Zukunft Bau

ABSTRACT of the research project (SWD-10.08.18.7-15.35)

Title

Long title: „Efficient Structural Health Monitoring with MEMS-inclinometer and Microcontrollers“

Occasion / Initial situation

Structures are exposed to various environmental effects and damage mechanisms and therefore require regular checks. Sensor-based monitoring systems can also be used to capture the structural condition. These monitoring systems are expensive and require expert knowledge, thus monitoring is reserved for a few selected structures such as bridges. Part of the existing building stock also requires condition monitoring when exposed to intensive loading.

Subject of the research project

Within this research project, scientific questions and application-related issues in connection with the use of cost-effective inclination sensors and microcontrollers have been addressed. The aim of the research project was to develop a sensor-based monitoring system that can be utilized for structural health monitoring of existing structures in the future. Sensors based on novel MEMS technology and modern microcontrollers form the basis of the innovative monitoring system.

Local rotations on the structure can be measured by means of MEMS inclination sensors. Subsequently, the stress state or the loading can be determined using the mechanical relationships. First, possible application scenarios for inclination-based monitoring were identified: (i) assuring safe operation of structures, e.g. roof structure of industrial halls; (ii) application for historical buildings, e.g. leaning towers; (iii) and for buildings in risk areas exposed to geotechnical events, e.g. sinkholes or landslides. Typical structures were assigned to each scenario and the required accuracies for the inclination measurements were defined. Thereby, a resolution down to a few millidegree is necessary. In order to determine the accuracy and precision of the inclinometer developed by the project partner First Sensor, extensive laboratory experiments have been carried out. The adaption of the sensors for usage in rough environments was conducted in several iterations. The sensors were integrated into suitable housings and the influence of the encapsulation on the achievable data quality and long-term stability was investigated.

Critical states of a structure can be detected by deformation measurements using the mechanical relationships and assumptions about the system behavior. For quantitative evaluation of different sensor setups, a methodology has been developed that is based on the identification of mechanical target quantities such as bending moments, stresses or deflections, by which the structural state can be described. Thereby, the uncertainty about the real loadings and their distributions are taken into account. The methodology is suitable for determining optimal sensor setups.

During the research project, a prototype measurement system based on a single-board computer (Raspberry Pi) was developed in several stages. The underlying operating system is Raspbian, which is a Linux distribution recommended for Raspberry Pi. A modular software framework has been developed for continuous acquisition, structured storage and processing of measurement data. Besides the realization of the measurement task, one focus during implementation was the reliability of the system. The interaction of the measurement system and the sensor has been investigated in several short-term measurements on a reinforced concrete beam and in long-term measurements, where the long-term stability was studied.

In order to proof the practicality under real operating conditions, the measurement system has been installed at two reference objects. For this purpose, an industrial hall where the roof structure was to be monitored and a church tower where the long-term change of the tower inclination was to be observed have been chosen as reference cases. The application potential as well as the limits of this new generation of efficient monitoring systems has been demonstrated. Especially with the short-term measurements, local inclinations at load carrying elements can be detected by means of the developed measurement system with high accuracy. Smallest load effects are detectable from measured changes in inclination when temperature compensation is applied. While the components of the system have proven themselves to be durable even under adverse environmental conditions, during long-term measurement campaigns drift effects of the sensor caused uncertainties in the data interpretation. Further measures to improve the stability of the sensor are therefore necessary.

Conclusion

As part of the research project, a prototype measurement system for sensor-based monitoring of structures has been developed. In short-term measurements, the required accuracies for typical applications of structural monitoring have been achieved. In case of long-term measurements this has not yet been achieved by the sensor prototypes. Further material and component optimizations are required to improve the long-term stability of the sensor. Nevertheless, this new generation of compact and cost-effective monitoring systems has great potential to open new fields of application for conventional structures.

