DAMAGE DETECTION ON BUILDING SURFACES WITH MULTI-SPECTRAL TECHNIQUES

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ABSTRACT

Multi-spectral imaging methods give the possibility to detect damages, like moisture and natural cover (e.g. moss), on surfaces of building structures. An Infrared Vidicon system and two digital cameras have been tested concerning their applicability for multi-spectral analysis. The results of the evaluation with multi-spectral image classification are compared. Digital cameras simplify the acquisition of image data. The classification of images taken with digital cameras achieves promising results. Still there are difficulties with the influence of inhomogeneous illumination on the classification results. Therefore, a multi-spectral laser-scanning system was developed, which uses four semiconductor lasers at different wavelengths for the defined illumination of the object surface.

1. INTRODUCTION

Preliminary examination of building structures plays a crucial role concerning the planning of construction and restoration tasks. Because of the multitude of the occurring damages on building surfaces, manual damage mapping is extensive and time-consuming. Therefore it is desirable to apply an image-based method for damage assessment, which also covers inaccessible parts of the building surface. It should also provide data for further analysis and classification of the existing damages. This approach offers good preconditions for an automation of damage detection. Beside the surface structure und -condition, especially its changes are to be detected. Important damages on building surfaces are weathering, corrosion, salt blooming and biological changes like moss, lichen, moulds and moisture. The quantitative measurement of the moisture content has a particular importance, as most of the other damages are correlated with the moisture content.

Multi-spectral techniques offer the possibility to detect damages on building surfaces. Image regions can be assigned to different affected (e.g. damaged by moisture or vegetation) surface regions. The dimension of the damaged area can be quantitatively measured. Therefore, the results of a multi-spectral analysis can serve as a basis for damage mapping, delivering quantitative results on the damaged area and about the nature of the damage. Measurements are accomplished with an Infrared-Vidicon-camera with suitable band-pass filters and two digital cameras. The classification of the image data was performed with a standard image processing software, generally used for remote sensing applications. As a further development of the described multi-spectral image acquisition and classification methods for the detection of building damages, a multi-spectral laser-scanner system is introduced. The advantages of semiconductor lasers as active illumination are a better signal-to-noise ratio and reproducible measurement conditions, allowing quantitative measurements of the damages.

2. OVERVIEW OF MULTI-SPECTRAL TECHNIQUES FOR THE DETECTION OF DAMAGES ON BUILDING SURFACES

The use of multi-spectral image acquisition for the detection and classification of damages on building surfaces is known since a long time (Strackenbrock, 1990). First, the image acquisition was carried out on special sensitised films (i.e. infrared film) in combination with appropriate filters. After digitisation with a flatbed or rotational scanner digital data were analysed by means of digital image processing. As a first step, images had to be aligned geometrically. In case of the application of different cameras or films, this procedure was very time-consuming. Using a metric camera with fiducial marks and given interior orientation, the rectification is performed in a better and faster way. Following, the aligned image data set can be analysed with the help of algorithms known from multi-spectral remote sensing.

The application of opto-electronic imaging devices simplified the process of image acquisition significantly. First investigations concerning the application of CCD-cameras show the principal ability to use this technique for multi-spectral analysis of building surfaces (Godding, 1992). An alternate way for the acquisition of multi-spectral images is the application of Infrared-Vidicon-cameras in combination with a suitable filter set. The main field of application is the detection of moisture on building surfaces, especially when using active illumination techniques (Böttcher, 1982; Büscher, 1999; Wiggenhauser 2002).

The analysis of multi-spectral image data is performed the easiest by visual interpretation or combination of the image channels. Operations with different channels are possible, i.e. the calculation of the vegetation index, which helps to detect areas covered by chlorophyll (moss, lichen, moulds). A better characterisation of damages is possible by means of multi-spectral classification. Different approaches for classification strategies applied to facades are explained in (Lerma, 2001).

Multi-spectral classification methods base on the fact, that specific object classes have wavelength dependent reflection characteristics. Transferring the digitised intensity values of an object point of n image channels into an n-dimensional feature space (with n = number of the used wavelengths), a cluster for each object class is formed.

