An Intelligent IoT Wearable for Monitoring and Preventing Asthma Attacks

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Abstract: Asthma is a chronic disease that affects the respiratory tract, inflicting coughing, wheezing and difficulty for breathing. In order to mitigate these problems, this paper introduces an IoT wearable that is able to monitor the state of an asthma patient: breathing frequency, heart rate and oxygen saturation level. It also detects parameters that may worsen the situation of the patient: temperature, humidity and presence of gas or particles. The system also notifies the patient when he/she has to take his/her asthma medication. The value of the parameters is shared in real time by Bluetooth and historic values are stored in a database. The system uses color-based indications to calculate the risk level. With this information, the user can detect an asthma attack before it happens. To illustrate how the system operates, asthma attacks were simulated, showing that the system is able to determine that the attack is happening based on the specified input parameters.

1 Introduction

A wearable is an IoT device that is designed to be worn, like a smart watch, for different purposes like measuring data while providing wireless communications (Fernández-Caramés and Fraga-Lamas, 2023). In this paper, it is presented a wearable capable of measuring, showing and storing different parameters that can be crucial for asthma patients, warning them about threatening environments or irregular vital signs.

Asthma affects around 5% of people globally, and specially at young ages (Lancet, 2020). The more industrialized the country, the more asthmatics there are (Mancilla-Hernández et al., 2015). An asthma attack occurs when airways become inflamed and narrowed causing coughing, wheezing, tightness in the chest and less amount of air getting in and out the lungs. Additionally, the body produces mucus obstructing even more the airways (CDC, 2019).

There are some external factors that may impair patient breathing or trigger an asthma attack. Although such factors can vary between different people, some of the factors are: tobacco smoke, dust mites, atmospheric contamination, smoke from burning wood or grass, pets, cockroach allergens, mold, infections like flu or COVID, weather, sports which keep competitors constantly moving and even strong emotions (CDC, 2019).

2 Design and Implementation

The developed IoT system is able to measure the previously mentioned parameters through sensors. To notify the user when to take his/her medication, the system allows for configuring alarms that are notified by turning on an LED, which is turned off by pressing a button.

Real-time data are displayed on a smartphone by connecting it via Bluetooth Low Energy (BLE). The board also stores data on RAM (removing the oldest data when it runs out of memory) and can uploads them later opportunistically (i.e., once the ESP32 detects that an Internet connection is available) to a web application developed in Django, which stores all data on a database and provides an interface that shows them through a graph.

The wearable consists of an embedded board based on an ESP32 connected to a set of sensors using the I²C interface. The used sensor are: an RTC DS3231 is used to measure temperature and to configure alarms; a BME280 is used for measuring atmospheric pressure, temperature, relative humidity and altitude; a SEN0460 is used for measuring air quality (PM2.5, PM1.0 and PM10); a MAX30102 is to measure heart rate and oxygen levels on blood; MPL3115A2 is used for determining the breathing rate; and, finally, a CCS811 is used for detecting the presence of CO2 and TVOC (Total Volatile Organic Compounds).

Breathing frequency is calculated with the barometer MPL3115A2, potentially embedded in a smart mask that the user wears. For doing this, an algorithm was created to compare continuously the latest obtained value with the previous one (obtained roughly every 20 seconds), thus determining whether atmospheric pressure has increased or decreased. The number of times pressure has increased and decreased during a time interval indicates the breathing frequency.

