Air Quality Monitoring and Alerting System to Help in Reducing Asthma Attack in Asthmatic Children

Khawla Alzoubi[1,2], Manal Al-bzoor[3], Omar Aljalahma[1] and Mohamed Ali[1]
[1]*Qatar University, Doha, Qatar*
[2]*Community College of Qatar, Doha, Qatar*
[3]*Yarmouk University, Irbid, Jordan*

Keywords: Asthma Attack, Air-quality, Alerting Subsystem, Bluetooth, Environmental Factors, Monitoring Subsystem.

Abstract: Asthma attack is one of the most common emergency cases seen in hospitals. It can be dramatically triggered by environmental factors such as air pollution, temperature and humidity. In this paper, we developed a system to avoid asthma attacks, especially for children, by informing parents about the air quality conditions. Our developed prototype system consists of two main subsystems that communicate wirelessly. The first subsystem is an Air-Quality Sensing Subsystem, and the second subsystem is a mobile phone application. The Air-Quality Sensing Subsystem (AQSS) collects data from surrounding environment about the air-quality using different sensors that measure the main environmental factors (temperature, humidity, dust, and Carbon Monoxide (CO)) that trigger asthma attack in our region (Qatar). This subsystem processes the collected data and decides whether the air-quality is safe for asthmatic children. The processed data along with alerting messages are sent to the smart-phone app wirelessly using Bluetooth technology. The Smart-phone app shows the measured air-quality factors as well as sends a message to inform the parents if the air-quality outside is safe for their asthmatic children or not. Accordingly, parents can take precautions to protect their asthmatic children from having asthma attack. This would help in stabilizing the health condition of asthmatic children/person and avoid costly hospitalization procedures.

1 INTRODUCTION

Asthma is a chronic disease in respiratory system associated with the airway. Asthma is a Greek word that refers to the difficulty of breathing. The triggers of this disease are different in adults, children's, and vary in relations to gender. (Guarnieri et al, 2015).

The real causes of asthma are not fully understood. The causes are combined of both genetic and non-genetic factors. The causes include chronic obstructive pulmonary, bronchitis, chronic sinusitis, respiratory infections and heart disease. According to the Global Asthma Report 2018, asthma is estimated to affect as many as 339 million people around the world. However, deaths of asthma were estimated to be 1000 people per day, most commonly in poor countries.

Asthma attack leads to tightening the muscles around the airways, causing some dangerous symptoms to the patient. The known symptoms of asthma attack are wheezing, dyspnoea, chest tightness, cough, weak exercising, changes in lung function, and trouble sleeping (Holgate, 2010). Many factors affect asthmatic people, and can trigger their asthma if these factors exceed specific values and limits. These factors can result from weather conditions (Humidity, heat, dust, cold), air pollution (chemical gases), and other sources (pet dander, pollen and mold, food, and drugs).

Managing asthma is the best way to avoid asthma attack and its consequences. Asthma has no cure; hence, the only way to reduce its effects is by following these steps in sequence: First, controlling asthma with medications and using the flow meter to prevent the symptoms by allowing Oxygen to enter the airways and help maintain good lung function. Second, working with doctors to treat other diseases that can trigger asthma attack. Third, avoiding factors that could trigger asthma attack (Haughney et. al, 2020).

Environmental factors may result from weather conditions and air-pollution. Air could be poluted by Ozone (O3), Sulphuric Dioxide (SO2), Carbon Monoxide (CO), oxides of nitrogen (NO, NO2), and Carbon Dioxide (CO2) (Diette et. al, 2008). Ozone gas has a serious effect on asthmatic people. In Qatar

Alzoubi, K., Al-bzoor, M., Aljalahma, O. and Ali, M.
Air Quality Monitoring and Alerting System to Help in Reducing Asthma Attack in Asthmatic Children.
DOI: 10.5220/0009971200910098
In *Proceedings of the 14th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2021) - Volume 1: BIODEVICES*, pages 91-98
ISBN: 978-989-758-490-9

specifically, air-pollution with greenhouse gases and toxic gases emissions generated by vehicles and factories may have a serious impact on asthmatic patients. Furthermore, dust and sand in this region create serious health problems to people with asthma and respiratory system related diseases. Moreover, the high levels of temperature and humidity can also trigger asthma attack as humidity and heat pose a particular risk as a breeding ground for mold spores, which contribute to asthma attack (Haughney et. al, 2020).