In case of an unsupervised classification these clusters are identified and marked off without any predefined knowledge. But in case of a supervised classification, predefined knowledge in form of reference areas is used and thus allows quantitative statements concerning the distribution of the object classes.

The simultaneous investigation of reference objects provides reference areas, which enables a supervised classification and therewith the explicit allocation of the detected classes to the defined damage symptoms.

Further improvement of the results of multi-spectral classification methods is possible with the application of image processing methods (i.e. texture analysis, pattern recognition). This approach was also applied for the analysis of facades of historical buildings (Lerma, 2000; Ruiz, 2002). New opportunities for the evaluation of multi-spectral image data are given by the combination of classification methods with object-oriented approaches, which also take into account the topology of the investigated objects (Neusch, 2003).

Most common problems in multi-spectral classification methods on building surfaces appear with the illumination of the objects. Illumination conditions are changing in dependence on daytime, weather and the object surface. A special challenge is the quantification of the results, especially the calculation of humidity values.

3. MULTI-SPECTRAL ANALYSIS BASED ON INFRARED AND DIGITAL CAMERAS

3.1 Choice of the test object

An evidently affected masonry wall was selected for the investigations. Damages like moisture and biological cover (moss) are clearly seen on the building surface, shown in figure 1. The region, selected for image acquisition, contains old and new bricks, dry and wet areas.

Figure 1. Test object: Masonry affected by moisture and biological cover

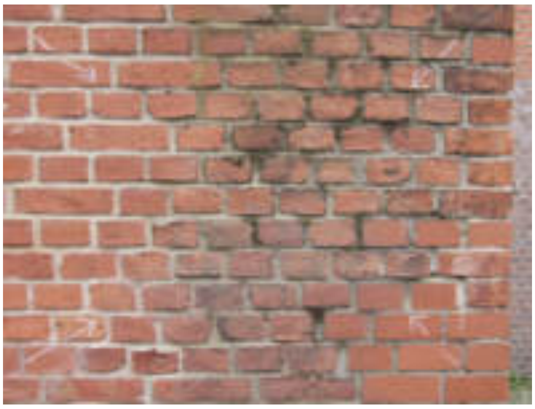

Figure 2. Selected region for image acquisition

3.2 Image acquisition and analysis with an Infrared-Vidicon-camera

The aim of this part was the investigation of the usability of an Infrared-Vidicon-camera for the acquisition and evaluation of multi-spectral image data. For this purpose an Infrared-Vidicon-camera from Hamamatsu was used (table 1).

Manufacturer	Hamamatsu
Model	C2400-03
Type	IR-Vidicon-camera
Wavelength	800-2100 nm
Lens	Xenoplan 1,4/23 mm
Resolution	720 x 576 Pixel
Used filters	Band pass filter with 810, 850, 900, 950, 980, 1000 nm (with 100 nm FWHM)

Table 1. Technical data of the IR-Vidicon-camera

Figure 3. IR-Vidicon-camera with controller and notebook

The camera includes an adapter for suitable band-pass filters. Regarding the selection of appropriate filters it has to be considered, that they have a minimum bandwidth to get a feasible signal-to-noise ratio in the image data. Furthermore, attention has to be paid to the adjustment of the wavelength of the camera, the used lens and filters. Because of the loss of power of the lens for higher wavelengths, in our case only six filters were used for the image acquisition.

For the digitisation a commercial frame-grabber was used. It allows the connection of the camera with a notebook (see figure 3). During image acquisition attention was paid to have diffuse illumination, ideally given by a cloudy sky. Using a lens with a focal length of 23 mm, the object distance was about three meters.

Figure 4 shows a near infrared (NIR) image of the selected region, acquired with the Vidicon-camera without filter. The image shown in figure 5 was captured in combination with the band-pass filter at 850 nm wavelength and differs significantly from the image captured without filter. Due to the minimal chlorophyll absorption in this wavelength region, intense reflections of areas covered with moss are visible (figure 5). Such differences between images taken in different wavelength regions are the basis for multi-spectral imaging.