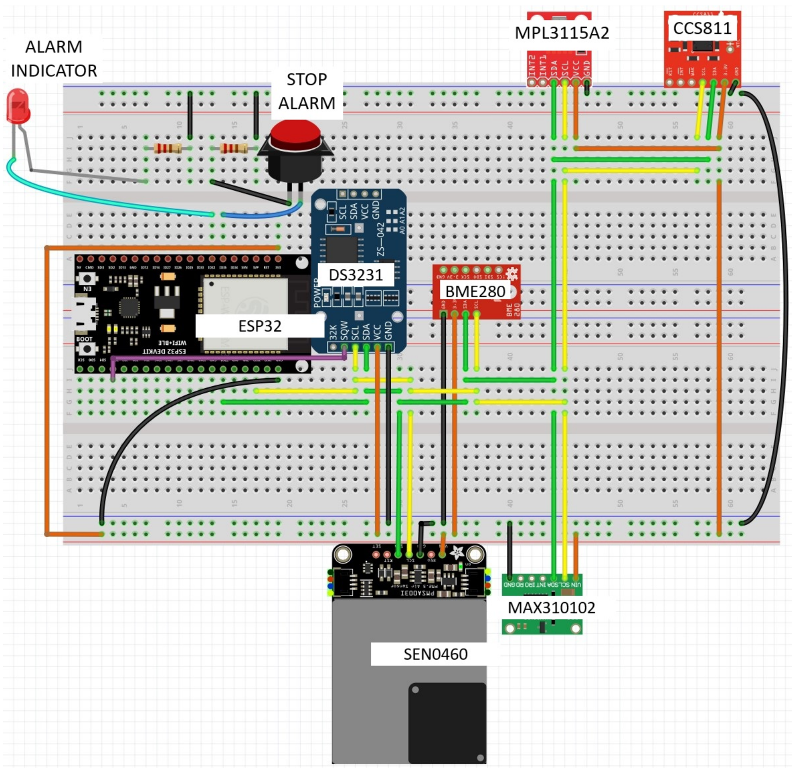
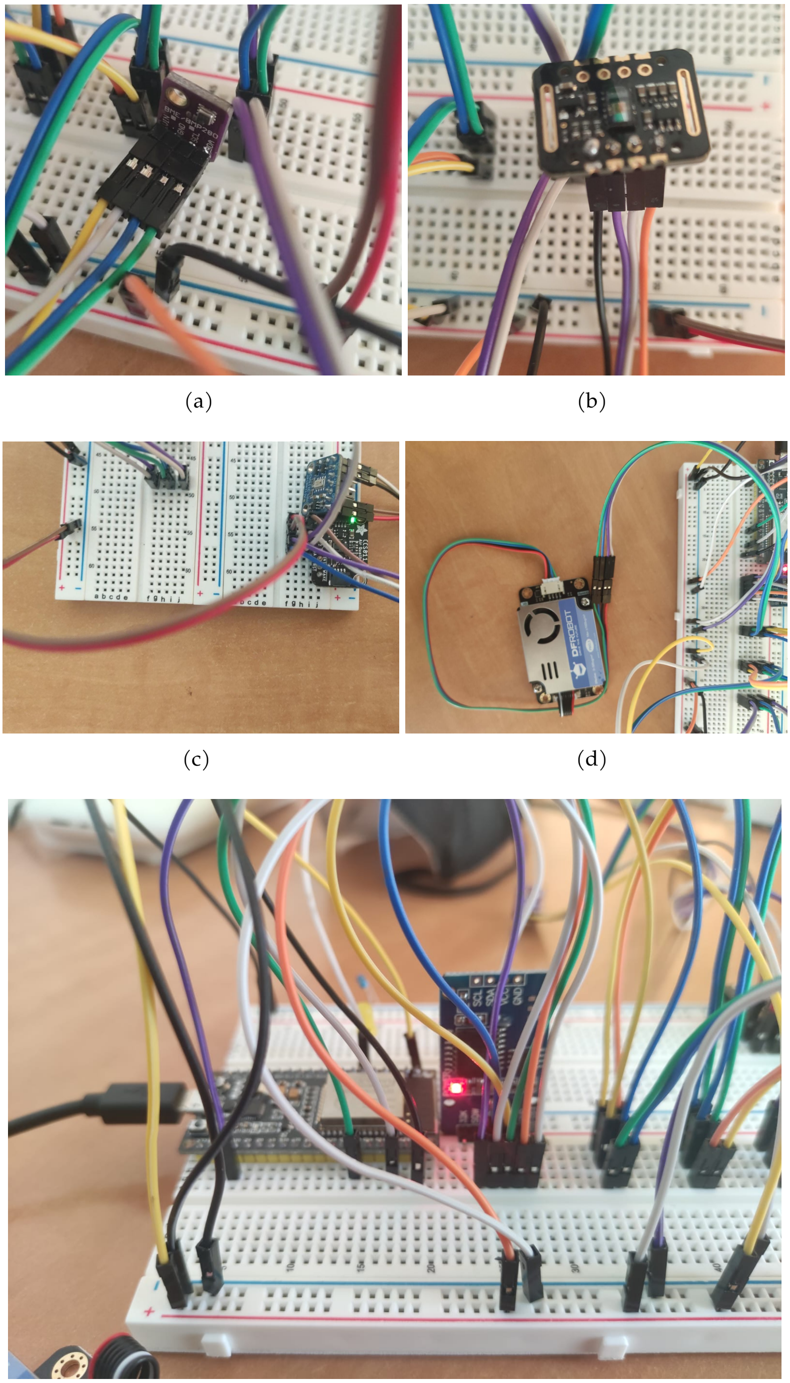


Figure 1: Connections and components of the prototype of the IoT wearable.

