# Indoor Monitoring System For Well-being

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***Abstract*—The work address the indoor air quality monitoring enabling to monitor the well-being and comfort of occupants. A monitoring system is able to measure room temperature, humidity, barometric pressure, CO2, luminosity, and dust pollution using chip sensors. The measurement devices are connected wirelessly via ZigBee 3.0 technology enabling mesh network topology and the measured data is collected into a database. The data will be then processed and presented using a cloud application enabling advanced control and alarm management, when a value exceeds the health limits. The measurement system comprises of measurement devices and a gateway. The measurement device is designed as a sandwich architecture comprising sensor and communication module. The created sensor module is interfaced with Adafruit Feather interface in order to use any available Adafruit SoC kit as the communication module. The conducted results also suggest that ESP32-H2, which is now in pre-production phase, operates as ZigBee 3.0 SoC in an embedded device.**

***Index Terms*—Indoor air quality, ZigBee 3.0, ESP32-H2, NRF52840, Smart Home, IoT**

## I. INTRODUCTION

Indoor air quality (IAQ) is an issue on which many companies and health-care researcher are focusing to improve user's health and well-being in a space. The purpose of a monitoring system is to provide data based on biological, physical, and chemical sensors to improve maintenance and management strategies enabling also other benefits like energy reduction. [12]

IAQ monitoring system is traditionally designed as a star topology system comprising of measuring devices and edge device (gateway) transmitting data to a cloud service. The communication could be achieved by a local area network technology; in order to reduce the power consumption of a device, ZigBee technology (moreover, offers mesh network topology) could be selected. [13]

To integrate the ZigBee technology in a MCU-based device, SoC chips ensure small footprint while sufficient computational power. Among the leading market chips, nRF52840 and CC2530 could be highlighted. Other manufactures try to enter the market, such as Espressif with ESP32-H2 chip, which is now in the pre-production phase. Another way implementing ZigBee into a device rests in use of XBee module or its derivatives [14].

The purpose of the work is to create a measurement system for various room variables using COTS (Commercial off-the-shelf) devices to collect IAQ data. Another purpose rests in the validation of the use of ESP32-H2 (as the begin to market SoC) and ZigBee 3.0 technology. The sensor module was designed and created. The communication module firmware was also designed and created in order to validate the proper selection. After it is integrated into a system comprising cloud database and web data application, the measurements will be conducted and the system could be validated. Due to the validation of the system architecture, database and visualization were implemented only locally and tested separately.

Our work contributes several innovations, which other indoor monitoring systems could benefit from. Our measurement device architecture allows to combine different sensor and communication module which follow Adafruit Feather interface; thus, a commercially available communication module is able operate with our sensor board. Moreover, the sensor board could be replaced to measure a different set of variables. We could also highlight the use of dust pollution and luminosity sensor. Another outcome of the work rests in the one of the early applications of ESP32-H2 as the ZigBee communication SoC.

## II. SYSTEM ARCHITECTURE

The system can be divided into four parts. There are two hardware parts (sensor unit and communication module based on SoC), which create together the whole measurement device as it is shown at the figure 1, and two software parts (database and visualization).

The measurement devices (acting as ZigBee end devices) are periodically awaken from sleep mode to perform a measurement; then, the data is transmitted via a ZigBee network into the gateway (Windows OS based machine acting as ZigBee coordinator) and stored in the database running on the machine. The same machine hosts visualization which scrapes data from the database.

The used database is the InfluxDB enabling time series storage architecture which is suitable for periodic measurement collection. As a visualization software, a lot of commercial and open-source software can be used, which InfluxDB 2.0 or Grafana application could be suitable candidates from. Grafana has been selected to favor micro-services architecture against a centralized solution. In the integration phase of the project, the cloud option of database and visualization will be adopted.

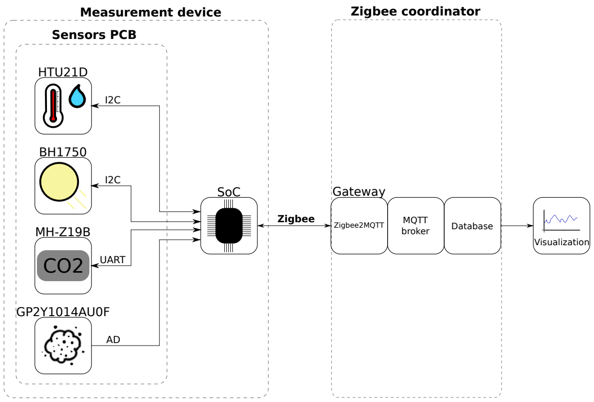


Fig. 1. Block diagram of the monitoring system

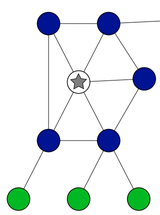

Fig. 2. ZigBee mesh topology

### A. ZigBee

ZigBee is wireless communication protocol invented in 1998 by ZigBee Alliance (In nowadays CSA - Connectivity Standards Alliance). This communication standard is designed to have low consumption requirements in battery powered devices. The standard has been built on top of the wireless standard IEEE 802.15.4 for low-rate wireless personal area networks.

