Short report for the research project:

Continuous Monitoring of Wide-Span Timber Roof Structures on the Basis of Digital Image Processing

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Funded by:

Forschungsinitiative Zukunft Bau
Bundesamt für Bauwesen und Raumordnung
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Duration:

August 2008 – September 2011

This research project was funded by
Forschungsinitiative Zukunft Bau, Bundesamt für Bauwesen und Raumordnung.
(Reference number: Z6-10.08.18.7-08.18/II2-F20-08-20)
The responsibility for the content of this report lies with the authors.

München / Karlsruhe, 30. September 2011

1 Goals of the research project

The collapse of numerous timber buildings in Germany and neighboring countries during the past winters resulted amongst other things in the demand for new and improved ways of monitoring wide-span roof structures as a preventive measure.

The purpose of the research project was the development of a simple, robust and economical system to continuously monitor the deformation of wide-span roof structures. In order to do this, parts of the structure were periodically recorded and analyzed digitally with the help of electronic cameras. Finally, the practical applicability of the system was tested in the course of a pilot project.

2 Realisation of the research project

2.1 Solution principle and preliminary tests

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 were employed as measurement and reference points. The spectral sensitivity of the camera was adjusted by removing the built-in infrared barrier filter and installing a special day light filter.

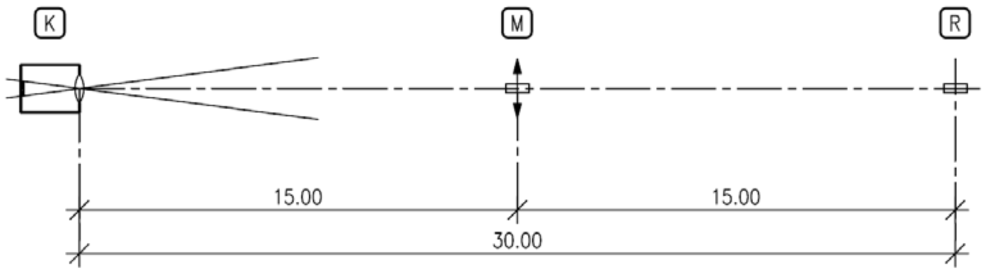

Figure 1: Preliminary tests: Arrangement of system components

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 Figure 1. The individual components can be seen in Figure 2. During the preliminary tests, the measuring point was moved vertically in single millimeter 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 millimeter setting; the orange lines are measurements within the image.

Figure 2: Preliminary test: Camera (left), movable measuring LED (center) and reference LED (right)

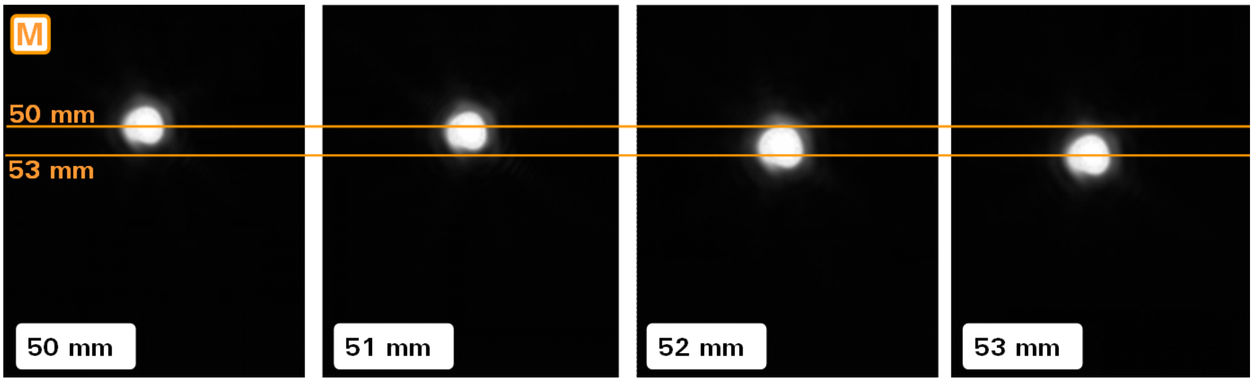

Figure 3: Preliminary test: four measurement images with different LED positioning

With this preliminary test 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 millimeters.

2.2 Pilot project

The practical feasibility of the system was tested as part of a pilot project. For this, the school gym of the Staffelseegymnasium in Murnau in the district of Garmisch-Partenkirchen was chosen. (Figure 4)

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.

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

A permanent monitoring system was installed inside the gym in order to guarantee a safe working environment without extensive measures to reinforce the structure. It's 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).

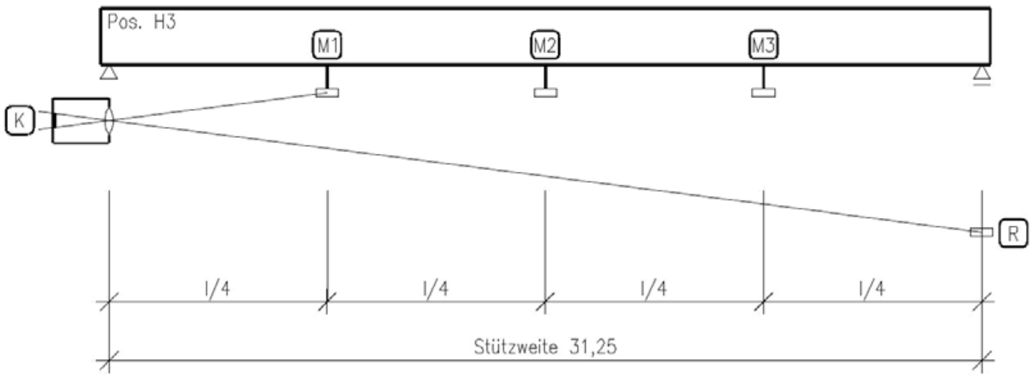

Figure 5: School gym in Murnau, deformation measurement system: Arrangement of camera (K), measurement points (M1-M3) and reference point (R)

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.

