DIGITAL IMAGE PROCESSING IN THE MONITORING OF WIDE-SPAN TIMBER ROOF STRUCTURES

Klaudius Henke[1], Robert Pawlowski[2], Peter Schregle[3], Stefan Winter[4]

ABSTRACT:

In order to achieve a simple, robust and economical system to continuously monitor the deformations of wide-span timber roof structures the methods of digital image processing were employed. The practical applicability of the system was tested in a pilot project.

KEYWORDS: building stock, wide-span timber roof structures, deformation, digital image processing, monitoring

1 INTRODUCTION

This topic came into the spotlight with the collapse of numerous timber buildings in Germany and neighbouring countries during the past winters. These incidents resulted amongst other things in the demand for new and improved ways of monitoring as a preventive measure.

The work presented here focuses on ways of employing digital image processing in the monitoring of buildings to gauge deformations in wide-span timber roof structures.

2 SOLUTION PRINCIPLE

An industrial camera (K) is pointed at a measuring point (M). The camera is connected with a computer with specialized image processing software. The measuring point is captured by the camera sensor. Movement of this point parallel to the image plane of the camera leads to a shift of the image of this point. By using the laws of visual perspective, the point's actual displacement can be calculated. In addition, a stationary reference point (R) is also captured. The relative distance between the measured point and the reference point in the image is used to avoid errors due to unintended movement of the camera itself. To eliminate any interference from ambient light, LEDs emitting a radiation within the infrared range are employed as measurement and reference points. The spectral sensitivity of the camera is adjusted by removing the built-in infrared barrier filter and installing a special day light filter.

3 PRELIMINARY TESTS
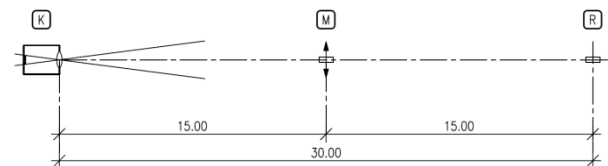
Figure 1: *Preliminary tests, arrangement of system components: Camera (K), LED-target as measuring point (M) and LED-target as reference point (R)*

Figure 2: *Preliminary tests, system components: Camera (left), movable LED-target as measuring point (center) and LED-target as reference point (right)*

To test the proposed procedure, preliminary tests were conducted in the lab and later in the gym hall of the pilot project described below. The test setup is pictured in

[1] Klaudius Henke, Research Associate, Technische Universität München, Chair for Timber Structures and Building Construction, Arcisstraße 21, D-80333 München. Email: henke@tum.de

[2] Robert Pawlowski, Professor, Hochschule Karlsruhe - Technik und Wirtschaft, Moltkestraße 30, D-76133 Karlsruhe. Email: robert.pawlowski@hs-karlsruhe.de

[3] Peter Schregle, Impuls Bildanalyse GmbH, Bahnhofstraße 40, D-86807 Buchloe. Email: p.schregle@impuls-imaging.com

[4] Stefan Winter, Professor, Technische Universität München, Chair for Timber Structures and Building Construction, Arcisstraße 21, D-80333 München. Email: winter@tum.de

Figure 1. The individual components can be seen in Figure 2. During the preliminary tests, the measuring point was moved vertically in single millimetre increments and recorded after each step. Figure 3 shows four different images of the test. The writing in the lower left corner indicates the current millimetre setting; the orange lines are measurements within the image.
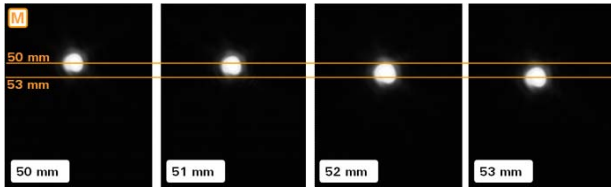
Figure 3: Preliminary test: Four measurement images showing different positions of LED measuring point (M)

With these preliminary tests it was possible to prove that the proposed system is capable of registering changes in the positioning of the measurement point with an accuracy of single millimetres.