Asthmatic children, in Qatar, are at a higher risk from exposure to the aforementioned environmental factors that trigger asthma attack due to their immature lung development and their weak and sensitive bodies. Therefore, this project aims to develop an air-quality monitoring and alerting system to monitor the most environmental factors that would trigger asthma attack in asthmatic children in Qatar and other regions that have similar circumstances. This project will equip parents with a mechanism to check the outdoor air-quality in a specific region and alert them if any of the environmental factors exceed the safe standards. These safe standards are decided based on the reported values and ranges of dangerous level of the enviromental parameters in previous studies. These levels will be presented in this work.

Recently, monitoring Air-quality has been explored by many researchers in the aim to measure the air-quality in-doors and out-doors for health and safety issues. A research group in Qatar was designed and implemented a system to measure the indoor and outdoor air quality (Alassi et al. , 2016). In their work, they developed a system to measure and monitor the environmental harmless gases such as Carbon dioxide (CO2), nitrous oxide (N2O), and methane (CH4). In addition, they focused on the nature parameters such as dust, temperature and humidity. The data was collected by a sensor node, which communicates wirelessly using IEEE 802.15.4 protocol with a host computer that receives the collected measurements, processes them, and shows them using the LabVIEW software (Alassi et al. , 2016). In their work, they only monitored the air-quality without providing a mechanism for alerts on the air-quality. Their system was general system that monitors air-quality without considering asthmatic patients and children.

Another research group (Lal and Kulkarni, 2016) developed a prototype for a system to monitor air-quality to measure factors that might trigger asthma attack. Their system consists of PIC microcontroller and different sensors such as temperature, humidity and gas sensor that sense Carbon Monoxide, Hydrogen, Oxygen and alcohol vapor. The developed prototype system was capable of showing the measured gases on an LCD as well as sending these measurements wirelessly using ZigBee to a database for further analysis. Their system was capable of measuring just two quanties, the ozone level and the dust particles.

Plume Air application (Betts, 2020b) was made for the people who want to adjust their outdoor activity according to air quality. The application has a simple GUI that is easy to use which ensures the user can do outdoor activates such as exercising. The screen shows the state of the air quality index. Furthermore, the application can use statistical data to inform the user of the best day to go out within a week. Plume also offers a social image tool, periodic alerts, and map comparing the air quality in different areas. This application cannot be used in all regions as it just provides information about the air-quality in specific areas. This mobile app and other similar mobile apps give general information about the air-quality without considering asthmatic patients and asthmatic children (AIR MENTOR, 2019).

To address the shortcoming in the previous reported works, this paper presents the development of a portable wireless air-quality sensing unit, and a mobile application to display the air-quality data and inform the parents of any environmental risk that would trigger asthma attack for their asthmatic children.

The rest of this paper is organized into four sections. Section two discusses the system design. Section three presents the process of selecting the usensors and components,and implementing the system. Section four discusses the whole system testing and packing. Finaly, section four concludes our works and discusses the future extension for this work.

2 SYSTEM ANALYSIS AND DESIGN METHODOLOGY

To develop the proposed solution, a portable air-quality sensing unit, and a mobile application should be designed and implemented. As our system should be portable, thus parents can carry it anywhere and check the air-quality outdoor before letting their children to go to that region or area. The system should be equipped with the sensors that can measure the riskier environmental factors that would trigger asthma attack in asthmatic children.

Based on our analysis and studies of the most environmental factors that would trigger asthma attack in our region, we have decided to equip the air-quality sensing unit with the following sensors:

1) Temperature sensor to measure the temperature as the high level of temperature in Qatar is one of the main factors that triggers asthma attack in children.
2) Humidity sensor to measure the level of humidity as the high level of humidity affects the asthmatic children. And high level of temperature leads to increase the humidity level.
3) Carbon Monoxide(CO) sensor to measure CO gas as it is one of the most common gases that affect asthmatic children in Qatar.
4) Dust sensor to measure the size of the dust. As Qatar is located in desert region its location made the country exposed to frequent dust storms that are full of dust particles which highly trigger the asthma attack in asthmatic children.

