

Reduction of an Irregular Sensor Network for Continuous Humidity Monitoring in Wood Structures

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Summary:

This work demonstrates a sensor network that regulates the temperature of heating bands to reduce the moisture content within the wood structures of existing buildings. The system is designed to monitor the condition of the walls and determine the appropriate level of activation of the heating bands. To find the characteristic points for identifying the moisture behavior, a cluster analysis was carried out on the irregular network.

Keywords: Sensor Network, Cluster Analysis, Wood Structures, Reduction, Climate Monitoring

Background

In the past, it has been shown that the ability to effectively monitor complex systems in a safety-relevant way is significantly limited, e.g. the unexpected collapse of bridges [1]. This is mainly due to the considerable number of influencing factors that are not yet continuously and digitally monitored. Buildings are subject to physical processes within the walls during their design, construction and use. The external climatic environment influences the type, intensity and extent of chemical and biological corrosion in the structures [2]. One major issue is mold, which is caused by excessive humidity. Heat and humidity have a strong indirect proportional relationship, so trying to increase temperature causes humidity to decrease [3]. However, there are climate targets in Europe to keep CO₂ emissions low and therefore there are limits to the continuous supply of heat [4]. To provide heat only at certain times, a monitoring system is required which provides information about the moisture content and its location. Sensor networks are already being used in various areas, including structural monitoring. They are suitable for monitoring different parameters at different locations, but have significantly limited resources in terms of energy, bandwidth, storage space and more. Cluster technologies are used to efficiently increase the service life [5]. The measured data from the sensor network is used to control heat bands in the insulated walls and thus reduce the moisture content.

Method

In a house built in 1872, a network of 30 multi-modal sensor nodes was installed during the latest renovation process. The sensor nodes were placed due to power supply possibilities over three floors and were provided with an index based on their location, as illustrated in Table 1. To ensure the successful activation of the heating bands at the intended time and location, it is essential to obtain comprehensive location and time data.

Tab. 1: Position of Sensors

Floor	Sensor index
Ground floor	5,6,7,13
First Floor	1,2,3,4,16,18,20,21,22,23
Top Floor	8,9,10,11,12,14,15,17,19

Figure 1 shows the sensor head (diameter: 1cm) with the sensors for acceleration, ambient light, temperature and humidity. The sensor system combining six channels of analog-to-digital conversion, complemented by a high bandwidth pre-processing stage used for filtering and signal conditioning. Following data processing, analysis and compression performed by the microcontroller, data is sent via standard UART interface to the communications module which allows both, wired as well as wireless communication.

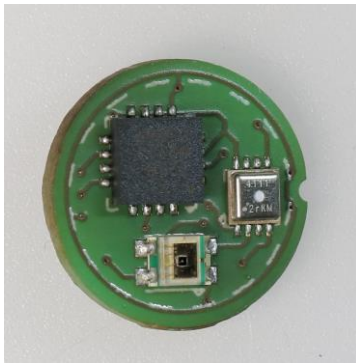


Fig. 1. Multimodal sensor node with 3 axis accelerometer sensor (top left), ambient light sensor (bottom left) and relative humidity and temperature sensor (right).

Results

To further develop a resource-efficient sensor network, it is grouped using cluster analysis (Fig. 2), where the temperature data is plotted over the humidity data. The next step is to determine the similarity of the measurement points. To ensure comparability, the temperature and humidity values are standardized with the z-score (fig 2, Step 1). On this basis, a similarity matrix is created showing the distances between all the points (fig. 2, Step 2). The shortest distance is determined, and the two points are grouped together (fig. 2, Step 3). Depending on the degree of clustering, the distance matrix is updated repeatedly until only two groups remain.

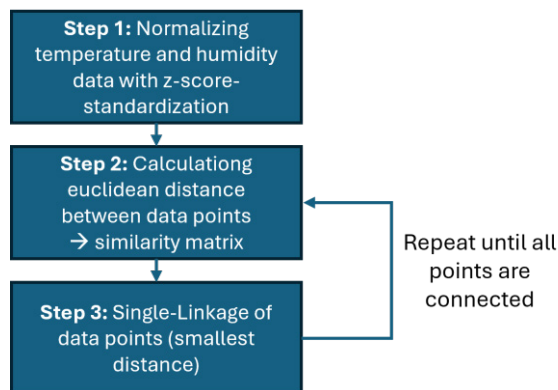


Fig. 2. Procedure of Cluster-Analysis

As illustrated in Figure 3, the cluster analysis of the temperature-humidity behavior of the sensors on March 1, 2025, demonstrates clear distinctions in the data. The similarity is illustrated on the y-axis, while the indices of the sensors are represented on the x-axis.

In general, the dendrogram has a flat structure with similarity values below 1. The highest similarity is shown by sensors 8 (top floor) and 20 (first floor), with the last sensor placed between the outer wall and the inner insulation of the first floor. Sensor 23, which represents the closest connection to the first cluster, has a similar

position. Sensors 3 and 4 are also very similar ($S=0.114$). Both are in rooms on the first floor on the east side. Sensors 5, 6 and 7 are grouped at a level of 0.5-0.6. All three sensors are in rooms on the ground floor. The sensor with the least similarity is sensor 2, which is in a room on the first floor.

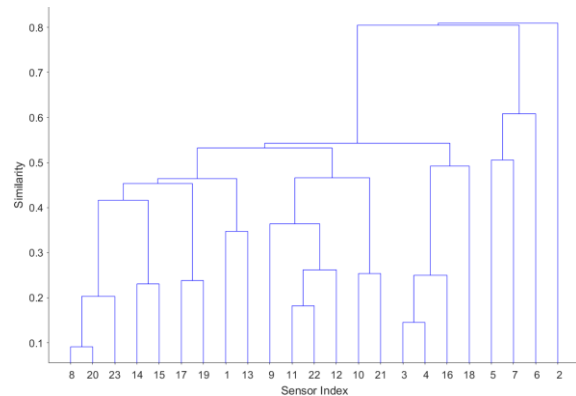


Fig. 3. Cluster analysis for temperature-humidity relation over sensor index

Conclusions

In summary, the results of the cluster analysis show a tendency towards different behavior depending on the floor of the building, especially on the first floor compared to the other floors. It can also be seen that the sensors between the outer walls and the insulation on the same floor show similar behavior ($S<0.6$). Therefore, in the next step, the room sensors from the ground floor and within the external walls on the first floor can be grouped together.

References

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