Analysis of the surface of historical buildings using terrestrial hyperspectral techniques.

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The examination of the condition of the façades of historical buildings is crucial when conducting cultural heritage documentation. Because of the vast amount of details on the surface of most historical structures, manual mapping can often be very extensive and time consuming. Therefore remote sensing techniques are the best solution. The overall shape and structure of the building can be mapped using terrestrial laser scanning equipment. A laser scanner, however, will not allow for the acquisition of data concerning certain damaging natural processes occurring on the surface of the structure. Such damaging processes include weathering, corrosion, salt blooming and biological changes like moss, lichen, moulds and moisture.

A hyperspectral imaging system is ideal for detection of these changes. A sequence of images in the 420-1100 nm range with a 10 nm bandwidth and 10 nm step is acquired using a hyperspectral imaging system. Registered images, especially those in the infrared range, can be very useful for the detection of areas of excess moisture on the surface of the building. The measurement of moisture content has a particular importance, as most aforementioned damages are caused by higher than average levels of moisture. Having acquired a hyperspectral image sequence it is possible to conduct a simple unsupervised image classification, which will highlight areas of higher moisture content. These areas can then be more closely monitored and analyzed to determine the nature and extent of the damages caused by moisture. As a result an image representing certain damages on the surface of the building is created.

1 Documentation of cultural heritage structures

Nowadays the digital documentation of cultural heritage structures and sites is receiving much more attention. This is due to the fact, that new technologies, ensuring fast and accurate results have become widely available. There are a great number of techniques, which enable the acquisition of digital data about the size and shape of the documented building or structure. It is possible to distinguish three main approaches for the optical recording, documentation and visualization of heritage structures:

1. Image-based methods (e.g. photogrammetry): these methods are widely used for the 3D reconstruction of architectural objects, for the precise modeling and lately also for precise and detailed modeling of complex objects using consumer-grade digital cameras.

2. Range-based methods (e.g. laser scanning): these techniques are based on active sensors that directly capture the geometric 3D information of an object using artificial laser light.

3. Combination of image- and range-based methods: photogrammetry and active sensors have been often combined in particular for the recording of large architectural objects or complex archaeological sites, where no technique by itself can efficiently and quickly provide a complete and detailed model.

In the process of documenting a cultural heritage site of structure, one of the main areas which is investigated and reported, is its condition. All of the above mentioned methods are used only to measure and model the overall shape of a structure. They however do not allow us to obtain any information about the condition of the building materials of which the structure had been built. Degradation in these materials can be caused by changing climatic conditions, by the rise in humidity within the structure, by a fungi or insect attack, and by fire or other natural disasters. In order to determine if there had been any degradation of these materials, usually very invasive methods must be used. These methods, despite giving very accurate and detailed information about the structure, can be very harmful and cause further damaging effects.

With the development of remote sensing techniques, many institutions have been working on developing a method of non-invasive detection of physical and chemical factors affecting historical buildings and monuments. The International Scientific Committee for Documentation of Cultural Heritage (CIPA) is one of the international committees of ICOMOS (International Council on Monuments and Sites) and it was established in collaboration with ISPRS (International Society of Photogrammetry and Remote Sensing). *Its main purpose is the improvement of all methods for surveying of cultural monuments and sites, specially by synergy effects gained by the combination of methods under special consideration of photogrammetry with all its aspects, as an important contribution to recording and perceptual monitoring of cultural heritage, to preservation and restoration of any valuable architectural or other cultural monument, object or site, as a support to architectural, archaeological and other art-historical research* [6]. ISPRS and ICOMOS created CIPA because they both believe that a monument can be restored and protected only when it has been fully measured and documented and when its development has been documented again and again, i.e. monitored, also with respect to its environment, and stored in proper heritage information and management systems.

2 A hyperspectral approach

A research team from the Department of Remote Sensing and Photogrammetry at the Warsaw Military University of Technology has been working on using hyperspectral imaging techniques in analyzing the condition of building surfaces, especially areas of high moisture content.

Hyperspectral techniques enable the acquisition of imagery in very narrow and contiguous spectral bands. Such detailed information about the spectral characteristics of objects found within the acquired scene, can be used to generate fairly accurate spectral response curves of these objects. Spectral response curves describe the percentage of incident light which is emitted, reflected or absorbed by objects in relation to its wavelength. A detailed analysis of spectral response curves for objects with slightly different chemical properties (eg. moisture content), can point to spectral bands, in which these objects will be distinguishable. The knowledge of these spectral differences can then be used in future studies for the fast detection of “suspicious areas”.

The aforementioned research team had designed and assembled a hyperspectral set for the acquisition of hyperspectral imagery in the 400-1100 nm range of the electromagnetic spectrum with a 10nm step. The set consists of a monochromatic camera, two interchangeable optoelectonically tunable filters (one in the 400-720 nm range and the other in the 650-1100 nm range) and a computer equipped with the appropriate software used to control the entire set.