4 PILOT PROJECT

The basic concept of the solution proposed here was already presented at WCTE 2008 [1]. In the meantime the suitability of the method for daily use was verified in a research project [2]. For this, the school gym of the Staffelseegymnasium in Murnau in the district of Garmisch-Partenkirchen in Southern Bavaria was chosen as pilot project. (Figure 4)


Figure 4: School gym in Murnau, district of Garmisch-Partenkirchen, Southern Bavaria

The snow load determining for this building was increased from $s_0=1.50$ kN/m² (DIN 1055-5:1975-06) to $s_k=3.78$ kN/m² (DIN 1055-5:2005-07) with effect from 1.1.2007. In the light of the new snow load guidelines, the operating ratio for the main supporting beam works out at $\eta = 1.09 > 1.00$. In other words the roof structure is under excessive strain (amounting to a 9% overload) and its structural safety is inadequate.

A permanent monitoring system was installed inside the gym in order to guarantee a safe working environment without extensive measures to reinforce the structure. Its main component is a deformation measurement system consisting of a camera (K), three measuring points (M1-M3) and a reference point (R) for each of the four main beams (Figure 5, Figure 6 and Figure 7).
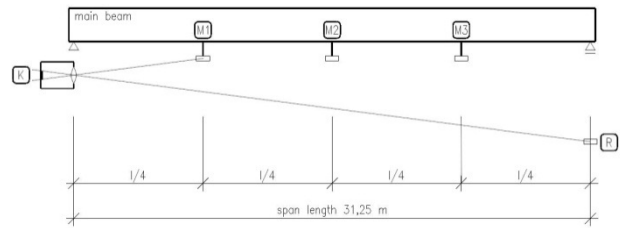
Figure 5: Layout of the monitoring system: Camera (K), LED-targets as measuring points (M1, M2 and M3) and LED-target as reference point (R)
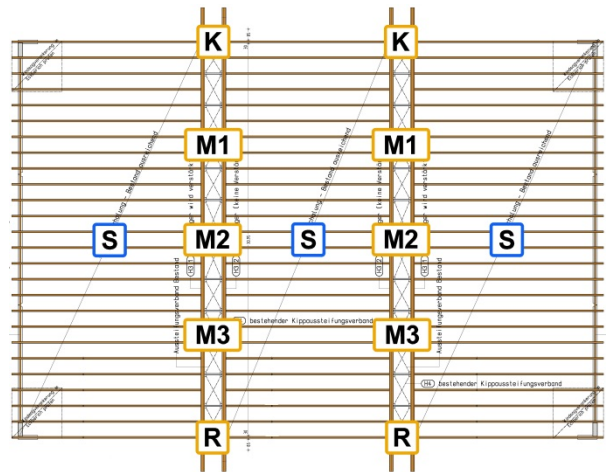
Figure 6: Plan of roof structure and main components of monitoring system: Camera (K), LED-targets as measuring points (M1, M2 and M3), LED-target as reference point (R) and snow load measuring units (S)
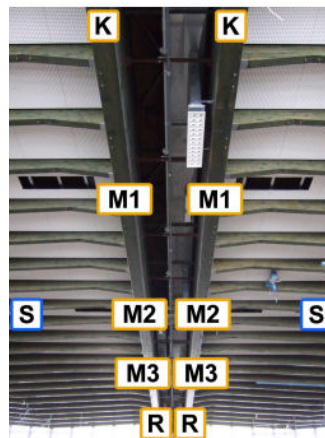
Figure 7: Photo of roof structure with main components of monitoring system: Camera (K), LED-targets as measuring points (M1, M2 and M3), LED-target as reference point (R) and snow load measuring units (S)

Additional control measurements can be carried out with a permanently installed laser gauge. To observe correlations between the climate and deformations, a weather station was installed with snow cushions (S) and sensors for air temperature, air humidity, global radiation, wind direction and wind speed. An overview of the location of the individual components is shown in Figure 6.

The cameras used here are so called "intelligent" cameras with a built in processor. The type of cameras used are Matrix Vision mvBlueCOUGAR-P with a ½" CMOS sensor with a geometric resolution of 1280 x 1024 pixel and a frame rate of up to 30 images per second. The lenses have a 100 mm focal length. As in the preliminary tests, the infrared filters of the cameras were removed and special day light filters installed, making them sensitive only to light near the infrared spectrum. The measurement points and reference points were fitted with LEDs (5 mm diameter). All LEDs operate near the infrared spectrum with a wavelength of 850 nm.