The ZigBee usage enables a mesh topology which is shown at figure 2. In this topology there are devices connected between each other except of the end devices that makes the topology self-healing which means that even when the link to the device is down, the new different route to the device can be established if there exists one.

In ZigBee network, devices can play three roles:

- coordinator (star - Fig. 2, 3) - manages the network and runs an application
- routers (blue - Fig. 2, 3)) - makes routes to target devices and runs an application
- end devices (green - Fig. 2, 3)) - runs an application

*1) Link Quality Indicator:* Link Quality Indicator (LQI) is characterization of strength and quality of received packet.

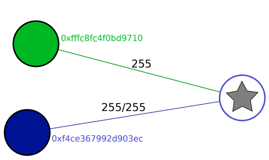


Fig. 3. ZigBee test network with maximal LQI (real distances = 1m)

This measurement should by done for every received packet ( [10], page 63). This indicator can acquire 0 to 255.

The figure 3 shows small test network which has been created with nRF52840 SoC (blue) acting as a router device and ESP32-H2 (green) acting as a end device. Above the links to coordinator there is displayed LQI, because of the short distances (1 $m$ each, without obstacles) the LQI reached maximal value 255.

*2) Security:* Security of a ZigBee network is based on link and network keys. The keys have size of 128 bits. Link keys are for unicast communication and broadcast communication uses network key shared with every device in the network. ( [11], page 400)

## III. Design of Measurement Device

This chapter describes design of measurement device. Embedded sensors enable temperature, humidity, barometric pressure, CO2, luminosity, and dust pollution measurement. Communication between sensors and SoC is via I2C, UART, or AD converter.

The Communication Module and the Sensor Module are designed to have compatible bus with each other and they are Adafruit Feather compatible. This design makes measurement device modular in built-in sensors and in data transfer used technology. Figure 4 shows the design and integration of the sensor module.

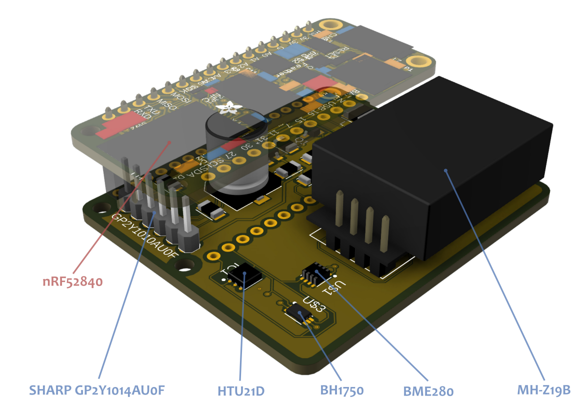


Fig. 4. Sensor module visualization

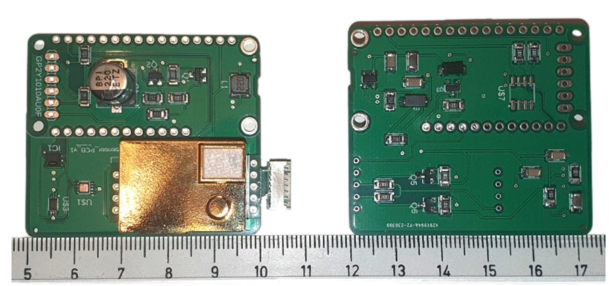


Fig. 5. The created sensor module (units in $cm$)

### A. Communication Module

The communication module contains SoC and components with power management and there should be for example USB to UART bridge for direct firmware upload from computer. Also there should be battery power management with battery level monitor circuit.

The figure 3 shows connection of different SoCs used in ZigBee network. The blue node in the picture is nRF5240 acting as a ZigBee router and the green node is a ESP32-H2 acting as a ZigBee end device.

### B. Sensor Module

The sensor module is designed and created to measure lot of variables while small dimensions are achieved. The module is powered from battery, which has power management on the communication Module. On Sensor Module board there is step-up for 5 $V$ so there are 3.3 $V$ and 5 $V$ busses which means both voltage level sensor types can be used.

For communication between sensors and SoC there are two busses - I2C and UART. Also AD converter pin and PWM is embedded if needed in another combinations of sensor communication module.

Although level-shifters and other converters need to be used, the created sensor module gives a reference sensing module that is compatible with COTS communication modules.

## IV. Indoor environment recommendations

This chapter summarizes recommendations for indoor environment from different standards for variables that are being monitored by the system. This recommendations can be used in analysis, for alerts, or as a target value of actuators where the actual value is given by this monitoring system.

