Validation of a Sensor Node Prototype for Multimodal Climate Measurement Network

Madeleine Bankwitz[1], Christian Engel[2], Sören Hirsch[1]
[1] Brandenburg University of Applied Sciences, Magdeburger Str. 50, 14770 Brandenburg/Havel, Germany,
[2] TEPROSA GmbH, Paul-Ecke-Str. 6, 39114 Magdeburg, Germany
madeleine.bankwitz@th-brandenburg.de

Summary:

This work introduces a multimodal microsensor system for intelligent building analysis. The sensor captures temperature, humidity, brightness, and acceleration on a building facade. Analog measurements are processed as a data matrix and analyzed using correlation coefficients against commercially available weather data. The results demonstrate reliable performance, supporting its potential in smart building applications.

Keywords: multimodal sensor system, sensor network, climate monitoring, building, digitilization

Background

There are a number of areas in which the use of digital analysis is essential. It is of the most crucial importance to ensure efficiency and predictive planning, particularly in regard to the objective of achieving sustainability. To facilitate mathematical and trend analyses, access to digital data is important [1]. It is therefore necessary to develop measuring systems that can be installed in a variety of environments, are compact in size and measure a range of parameters. Due to the major influence of the building sector on the greenhouse gas effect, we are concentrating on measuring systems for climate monitoring [2,3].

Arnesano et al. conducted a literature review identifying horizontal air temperature distribution as a critical aspect of climate characterization. The review emphasizes the importance of accounting for external influences—such as solar radiation, shadowing elements, and seasonal variations—in comprehensive indoor climate assessment and monitoring strategies [4]. Coulby et al. (2021) presented an indoor environmental quality (IEQ) sensor system that measures CO2 concentration, temperature, humidity, atmospheric pressure, and light intensity. While the system successfully indicates and adapts to changes in environmental quality, potential biases in accuracy limit its applicability in more rigorous contexts, such as occupational health assessments and compliance with industry standards [5]. Chen et al. (2024) introduced an innovative multimodal intelligent flooring system capable of detecting position, pressure, material type, user identity, and activity. The system demonstrated strong signal robustness and achieved high sensitivity and linearity, underscoring its potential for responsive environments and intelligent building applications [6]. Yun et al. developed a wireless sensor network for indoor climate monitoring, which collects diverse environmental parameters, including temperature, humidity, CO2 levels, light, and occupancy. This system provides insights into building climate dynamics, supporting informed adjustments for indoor comfort and energy efficiency [7].

Method

A preliminary prototype has been developed for the current stage of the project. It is based on an ultra-low energy and miniaturized but nevertheless modular multi-channel data-capture platform with an advanced microcontroller platform at its core (Fig. 1). It is intended to measure crucial environmental parameters like temperature, humidity, brightness as well as mechanical loads. The integration of this system into various components and spaces requires a novel approach, combining advanced circuit design and packaging technologies to create a super compact but robust design. For this purpose, a sensor system was designed, combining six channels of analog-to-digital conversion, complemented by a high bandwidth preprocessing 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 wired as well as wireless communication. By using multilayer circuit design together with minimum copper structure width of 50 µm together with innovative stacked micro-via technology and state-of-the-art sub-miniature XQFN and BGA packages, we were able to integrate all mentioned components of the sensor system within dimensions of only 10 mm x 50 mm.

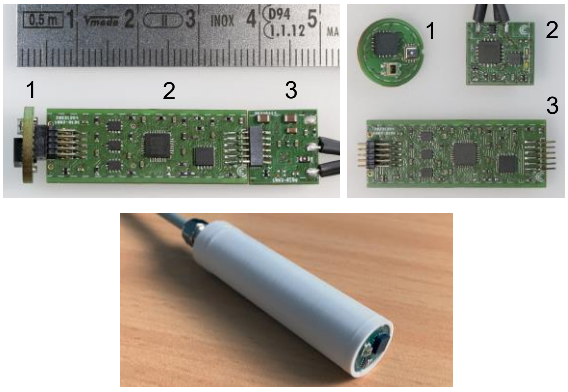

Fig. 1. Sensor Node Prototype

A single-digit mA average power consumption was achieved with standby currents in the lower µA range. This allows the use of energy harvesting as power source together with next generation solid-state batteries.

The sensor was installed on the outside of a building on a window sill. In order to validate the sensor system, commercially available weather data from the nearest weather station was also obtained via the weather application programming interface (API), which is provided via the Visual Crossing website. The Pearson correlation coefficient of the sensor and weather data is calculated for the statistical validation and allows a statement to be made about the linear correlation of the metric variables.