The design of whole system is shown in Figure1. The Air-Quality Sensing unit consists of the sensors, Microcontroller unit, power management unit, Wireless Bluetooth module. Sensors measure the physical environmental factors from surrounding and convert them to readable measurements that can be handled by Microcontroller unit (MCU). The MCU reads, collects, and manipulates the sensors measurements to make decision about the air quality condition. A Power Management Unit(PMU) is used for charging/discharging the battery that power the system.

The mobile app is a user friendly app shows the parents the air-quality of the surrounding, and alarms them if any of the environmental factors that trigger asthma exceeds its safety level for asthmatic children. As everybody has a smart mobile these days, parents can install this app in their smart-phone and connect it with Air-quality Sensing unit. To enable parents to use our system as standalone system, in case if they do not like to see details information, the air-quality Sensing unit will be equipped with a RED LED and GREEN LED. If any of the environmental factors exceeds its safety level, only the RED LED will turn The Bluetooth module is used to send wirelessly the manipulated sensors measurements and decision about the air-quality to the mobile app.

A Bluetooth Low Energy (BLE) module to save power.

ON, and if the Air-quality is safe for asthmatic children the GREEN LED only will turn ON.

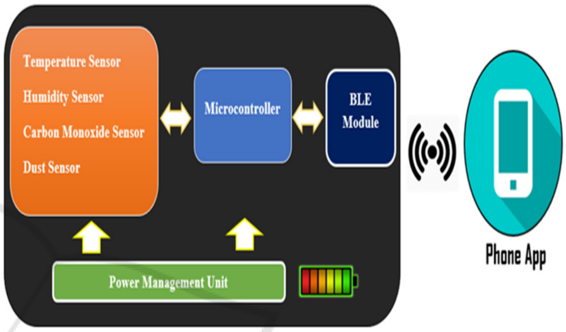


Figure 1: System Design. Block Diagram.

The ranges of asthma triggering parameters are not determined yet in literature. We have searched the literature and different resources about the ranges of environmental factors according international health organizations (‘High and low humidity not good for asthma - Minimizing Triggers – Asthma, 2019). The collected data about the safe ranges (low, medium, high) and danger ranges are summarized in Table 1.

Table 1: Range of Environmental Parameters.

Parameter	Low level (safe)	Medium level	High level	Dangerous level (alert)	Unit
Temperature (Vann, Madeline R., et al, 2012)	30 - 34	35 -39 29 - 20	40 – 48 19 - 10	>48 or < 10	Celsius
Humidity (| (Bottrell, 2009)	30 – 40	41 – 49 29– 20	50 – 60 19 – 15	> 60 or < 15	%
Dust (Airveda team, 2017)	PM 1: 0-5 PM 2.5: 0-30 PM 10: 0-50	PM 1: 6-10 PM 2.5: 31-60 PM 10: 51-100	PM 1: 11-21 PM 2.5: 61-90 PM 10: 101-250	PM 1: >21 PM2.5: >91 PM10: >251	$\mu g/m^3$
CO (Kidde, 2018)	0 – 50	51 – 100	100 – 400	> 400	PPM
NO_2 (E Instruments, 2018)	0 – 0.1	0.2 – 5	6 – 10	>10	PPM
NO (E Instruments, 2018)	0 – 50	51 – 150	151 – 200	201 – 700	PPM
O_3 (CATA, 2018)	0 – 0.075	0.076 – 0.095	0.096 – 0.374	More than 0.374	PPM

The ranges in this table are used as the reference in this work. Thus, our system can decide and inform the parents if the air quality outside is safe or not for their asthmatic children. As all the available collected information about the safety of these factors for normal person, we would consider in our work that even late medium and high level as a dangerous level for asthmatic children as their lung system is more sensitive and their bodies are weak.

3 SYSTEM IMPLEMENTATIONS

To implement the Air Quality Monitoring and Alerting System, each subsystem has to be implemented separately. We started our work by implementing the Air-Quality Sensing Subsystem, and then we implemented the Mobile Application Subsystem. In the following subsections, the implementation of each subsystem is demonstrated.

