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Smart Monitoring System for Air Quality Control with Capacitive Sensors

Matthias Steinmaßl[1], J. Boudaden[1,2], H.-E. Endres[1], I. Eisele[1], C. Kutter[1], P. Müller-Buschbaum[3]*
[1]Fraunhofer EMFT, Institution for Microsystems and Solid State Technologies, Munich, Germany
[2]Institute of Electronic and Sensor Materials, TU Bergakademie Freiberg, Germany
[3]Lehrstuhl für Funktionelle Materialien, Physik-Department, TU München, Garching, Germany
**Corresponding author: matthias.steinmassl@emft.fraunhofer.de*

Abstract

A low power, network-ready demonstrator for sensing carbon dioxide, humidity and temperature simultaneously is designed. Contrary to conventional NDIR systems, the sensor's detection principle is based on a capacitive readout of an interdigitated transducer coated with polymeric sensing materials sensitive to CO_2 and humidity, respectively. A microcontroller is used to control the optimum working temperature of the sensor. The capacitance is measured based on the charge transfer capacitance measuring circuit. A restricted number of components is employed to meet low-cost and low power requirements. The system is tested in an office environment and compared to commercially available systems. It exhibits excellent results and is suited for an integration in automated HVAC systems.

Key words: carbon dioxide, capacitive sensor, low power, microcontroller, PID

Low Power Carbon Dioxide Sensor for IAQ

Recent studies show, that an intelligent control of heating, ventilation and air conditioning (HVAC) in indoor areas could save around 30 % of supplementary costs of total building energy consumption [1]. One marker for a good indoor air quality (IAQ) is the amount of carbon dioxide in the air not exceeding 1500 ppm (400 ppm is normal background concentration) [2]. Today's carbon dioxide sensors are mainly based on a direct measurement of carbon dioxide by infrared absorption or by an indirect measurement of volatile organic compounds (VOC). In most cases, the VOC concentration is strongly correlated to that of carbon dioxide, but one has to consider, that VOC and CO_2 are different chemical species [3]. The latter sensing technique meets low power requirements. However, there is currently no low power CO_2 meter on the market, which uses a direct measurement of carbon dioxide in air.

Chemical Capacitive Polymer Sensors

Polymer materials gain a fast-growing interest in recent sensor research and development. They can be easily functionalized and the deposition techniques can be applied to a wide range of electrical transducers. At Fraunhofer EMFT a material was developed, that shows a high sensitivity to carbon dioxide at 60 °C. It is based on a siloxane polymer which is functionalized with amino groups [4]. As most polymeric materials, a cross-sensitivity to humidity is observed related to its hygroscopic property. Gold interdigital transducers (IDT) were fabricated using a lithography process on a glass substrate. They are favorable for chemical sensors, because of their simple fabrication process and their well-known physics [5]. Recently, a similar hybrid material, based on nanoparticles was developed, that shows an even higher sensitivity and long-term stability [6]. Furthermore, polyimide coated IDTs have been used for humidity detection.

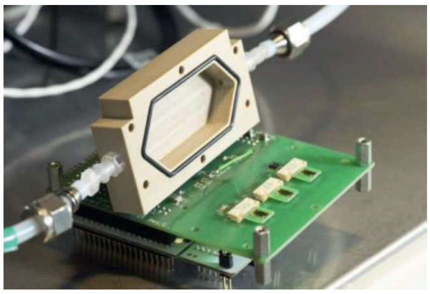

Fig. 1. Sensor system with two reference sensors (PT1000 and SHT25) and a PEEK chamber for gas calibration scenarios of CO2 and RH sensors.

Advantage of Interdigital Transducers

The established detection system (figure 1) consists of IDTs with different coatings and a microcontroller readout system. Based on a previous project [7], the low power STM32 Nucleo board, which was recently introduced, was used to establish this multifunctional readout system. Figure 2 shows the functional

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diagram of the system. The touch sensing controller (TSC) was used to obtain the capacitance with the need of only one additional capacitor. A PID algorithm was used to control precisely the CO_2 sensor temperature at 60 °C. On the hardware side, two wires around the interdigitated electrodes were designed. One was considered as a heater and the second one as resistive temperature device (RTD). Both were driven with respective circuits, by applying a constant current source (CCS) to the temperature wire and a pulse width modulation (PWM) to a MOSFET to set a heating voltage. An analog to digital converter (ADC) was used to read out the temperature resistance value. The values of the surrounding temperature, the capacitance of the humidity sensor and the capacitance of the CO_2 sensor are send to a master PC via a serial communication interface (UART). The STM32 Nucleo board includes a KNX Library (tapko.de/en/kaistack-for-stm.html), which can connect the sensor node to a home automation system, where a powerful data analysis algorithm calculates the gas concentration from the received data.

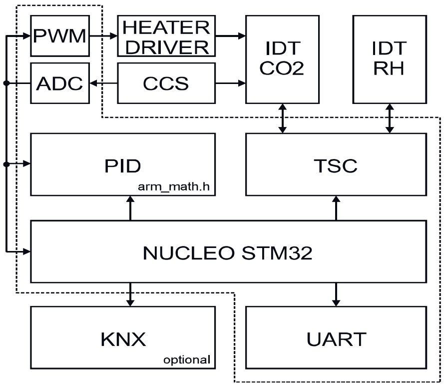

Fig. 2. Functional diagram of the established sensor system. The dashed line indicates the parts used from the Nucleo STM32 board.

Results

The system was tested in a student's office during a whole workday. Figure 3 shows the values of the capacitive sensors for CO_2 and humidity. The office room has a volume of 300 m³ and six students are working there. The CO_2 reference concentration, was measured with a Brüel & Kjær Multi-gas monitor Type 1302. The relative humidity (RH) measured by a Sensirion SHT25 was taken as a reference value. The amount of CO_2 in the office correlates with the number of present students. One can clearly identify the starting time of work of students (8:30), their working period, the lunch rest break (11:30 until 12:30) and the leaving time of workplace (16:30). The peaks in the CO_2 level indicate the entering of a supervisor (11:00 and 18:00).

Summary

A miniaturized, KNX-ready system for indoor air quality monitoring of CO_2, humidity and temperature is presented. The power consumption stays far below that of commercial CO_2 sensors and is ready for miniaturization and industrial application.

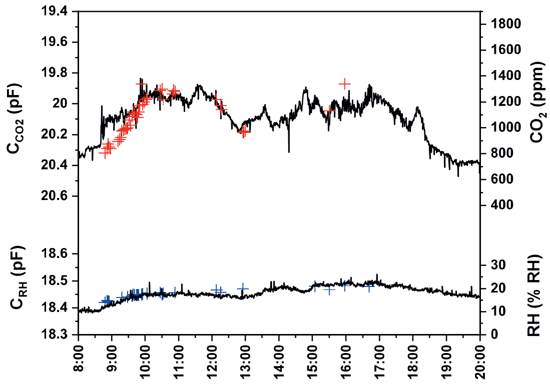

Fig. 3. Test measurement at a student's office. The red and blue crosses indicate CO_2 and RH values from commercial systems.

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