Table 1 shows the cost of the hardware used by the IoT wearable, including sensors, wires and other components (as of September 2023). Such a table does not include the cost of the final form-factor of the device. For instance, all the hardware described could be embedded, for example, in a smart mask. Figure 1 shows the internal components of the IoT wearable, while Figure 2 includes pictures of the different parts of the first working prototype. All sensors get power from the 3.3V pin of the microcontroller board, represented by an orange wire and use



(a) (b)

(c) (d)

(e)

Figure 2: (a) Barometer BME280, (b) Pulse Oximeter MAX30102, (c) Barometer for breathing rate MPL3115A2 & Air quality sensor CSS811, (d) Particle Counter SEN0460 and (e) DS3231 & ESP32.

the same ground (GND), represented as a black wire. Green and yellow wire are used for SDA and SCL connections, which are the connections used by I2C to share the communications bus with the microcontroller.

Table 1: Main components and cost of the IoT wearable.

Part	
Component	Price
Microcontroller Board	12€
Pulse oximeter Sensor	7€
Barometer Sensor	18€
RTC Module	8€
Breathing Frequency Sensor	15€
Particle Counter Sensor	36€
Air Quality Sensor	22€
External battery	14€
Resistors, LEDs, wires, etc.	19€
Total	151€

3 Results

After the development of the system, two scenarios were simulated:

- Detecting an asthma attack in real time. Using the vital signs parameters measured by the sensors, it is possible to detect when the user is suffering an asthma attack by detecting a noticeable increase in breathing rate even when the user is not doing physical activity (a regular value for breaths per minute is between 12 and 18 (MedlinePlus, 2008)). In Figure 3 it can be observed how the user starts with a normal breathing rate (around 18 breaths per minute) and then the asthma attack occurs, which increases up to 44 breaths per minute, as the beats per minute increase and the oxygen saturation in blood (SPO2) decreases from 95-100% to 85% (for this specific example, the SPO2 value has been simulated to illustrate the attack in a coherent way). Finally, the breaths per minute gradually decrease to 15 and the beats per minute and SPO2 return to their initial levels.

- Checking the environment via light signals. Besides the value for some parameters that indicate how dangerous the environment is, we use an heuristic value (score) which works like a traffic light, using green, yellow or red if the value is good, acceptable or bad for an asthma patient, respectively. For calculating this score, the system compares the parameter values to specific reference intervals: if the read value is between the reference values, it has a good score. For example, the reference value for temperature is between 15 and 25 Celsius degrees, but it can be easily configured to different scenarios. The color of the traffic light is internally represented by a number, so zero is a good value (green) and two is a bad value (red), while one is a value that is not optimal but it does not imply a dangerous situation for the patient. In a good scenario, most scores would be in green or yellow, while in a dangerous situation many red or yellow scores would be shown. As an example, Figure 4 shows the internal output of the system for different scenarios: Figure 40.4(a) illustrates a scenario where all scores are good or not bad, Figure 40.4(b) represents the outputs of a scenario where some parameters are bad for an asthmatic