Figure 4. Infrared image acquired with Vidicon-camera (without filter)

Figure 5. Infrared image acquired with Vidicon-camera (with 850 nm band-pass filter)

Multi-spectral image processing is shown exemplarily for four images with 850, 900, 950 and 1000 nm. The wavelengths are chosen, because the best image quality with the available optics (lens, filters) was obtained only in these wavelength bands. Unsupervised classification was performed with a cluster analysis. We used the ISODATA algorithm (Iterative Self-Organizing Data Analysis Technique) implemented in Erdas Imagine 8.7 (Erdas, 2003).

Figure 6 shows the results of a cluster analysis with 8 classes. Because of the unsatisfactory statistical separation of these classes, the same data set was processed with 12 predefined classes. The existing surface damages are clearly visible in the resulting map (see figure 7). On the other hand it shows, that classes are not exactly separated. This is determined by the combination of a small wavelength band and the use of wide-opened band-pass filters.

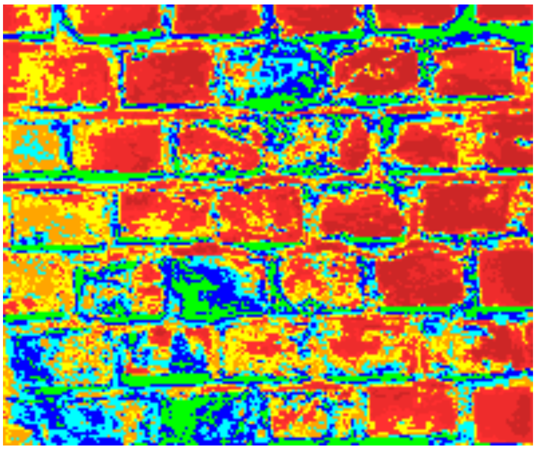

Figure 6. Results of multi-spectral classification of image data from Infrared-Vidicon-camera (4 channels, 8 predefined classes)

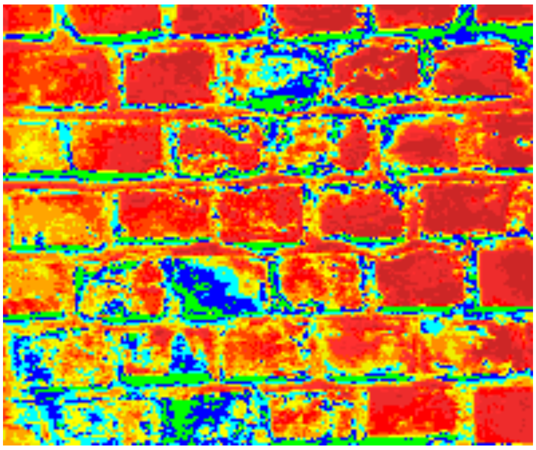

Figure 7. Results of multi-spectral classification of image data from Infrared-Vidicon-camera (4 channels, 12 predefined classes)

3.3 Image acquisition and analysis with digital cameras

Beside the acquisition and analysis of infrared images, the usability of digital cameras for multi-spectral techniques was investigated. In principle, digital cameras are suitable for multi-spectral approaches, because they have three colour channels, which are needed at minimum for image classification. Furthermore CCDs are capable of acquiring radiation in near infrared with the red colour channel.

Two different digital cameras were chosen for the investigations. First a simple Megapixel camera with a fixed focal length and second a professional 5 Megapixel SLR-camera with a zoom lens (see table 2). It has to be considered, that both cameras use non-lossless image compression, although actually, if the acquired image data were to be processed with classification methods, only lossless compression methods should be applied.

Manufacturer	Olympus	Kodak
Model	E20P	DC3200
Type	Digital-SLR 5 Megapixel	Digital 1 Megapixel
Lens	Zoom 2,0-2,4/9-36 mm	fixed focus 3,6/5,4 mm
Used focal length	9 mm (equal to 35 mm)	5,4 mm (equal to 39 mm)
Used resolution	1024 x 768	1152 x 864

Table 2. Technical data of the used digital cameras

Image processing is performed in the same way as for Vidicon images. An unsupervised classification, based on the ISODATA algorithm, was chosen for the evaluation of the image data, which were acquired with digital cameras. Statistical results of the classification show clearly eight separated classes. The results for images of both cameras are shown in figure 8 and 9. A visual comparison shows only minor differences between the results of both cameras and a satisfying accordance to the real damages. Figure 10 presents the results of the classification, using flashlight for the image acquisition with the Kodak DC3200. The differences demonstrate clearly the influence of different illumination.