### A. Temperature and humidity

The temperature and humidity are the most common comfort parameters which can be easily determined by a human perception.

Thermal comfort can be determined and interpreted of thermal comfort using calculation of PMV (predicted mean vote). In European standard ISO 7730 [1] there could be found for example the operative temperature for single office should be 24.5 $\pm$ 1 $°C$ at summer and 22 $\pm$ 1 $°C$ at winter.

### B. Light intensity

Another important parameter for well-being is the light intensity. For specific activities, there is a need for certain level of the light intensity; the values are described in Table I.

### C. Carbon Dioxide

Carbon dioxide (CO2) can be in high concentration for human even mortal invisible gas. So it is good to adjust it's level in the room at reasonable concentration. The concentrations are in Table II.

TABLE I
Table Light intensity and specific activities ( [2], page 355)

| ***Type of the space, task and activity*** | ***Light intensity [lx]*** |
|---|---|
| archive | 200 |
| reception | 300 |
| document storing, copying and so on | 300 |
| writing, reading, data analysis | 500 |
| CAD working station | 500 |
| conference room | 500 |
| technical drawing | 750 |

TABLE II
Potential danger of CO2 concentration [3]

| ***Description*** | ***CO2 [ppm]*** |
|---|---|
| average outdoor concentration | 400 |
| typical indoor concentration with good air flow | 400 – 100 |
| poor air quality | 1000 – 2000 |
| headache, sleepiness, lost of concentration | 2000 – 5000 |
| health problems | 5000 |
| immediate life danger in lack of oxygen | >40000 |

### D. Dust

Breathing a dust particles can lead to respiration issues. Limits are described in Table III.

## V. Sensor device parameters

Following chapter describes used sensors and relations between the real world value and measured value.

### A. Temperature and humidity

The temperature and relative humidity sensor is measured by I2C SMT chip HTU21D with parameters: [5]

- 3.3 $V$
- humidity 12 $bit$ resolution
- temperature 14 $bit$ resolution
- humidity: 0–100 $\%$, temperature: -40 – 125 $°C$ range

### B. Light intensity

Light intensity is measured by the SMT chip based on I2C communication BH1750 with parameters: [6]

- 3.3 $V$
- humidity 16 $bit$ resolution
- 0–65535 $lx$ range

TABLE III
Dust particles limits for safety of human life [4]

| ***Particle size [$\mu m$]*** | ***Average time*** | ***Limit [$\mu g \cdot m^3$]*** |
|---|---|---|
| 10 | 24 h | 50 |
| 10 | 1 year | 40 |
| 2.5 | 24 h | 25 |
| 2.5 | 3 years | 20 |

### C. Carbon dioxide

CO2 sensor embodies a MH-Z19B chip. It uses non-dispersive infrared (NDIR) principle for measurement. The output options are UART which provides direct CO2 concentration or PWM which needs a calculation to get CO2 concentration. Chip parameters: [7]

- 5 $V$
- 5000 $ppm$ range
- accuracy $\pm$(50 $ppm$ + 5 $\%$ reading value) $ppm$

### D. Dust

Dust particles sensor uses optical principle for measurement. It is the SHARP GP2Y1014AU0F sensor. The dust density is given by the linear dependency of output voltage. Chip parameters: [8]

- 5 $V$
- 0.5 $mg/m^3$ range
- accuracy 0.5 $V/(0.1mg/m^3)$

### E. Barometric pressure

Sensor for barometric pressure is BME280 which combines pressure, humidity and temperature sensor. The additional temperature and humidity sensor allows more accurate measurement for this values: [9]

- 3.3 $V$
- relative humidity
  - 0 – 100 $\%$ range
  - accuracy $\pm$3 $\%$
- pressure
  - 300 – 1100 $hPa$ range
  - accuracy $\pm$1.7 $hPa$

## VI. Future vision

When the system is implemented in a real environment, the data will be gathered to form a dataset. From the dataset, a model could be created to analyze the air properties in a room while daytime and season are changed; a preliminary research was conducted by [15].

The data and model could be helpful to estimate properties of an air quality for room appliances, such as an air conditioning system (HVAC), which could be then controlled based on the data in an advanced way to reduce the energy consumption; a preliminary research was conducted by [16].

## Conclusion

The article presents the design of an indoor air quality monitoring system for well-being, which should alert in case of any of the monitored value is out of the comfortable limit. The crucial part of the system is a measurement devices, which provides data to the server via a gateway using ZigBee 3.0 technology enabling mesh network. The measurement device is designed to provide a possibility to combine commercially available communication module with the created sensor module via Adafruit Feather interface. Besides the standard monitored variables, the sensor module is equipped by chips to measure luminosity and dust pollution. The results also suggest that ESP32-H2 communication module, which is now in the pre-production phase, is suitable for ZigBee 3.0 embedded devices.

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