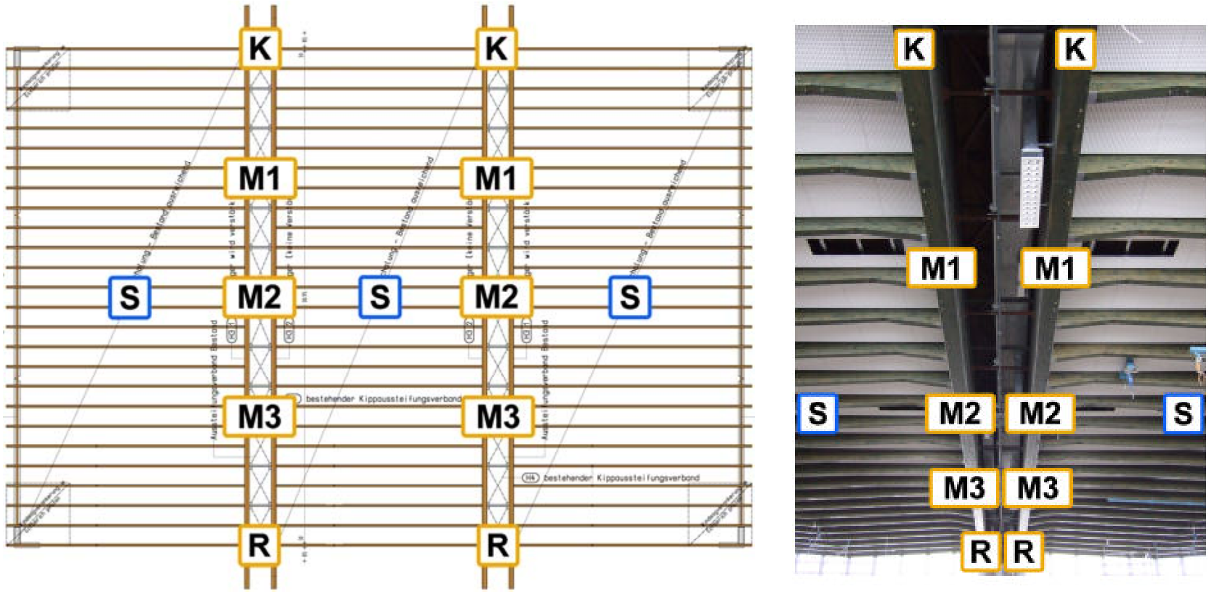

Figure 6: School gym Murnau, monitoring system: Schematic diagram of the locations of the snow cushions (S) and the deformation measurement system consisting of the camera units (K), measuring points (M1-M3) and reference points (R)

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 relevant 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.

Figure 7: Cameras below the bearings of the main beam - during (left) and after installation (right)

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 7). The LEDs of the measurement points are protected by a solid steel casing and mounted to the bottom side of the main beams

(Figure 8). 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 8: LED of a measurement point during installation with steel casing.

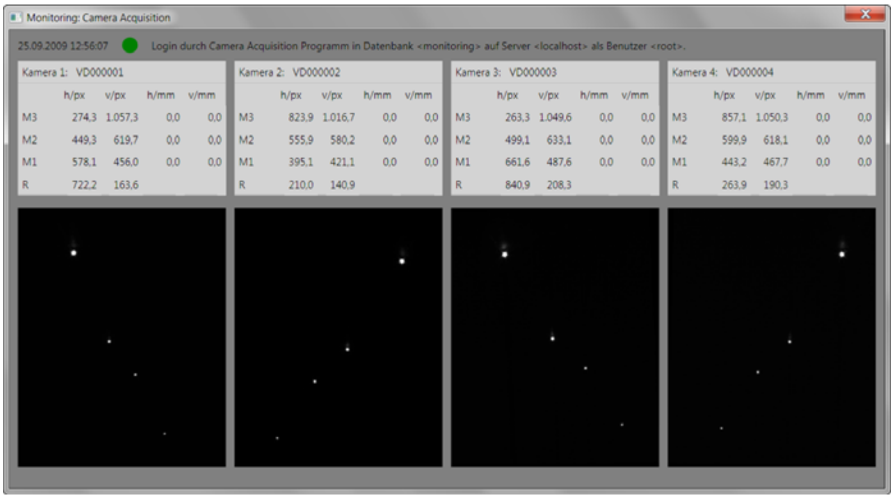

Figure 9: User interface of the measurement software Camera Acquisition with images of the LEDs mounted on the four main beams (bottom), deformation values (center) and warning notification area (top)

All data are stored and processed on a local central computer with remote access via the internet. Specially designed software analyzes 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 9. 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 10), the actual bending stiffness of the main beams was determined. Based on these findings, deformation boundaries were specified which, if reached, would lead to control actions or cause an alarm. The alarm was integrated into the same technical and organizational infrastructure as the existing fire alarm system.

Figure 10: Artificial load on the roof of the school gym in Murnau, consisting of 154 buckets of the size of 90l, filled with water

3 Summary of results

This report 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 shown that digital image processing is well suited for continuous monitoring of deformations in buildings. The achieved precision exceeds the requirements for the monitoring of wide spanning structures. 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.