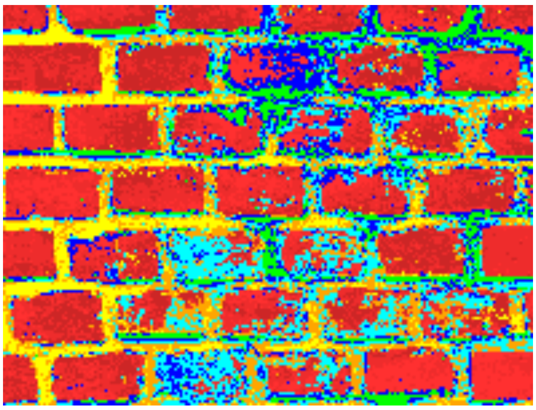

Figure 8. Results of multi-spectral classification of image data from digital camera Olympus E20P (3 channels, 8 predefined classes; see caption of figure 6)

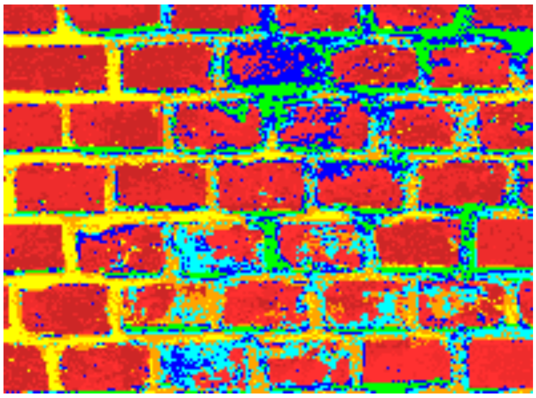

Figure 9. Results of multi-spectral classification of image data from digital camera Kodak DC3200 (3 channels, 8 predefined classes; see caption of figure 6)

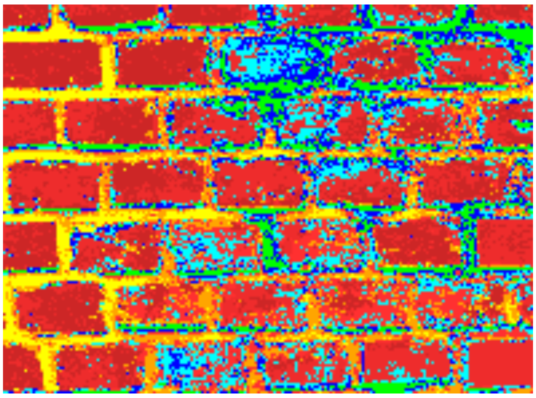

Figure 10. Results of multi-spectral classification of image data from digital camera Kodak DC3200 with flashlight (3 channels, 8 predefined classes; see caption of figure 6)

Considering the small wavelength band, errors resulting from image compression and variable illumination, the results look good and give motivation for further work.

4. COMBINATION OF MULTI-SPECTRAL TECHNIQUES AND LASERSCANNING

Until now, multi-spectral techniques for the detection of building damages, especially on building facades, usually work passively, which means, they use the existent surrounding illumination. In order to achieve quantitative results, not only for the spatial distribution, but also for the nature of damages, like moisture, active multi-spectral techniques are highly recommended. Moreover, active wavelength dependent irradiation in combination with optical or electronic filtering allows the minimisation of errors caused by inhomogeneous or changing illumination.

A multi-spectral laser-scanner works in principle as follows: The building surface is irradiated with laser light with defined wavelengths. The reflected radiation is measured with suitable detectors, like wavelength-sensitive photodiodes.

Dependent on the material, shape, condition and humidity of the surface, the reflected radiation has a varying spectral intensity distribution. In combination with a scanning system, the surface is covered grid-wise, which means the reflection characteristic is measured for every surface element. All measured data of the surface elements represent a multi-spectral image data set, which can be visualised and analysed with image processing techniques, especially with classification methods.