2.1 The experiment

An experiment was conducted within the grounds of the Military University of Technology using the hyperspectral set. The set allowed the acquisition of two series of imagery: one in the visible range of the electromagnetic spectrum (VIS - 420-720 nm) and a series in the near infrared range (NIR - 650-1100 nm). Even though the visible filter can register imagery in the 400-720 nm range, imagery in the 400-420 nm range was not acquired due to the very low transmission of the filter and therefore very long exposure times (over 30 minutes). Such long exposure times cause large amounts of noise and errors caused by changing lighting conditions occurring in field conditions.

Next, the registered imagery was processed to ensure that any changes in lighting conditions occurring between exposures will not affect the resulting spectral response curves. This postprocessing is made possible by ensuring that a white reference plate is visible on all acquired images. The white reference plate used in this experiment has a reflection of 95 %. Digital numbers (DN) of pixels depicting this reference plate on all images should be equal to 95 % of the maximum possible DN (243, when working with 8bit images). If this is not the case in any of the images, their histograms are adjusted accordingly.

Fig. 1 represents a color composition of imagery acquired in the visible range of the electromagnetic spectrum.

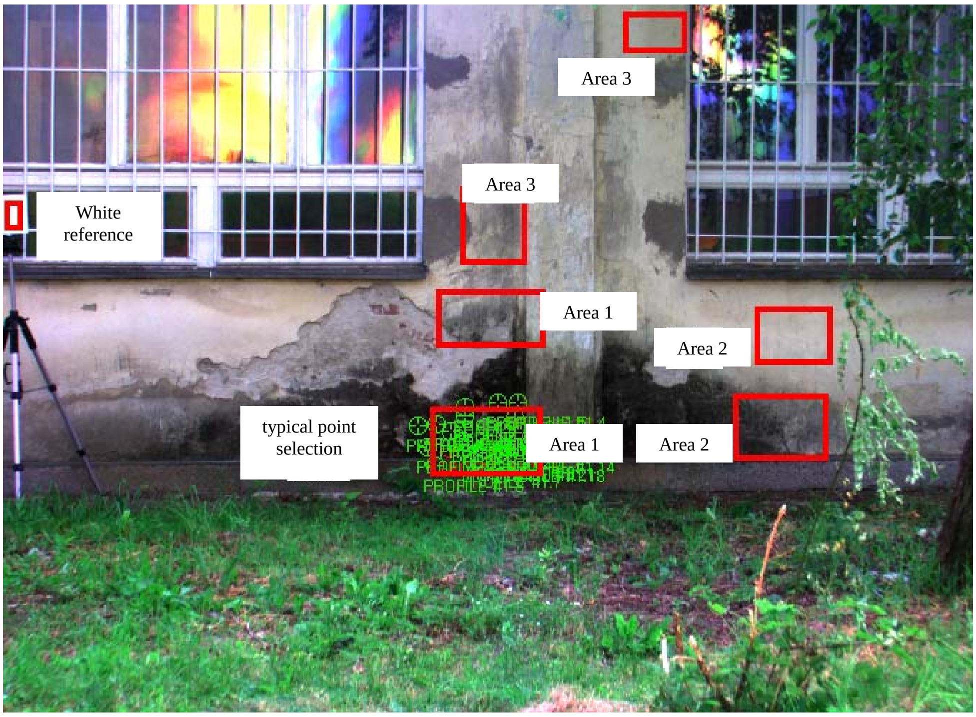
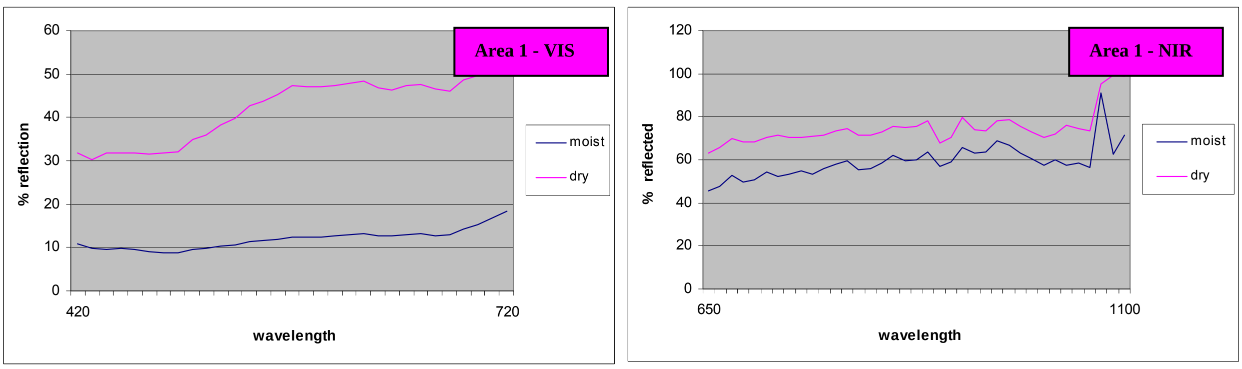


Fig. 1. Colour composition of images registered in the 420-720 nm wave length

3 Analysis of results and conclusions

Areas marked on the above image represent areas where spectral analyses were conducted. An analysis was made of both dry areas and evidently moist areas. Spectral response curves resulting from these analyses are shown in Fig. 2.