The cameras were mounted on the south side of the gym directly below the bearings of the main beams shielded behind the existing wood cladding (Figure 8, Figure 9). The LEDs of the measurement points are protected by a solid steel casing and mounted to the bottom side of the main beams (Figure 10). The LEDs of the reference points were mounted on the north side of the gym beneath the bearings of the main beams, also behind the wood cladding (Figure 11).

Figure 8: *Cameras during installation*

Figure 9: *Cameras hidden behind cladding*

Figure 10: *Measuring point on main beam*

Figure 11: *Reference points hidden behind cladding*
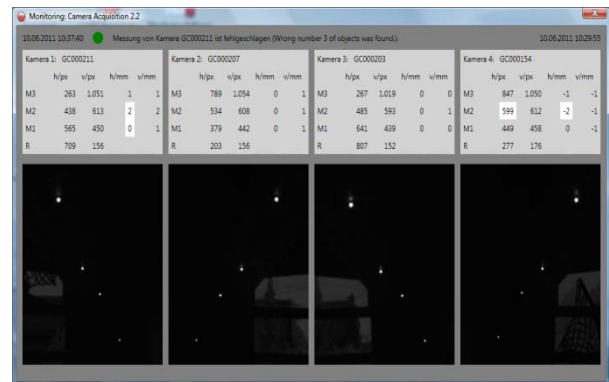
Figure 12: *Screenshot of measuring-software: At the bottom four pictures, each showing one of the four main beams of the gymnasium, on each picture the four LED (three measuring points and one reference point) can be located as bright spots, above each picture measurements in vertical and horizontal direction are displayed for each point using pixel and millimetres as units*

All data are stored and processed on a local central computer with remote access via the internet. Specially designed software analyses data and displays the resulting information. This software controls the cameras, manages the measurements and records all data in a SQL database. Additionally, the program displays warnings, measurements and images as seen in Figure 12. The measurements are displayed in pixel (raw data without modifications) and as deformation in mm relative to a fixed absolute zero. The frequency with which the system records, is linked to the speed and extent of the deformation.

During tests with artificial loads (Figure 13), the actual bending stiffness of the main beams was determined. Based on these findings, deformation boundaries were

specified which, if reached, lead to control actions or cause an alarm.

Three operating levels were defined. Operating level one and two lead to control actions like the inspection of the monitoring system or the manual measurement of the snow-water-equivalent by school staff. When the deformation of one of the main beams reaches a level that indicates that the actual snow load equals the maximum snow load of DIN 1055-5:1975-06, which was the determining load in the design of the structure, operating level three is activated. It leads to the same actions as level one and two but the measurement is carried out by an expert engineer.

Figure 13: *Artificial load on the roof of the school gym in Murnau, consisting of 154 buckets of the size of 90l, filled with water*

For deformations beyond this boundary, two levels of alarm were defined. Both levels lead to a removal of the snow from the roof of the building by the local fire brigade. The highest level, if ever reached, would also result in an evacuation of the gym.

The alarm was integrated into the same technical and organizational infrastructure as the existing fire alarm system.

5 SUMMARY OF THE RESULTS

This paper introduces a new system of measuring deformation in wide span roof constructions based on the principals of digital image processing. In the course of the research project the method was developed from the first idea over multiple steps of preliminary tests to a prototypical system ready for everyday use. Finally, it was tested and refined in a pilot project.

It could be proven that the measuring technique proposed is suited to gauge deformations of building structures on a high level of accuracy. At the same time, these systems prove to be simple, robust and affordable. Redundancy and thus increased safety can be achieved by including additional measuring systems such as snow load sensors and laser distance gauges.

The monitoring system does not aim to replace the assessment of complex interactions in structure bearing loads and serviceability by specialist. It rather offers an additional, reliable engineering tool, to guarantee a safe working environment in the long-term, even with changed circumstances as e.g. snow loads.

REFERENCES

[1] Pawlowski, R.; Henke, K.; Kreuzinger H.; Winter S.; Schregle P.: Monitoring of wide-span timber roof structures - development of a monitoring system, WCTE 2008 - 10th World Conference on Timber Engineering, Miyazaki, Japan, 2008

[2] Pawlowski, R.; Henke, K.; Winter, S.: Kontinuierliche Verformungsüberwachung weitgespannter Hallentragwerke auf der Basis digitaler Bildverarbeitung - Abschlussbericht zum Forschungsvorhaben im Rahmen der Forschungsinitiative Zukunft Bau des Bundesamtes für Bauwesen und Raumordnung, 2011