Experimental Results

Meteorological data were obtained from Visual Crossing Weather's online platform, which offers an accessible, cost-effective API that sources data from proximate weather stations. This weather dataset provides hourly readings and is likewise saved in a .csv file format for consistency with the sensor data.

Figure 2 shows a comparison of the measured parameters over 10 hours. A similar trend can be seen between the measured data from the sensor (solid line) and the meteorological data (dashed line). It is particularly noticeable that the temperature and humidity data from the sensor show an indirectly proportional behavior. This is confirmed by the negative correlation coefficient in Table 1.

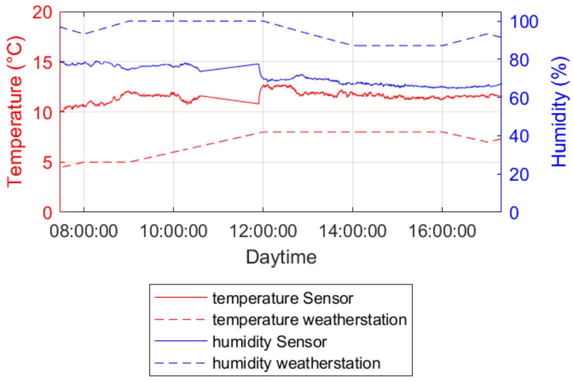

Fig. 2. Multiple Parameters in- and outdoor over time

To calculate the correlation index, the weather data was adjusted to the sample size of the sensor's measuring points. For temperature, there is a weak positive correlation between the data from the weather station and the sensor with a coefficient of 0.41. For humidity, on the other hand, a medium-strong positive correlation between the measured data can be recognised.

Tab. 1: Pearson's Correlation Coefficient r

	r
Temperature weather x sensor	0.41
Humidity weather x sensor	0.67
Sensor temperature x humidity	-0.43

Conclusion

A multimodal sensor node prototype was developed and its measurements were compared with data from commercially available weather monitoring systems. The results show that the measurement system exhibits comparable behavior to its meteorological counterparts, indicating its potential suitability for environmental monitoring applications. In the next step, the accuracy of the sensor will be investigated by controlling the environmental variables, for example using a climate chamber. In this way, precise error tolerances for the system can be determined.

The next phase of hardware development involves integrating a CO_2 sensor to enhance atmospheric monitoring capabilities. By adopting wireless communication, the new prototype aims to address the limitations by dependence on wiring, reducing infrastructural demands while enabling a more extensive deployment of sensors across different locations [8].

References

[1] Arabshahi, M., Wang, D., Sun, J., Rahnamayie-zekavat, P., Tang, W., Wang, Y. & Wang, X. (2021). Review on Sensing Technology Adoption in the Construction Industry. *Sensors, 21*(24), 8307. https://doi.org/10.3390/s21248307

[2] Li, Y., Han, M., Liu, S. & Chen, G. (2019). Energy consumption and greenhouse gas emissions by buildings: A multi-scale perspective. *Building And Environment*, 151, 240–250. https://doi.org/10.1016/j.buildenv.2018.11.003

[3] Lamb, W. F., Grubb, M., Diluiso, F. & Minx, J. C. (2021). Countries with sustained greenhouse gas emissions reductions: an analysis of trends and progress by sector. *Climate Policy, 22*(1), 1–17. https://doi.org/10.1080/14693062.2021.1990831

[4] Arnesano, M., Revel, G. & Seri, F. (2016). A tool for the optimal sensor placement to optimize temperature monitoring in large sports spaces. *Automation in Construction,* 68, 223–234. https://doi.org/10.1016/j.autcon.2016.05.012

[5] Coulby, G., Clear, A. K., Jones, O. & Godfrey, A. (2021). Low-cost, multimodal environmental monitoring based on the Internet of Things. *Building And Environment*, 203, 108014. https://doi.org/10.1016/j.buildenv.2021.108014

[6] Chen, Y., Hong, J., Xiao, Y., Zhang, H., Wu, J. & Shi, Q. (2024). Multimodal Intelligent Flooring System for Advanced Smart-Building Monitoring and Interactions. *Advanced Science*. https://doi.org/10.1002/advs.202406190

[7] Yun, J. & Kim, J. (2013). Deployment Support for Sensor Networks in Indoor Climate Monitoring. *International Journal Of Distributed Sensor Networks*, 9(9), 875802. https://doi.org/10.1155/2013/875802

[8] Yang, Y., Xu, W., Gao, Z., Yu, Z. & Zhang, Y. (2023). Research Progress of SHM System for Super High-Rise Buildings Based on Wireless Sensor Network and Cloud Platform. *Remote Sensing*, 15(6), 1473. https://doi.org/10.3390/rs15061473