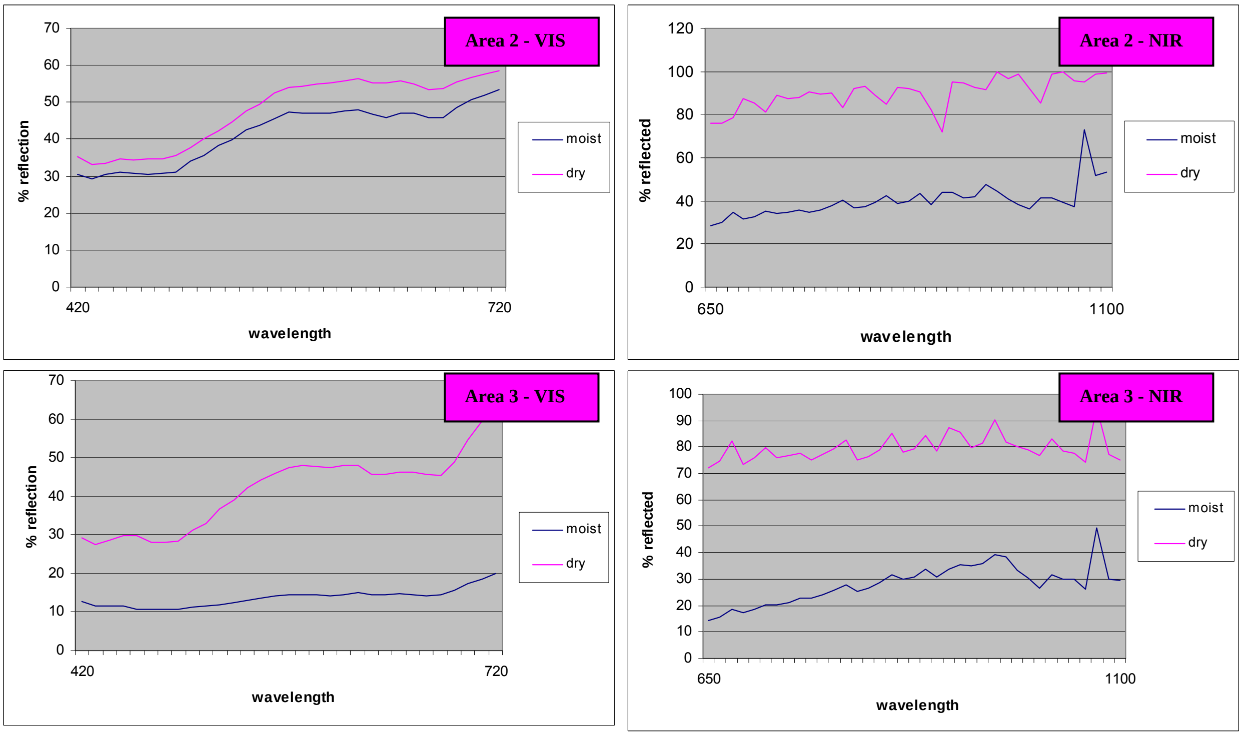


Fig.2. Spectral response curves for 3 areas on the acquired hyperspectral images.

The spectral response curves shown in Fig. 2 confirm, that hyperspectral methods can be used to distinguish dry areas on the facades of buildings from those with a higher moisture content. In the visible range, areas with a higher moisture content roughly reflect 20% less energy in comparison to dry areas. A similar phenomenon takes place in the near infrared range, but here the differences are much more visible. Dry walls reflect 40-60% more radiation in comparison to moist areas on the wall. The results represented in this article have been acquired from only one wall. The full experiment was conducted on three walls. Results obtained from the remaining two test sites are unanimous with the results presented above.

In both visible and most of near infrared ranges, the spectral reflectance curves for both types of surfaces are almost parallel, which means that there are no specific bands in which such analyses could be conducted. However, there is a visible peak in the 1010-1050 nm range, which could indicate that these bands may contain additional information about the moisture content of the testes structure. Additional work will be conducted, concentrating mainly on the 1000-1100 nm range of the electromagnetic spectrum.

Spectral response curves derived from such studies could be used to create a spectral library, which would enable a fast and automatic detection of problem areas on structure surfaces.

The research team is also planing to conduct an experiment and analysis in the thermal infrared range. Data obtained using this technology should also allow for a quick detection of moist areas on building surfaces.

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