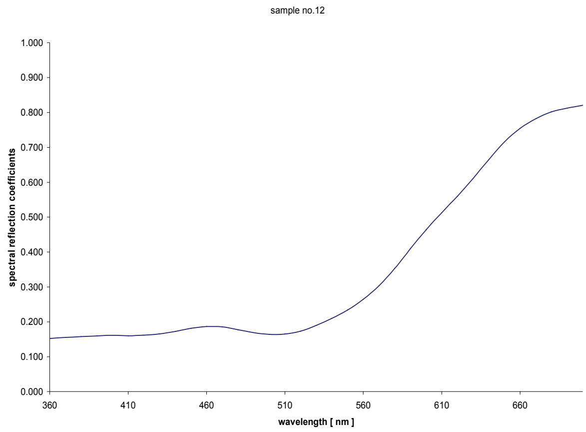


Fig no4. Characteristic curves of sample no.12

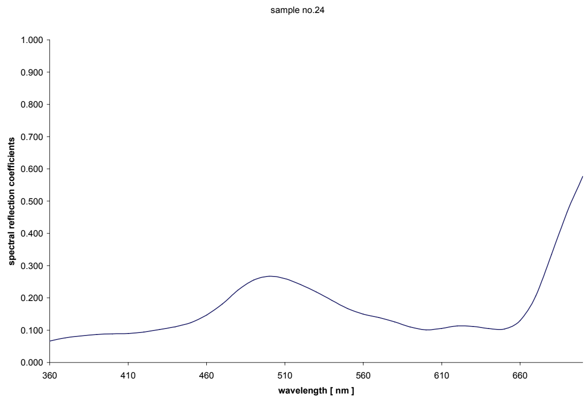


Fig no5. Characteristic curves of sample no.24

For every sample, in each band, in which images were taken, the average value of luminance from its surface was calculated. A special program was designed, which allowed for the automated establishing of these values, as well as for the drawing of the reflection curves in the whole spectral range. The calculation of the reflection coefficients by the program is based on the lowing equation:

$$\boxed{r_{\alpha\, i,object} = \frac{E_{i,wr}}{E_{i,object}} \cdot \frac{L_{i,object}}{L_{i,wr}} \cdot r_{\alpha\, i,wr}}$$

A comparison of the calculated reflection coefficients with reference data has shown, that the measurements are all affected by a systematic error caused by the set itself. The value of this error lessens along with the increase in wavelength. A method of calibrating the equipment was developed, based on 25 samples of the test. This method determines a constant correction value for the measurements for the given scene.

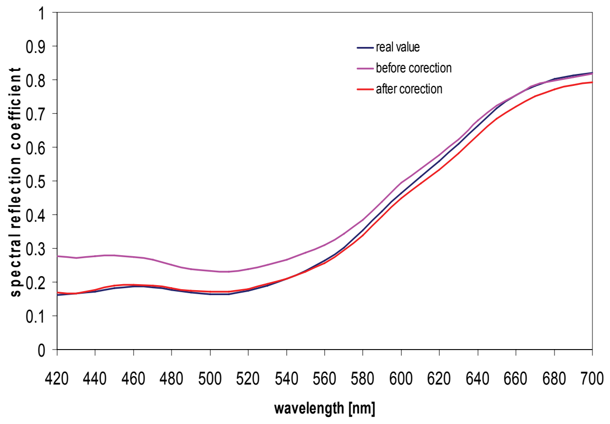


Fig no4. Characteristic curves of sample no. 12 acquired using hyperspectral video

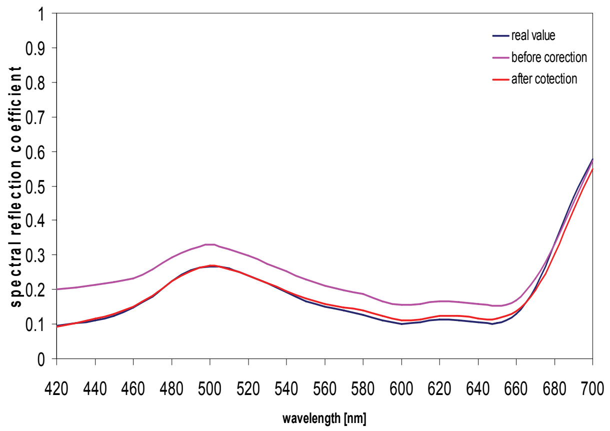


Fig no5. Characteristic curves of sample no. 24 acquired using hyperspectral video

5. CONCLUSION

Laboratory experiments have shown, that it is possible to use the designed set to determine the spectral reflection coefficients of any given object on a registered scene.
The proposed measurement method confirms the correctness of the images registered in the 420-720 range. The low transmission (4%) of the tunable filter between 400 and 420nm is most probably the cause of errors in image registration within this range.
In order to acquire reflection coefficients, the set can be used to capture imagery of the scene within the 420-720nm range, with a 10nm bandwidth and any chosen step (greater than 0.1nm).
The above results show the suitability of the proposed methods in acquiring imagery as well as of the created interactive programs used to control this process.

In further studies, we plan to broaden the range of the spectral experiments to 1000nm with the use of a tunable filter in the 650 – 1000nm range. We also wish to propose a method of image acquisition using the camera set in field conditions in different lighting conditions. Because such a method provides such vast amounts of images, we plan to design a program, which would select images to be used in further interpretation, based on the acquired spectral reflection coefficients.

The 50mm lens selected for this experiment lacks vignietting and therefore assures a uniform distribution of incident light on the matrix. We mean to position the tunable filter between the camera and the lens, which would permit the use of lenses with a greater viewing angle.

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