The developed laser scanner consists of fiber-coupled semiconductor lasers with four wavelengths, selected for the detection of moisture, natural cover and mineral changes. Suitable detectors in combination with optical filters are used for the measurement of the reflected radiation.

For the realisation of a scanning measurement system, two different devices were selected and tested under laboratory conditions: a pan-tilt-unit as carrier for the multi-spectral- head and a mirror scanning device, known from 3D laser scanners. Geometric and radiometric calibration experiments have already been carried out.

5. CONCLUSIONS AND FURTHER WORK

Multi-spectral acquisition and analysis techniques can be used for the detection of damages on building surfaces, especially facades. Both, images acquired with infrared-cameras as well as with digital consumer cameras, are suitable for detecting and classifying damages. However, the differences between the classification results, based on image data from both cameras, reveal some problems. The uniqueness and the reproducibility for both systems depend on several factors: Wavelength spectrum, selection and half-width of wavelength bands, sensor and illumination characteristics.

Compared to the Vidicon-images, the images from digital cameras cover a wider spectrum, which leads to a better separation of the classes. Another advantage is the easy handling of digital cameras. On the other hand, reliable detection and especially quantification of moisture are only possible using infrared wavelengths.

The focus of further developments lies on validation of the results of multi-spectral techniques. Geometric and radiometric calibration of the used cameras plays a significant role for the accuracy and reproducibility of multi-spectral classification methods. Calibration is also the precondition to combine measurements from different image acquisition systems or to cover larger areas. New software concepts also allow object-oriented classification, which uses predefined knowledge for a more reliable damage mapping.

However, changing or inhomogeneous illumination conditions remain as a major problem. In order to avoid this, techniques with active illumination have to be applied. For this purpose, a multi-spectral laser scanner, with four semi-conductor lasers in selected wavelengths, is under development.

REFERENCES

Böttcher, B., Richter, H., 1982. Ein Beitrag zum Nachweis von Feuchtigkeit in Mauerwerk mit Hilfe einer Infrarotkamera. Materialprüfung Nr. 1, 24, pp. 5-9.

Büscher, K. A., Wild, W., Wiggenhauser, H., 1999. Feuchtemessung mit infrarotoptischen Methoden. In: Feuchtetag ´99, DGZfP-Berichtsband BB 69-CD, Vortrag M2, pp. 1-15.

Erdas Field Guide, 2003. 7th Edition, Leica Geosystems GIS & Mapping LLC.

Godding, R., Sacher, G., Siedler, G., 1992. Einsatz von digitalen Aufnahmesystemen zur Gewinnung von Multispektralaufnahmen für die Erkundung von Bauwerksschäden. In: International Archives of Photogrammetry and Remote Sensing, Com. V, New York, pp. 794-798.

Lerma, J. L., Ruiz, L. A., Buchon, F., 2000. Application of spectral and textural classifications to recognize materials and damages on historic building facades. In: International Archives of Photogrammetry and Remote Sensing, Vol. XXXIII, Part B5, Amsterdam, pp. 480-483.

Lerma, J. L., 2001. Multiband Versus Multispectral Supervised Classification of Architectural Images. Photogrammetric Record, Volume 17, Issue 97, pp. 89-101.

Neusch, T., Grussenmeyer, P., 2003. Remote Sensing Object-Oriented Image Analysis Applied to Half-Timbered Houses. In: Proceedings of the XIX. International CIPA Symposium, Antalya, 4 pp.

Ruiz, L.A., Lerma, J. L., Gimeno, J., 2002. Application of Computer Vision Techniques to Support in the Restoration of Historical Buildings. In: International Archives of Photogrammetry and Remote Sensing, Com. III, Vol. XXXIV, Part 3A+B, 4 pp.

Strackenbrock, B., Sacher, G., Grunicke, J.-M., 1990. Image Processing for Mapping Damages to Buildings. In: Proceedings of the XIII. International CIPA symposium, Cracow, 7 pp.

Wiggenhauser, H., 2002. Active IR-applications in civil engineering. Infrared Physics and Technology 43, pp. 233-238.

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