Key data

Short title: Monitoring with inclination sensors

Researcher / Project leader: Prof. Dr. Guido Morgenthal (Project leader, Bauhaus-Universität Weimar, Institute of Structural Engineering, Chair of Modelling and Simulation of Structures)
Sebastian Rau MSc (Researcher, Bauhaus-Universität Weimar)
Dipl.-Ing. Markus Nowack (Researcher, First Sensor AG)

Total costs: 191.856,00 € €

Federal grant: 104.963,00 €

Project duration: 26 months

IMAGES:

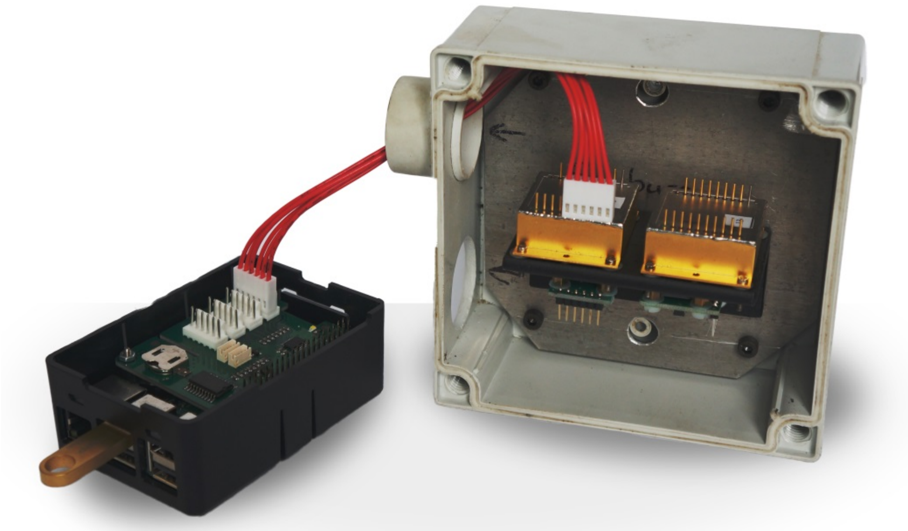

Figure 1: Prototype measurement system: single-board computer (Raspberry Pi, left) and inclination sensors (golden housing, right).

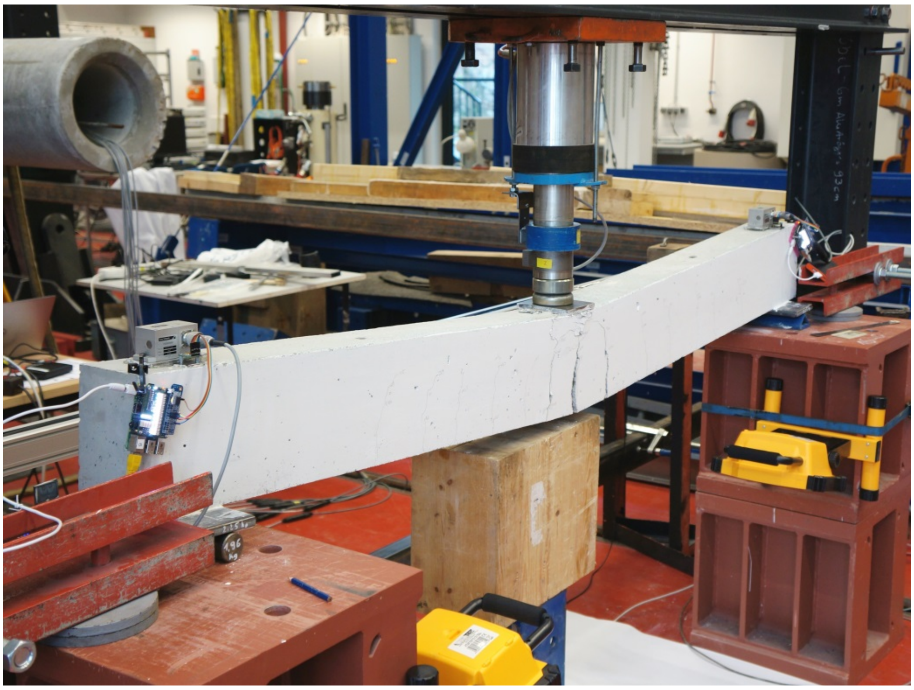

Figure 2: Short-term measurement during three-point bending test of a reinforced concrete beam.

Figure 3: Setup of the long-term measurement for evaluation of long-term stability of the sensor.

Figure 4: Installed measurement system inside a church tower.

Figure 5: Installed measurement system at the roof structure of an industrial hall.