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Advanced Sensor Systems for Sustainable Building Modernization: A Technological Approach to Enhance CO2 Savings

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Summary:
This work presents an advanced sensor-system design developed to improve diagnostic methods for sustainable building renovation, with focus on the optimization of energy efficiency and the achievement of significant CO2 reduction in the construction sector.

Keywords: Building Information Modeling, CO2 Reduction, Environmental Monitoring, Smart Sensor Networks, Non-Destructive Evaluation

Introduction

Considering the challenges posed by climate change, it is imperative to adopt innovative strategies in all sectors, with particular focus on construction and real estate, which are well-known contributors to energy consumption and CO2 emissions. Sustainable renovation represents a pivotal approach for enhancing energy efficiency, reducing energy demand and improving environmental footprints through precise resource management and energy-efficient construction practices [1].

In the field of building management, the focus on components such as facades, windows, insulating elements, etc. is of paramount importance, as regular inspections and condition assessments are vital for ensuring the structural integrity, functionality, reliability and lifespan of these complex structures [2]. However, conventional visual inspections are not capable of ensuring complete condition monitoring of these structures, resulting in incomplete evaluation and premature replacement [3]. Additionally, there is a lack of documentation, which is further compounded by the digitalization gap in this sector. The construction industry presents a challenge in the absence of reliable data to substantiate the accuracy of assumptions [4].

Consequently, integrated sensor systems may be regarded as a pivotal technology for overcoming these limitations, offering a non-destructive monitoring tool that may lead to an extension of the lifespan of the aforementioned elements [5].

Materials and Methods

The presented sensor system (Figure 1) 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. Its intended purpose is to measure crucial environmental parameters such as temperature and humidity as well as mechanical loads, for example vibrations or shocks. The integration of this system into various components and spaces necessitates a novel approach, combining advanced circuit design and packaging technologies to create a super compact yet 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. Additionally, a dual-stage voltage converter was added, providing a stable power supply from almost any source. Subsequently, the data undergoes processing, analysis and compression at the microcontroller level. This data is then transmitted via the standard UART interface to the communications module, which enables both wired and wireless communication. The integration of all components of the sensor system within very small dimensions was made possible using a multilayer circuit design, a minimum copper structure width of 50 µm,

innovative stacked micro-via technology and state-of-the-art sub-miniature XQFN and BGA packages.

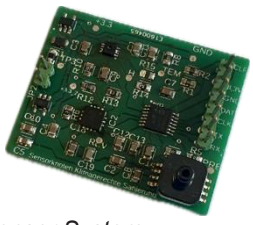

Fig. 1. Sensor System

By implementing highly efficient measurement and data processing routines, 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. Those features will be added to the sensor system in the near future.

A 3x5 (height x depth) array was constructed behind a balcony door using a sensor system. The sensors were positioned at a constant distance of 0.5m in both directions. The measurements were conducted in a 42m² room over a period of 35 minutes. The door was open for ten minutes.

Results

Figure 2 presents the results of the measurement, with the interval of airing marked in grey. The measurement matrix enables the analysis of dynamic changes over time and position. The temperature and CO2 concentration exhibit a rapid decline upon opening the door and a subsequent increase upon closure. In contrast, the humidity displays a precipitous decline following the opening of the door, followed by a gradual increase during airing. The outer humidity was above 50%. For graphical presentation, the sensor exhibiting the most characteristic behavior during the airing process was selected. The suitability of the sensor as a representative for the entire measurement array was evaluated through a correlation analysis of all values above the time.

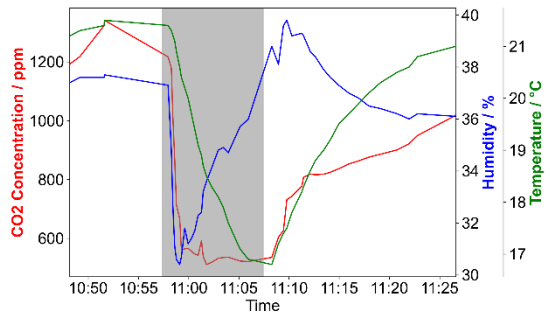

Fig. 2. Multimodal Status Measurement

Discussion and Conclusions

To summarize this process, it is possible to display a measurement with one point in this array. To analyze the dynamic sizes, it is necessary to include intelligent software. In the future, further miniaturization of the system is planned to facilitate the implementation of sensor networks in the field of building renovation. This development will be complemented by advanced wireless data management to ensure efficient and scalable monitoring of the renovation processes. Furthermore, preparations are being made for the integration of energy harvesting technologies to enable autonomous power supply for the sensors, thus contributing to the reduction of energy consumption and increasing CO2 savings. These technological advances lay the foundation for a new generation of sensor systems that pave the way for a more environmentally friendly and sustainable future in the renovation sector.

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