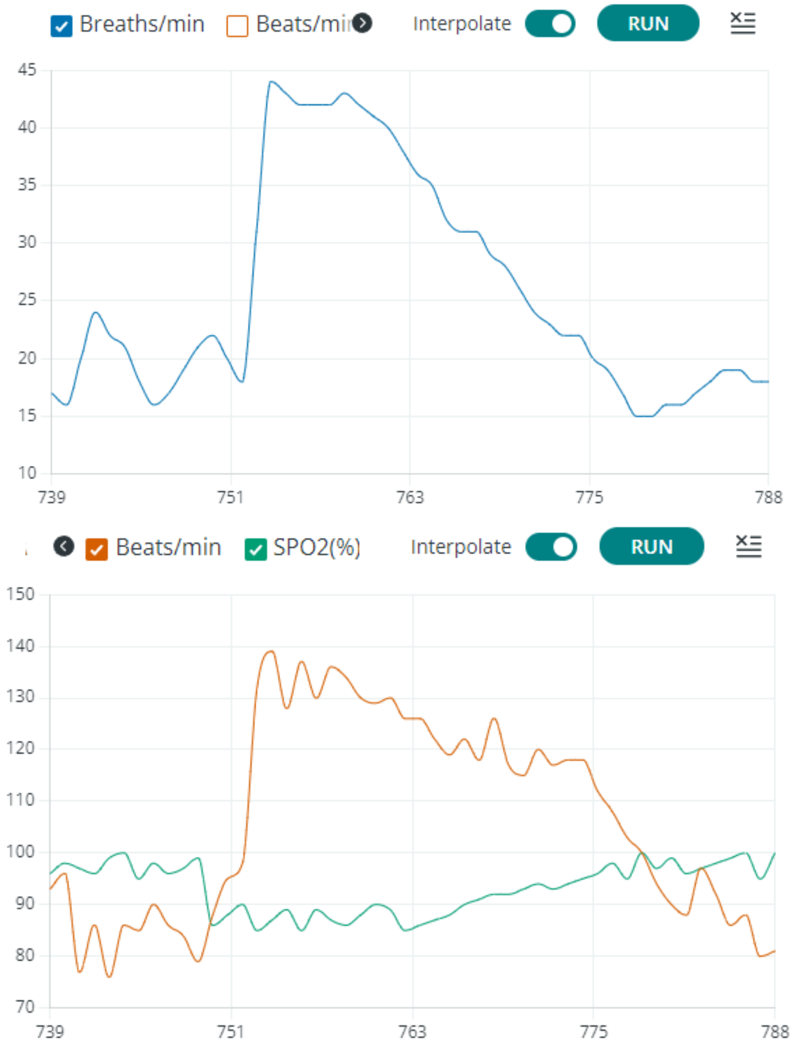


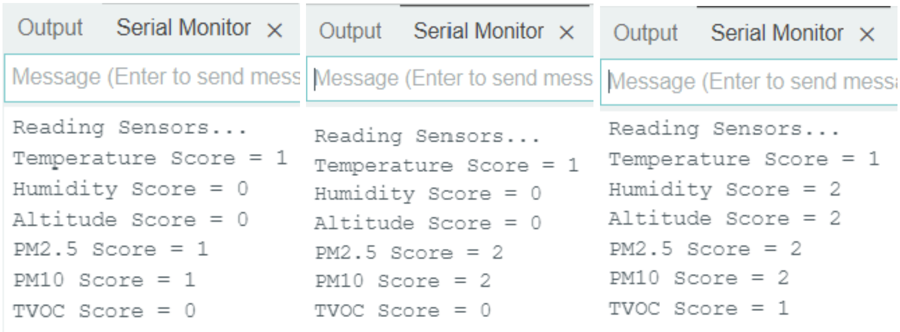
Figure 3: Breaths per minute, heartbeat and SPO2 during a simulated asthma attack.

and, finally, Figure 40.4(c) illustrates a scenario where most scores are dangerous for an asthmatic.

4 Conclusions

This paper has presented a prototype of an IoT wearable that is able to determine whether an asthma attack occurs and when the environment may trigger such an attack. The wearable makes use of multiple sensors to measure several important parameters for asthma patients, being able to monitor them in real time through a BLE device and to store them in its internal memory to dump them later opportunistically into a database when it is detected that an Internet connection is available.

The obtained results show that the system is able to perform the desired tasks adequately,



(a) (b) (c)

Figure 4: The system evaluates the situation using different scores for each parameter.

but the IoT wearable can still be considered as an early prototype. In the future, it can evolve towards a commercial system that integrates all the hardware into a smart mask. Moreover, the developed algorithm used for calculating the user's breathing rate might be refined to increase its accuracy.

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Bibliography

CDC. Salud ambiental.contaminación del aire y salud respiratoria.asma, 2019. URL *https://www.cdc.gov/asthma/es/faqs.htm#*. Source: https://www.cdc.gov/nceh.

T. M. Fernández-Caramés and P. Fraga-Lamas. Design of a fog computing, blockchain and iot-based continuous glucose monitoring system for crowdsourcing mhealth. *Multidisciplinary Digital Publishing Institute Proceedings*, 4(1:37), 2023.

T. Lancet. Global burden of 369 diseases and injuries in 204 countries and territories, 1990-2019: a systematic analysis for the global burden of disease study 2019. *The Lancet*, 396:1204–1222, 2020. URL *https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(20)30925-9/fulltext*.

E. Mancilla-Hernández, M. A. Medina-Ávalos, R. H. Barnica-Alvarado, D. Soto-Candia, and R. G.-V. andYahvéh Zecua-Nájera1. Prevalencia de asma y determinación de los síntomas como indicadores de riesgo. *Revista Alergia México*, 2015. URL *https://www.redalyc.org/articulo.oa?id=486755028006*.

MedlinePlus. Vital signs, 2008. URL *https://medlineplus.gov/ency/article/002341.htm*.