3.1 Air-quality Sensing Subsystem

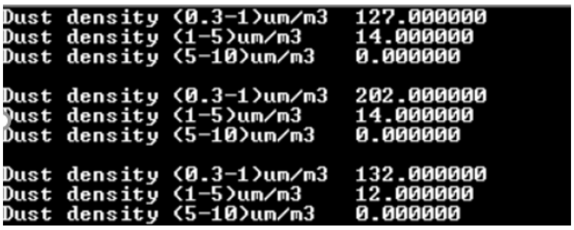
To implement this subsystem, sensors' modules, MCU, BLE module, and PMU were selected carefully considering the system requirements and constraints. The Mbed LPC1768 MCU is used as it has many peripherals which enable it to be capable of reading analogue and digital data, communicate serially with different modules using serial communication protocols such as UART, SPI, I2C, PWM and other peripherals' circuitry. Furthermore it is a 32-bit MCU running at 96 MHz and has 512 KB flash memory and 32KB RAM. In this project, for prototyping, we used the Mbed development board. Each sensor module that measure the most environmental factors (Dust, Carbon Monoxide Sensor, Temperature and Humidity Sensor) is selected, studied, and interfaced separately with Mbed MCU.

Dust Sensor. The selected dust sensor module is PMS5003. This sensor module can detect the small particles, which hurt the respiratory system for the asthmatic children. It can be easily interfaced with a MCU using UART serial communication protocol (Yong and Haoxin, 2016).

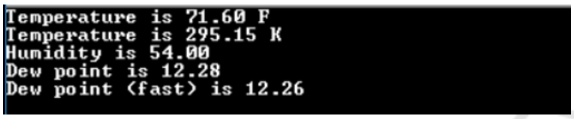
The circuit connection needs two 10kΩ pull-up resistors. The resistors are used to control the set level. High level or suspending is normal working status, while low level is sleeping mode. The sensor results should appear after 30 second from the wake-up state and the fan performance. The sensor measurements ranges are from (0.3~1.0 ; 1.0~2.5 ; 2.5~10) with a unit of micrometer (μ m/m3). The output is the number of each particles with different sizes per unit volume. For this sensor, the default mode is active the power. In this mode, the sensor starts to send the data to the microcontroller. For the active mode, it is grouped into two sub-modes, stable and fast mode. The sub-mode depends on the change of the concertation as if it is small it will be stable and if it is big it will be fast mode. The higher the concentration, the shorter the interval. The required code was written for Mbed MCU to read the sensor data and test the measurement. The results of testing the dust sensor shown in Figure 2(a).

Humidity Sensor. The Grove humidity sensor SEN51035P is used in implementing Air-Quality Sensing Subsystem. This sensor can measure both humidity and temperature. It measures humidity in the percentage range of 20-90% RH, and temperature in the range of 0-50C degree Celsius. This sensor provides digital measurements as it has ADC circuity inside that converts the analogue measurement to digital data that can be read immediately on a GIOP pin of MCU. It measures and provides humidity and temperature values serially over a single wire. This sensor module is interfaced with Mbed Microcontroller immediately as it needs just 5V voltage source and a pull-up resistor that should be connected with its digital output pin. In Mbed MCU as its ports are internally connected with pull-up resistor, this sensor was connected directly without using external pull-up resistor to streaming the measurements. The required code was written for Mbed MCU to read the sensor data and test the measurements. The results of testing this sensor is shown in Figure 2(b).

Carbon Monoxide Sensor. The MQ-7 CO sensor module is used to check if the air is polluted with Carbon Monoxide or not. This sensor is interfaced directly with Mbed Microcontroller by connecting the DO (Digital out pin) to one GIOP port of the Mbed Microcontroller, and connecting the AO (Analog out pin) with Analog input port of the Mbed MCU. Two LEDs are used in this sensor module: Power/ calibration LED and danger LED. When this sensor is powered and in calibration mode, the first LED turns ON. During the calibration mode, the user can adjust the sensitivity of CO sensor using the variable resistor. In this work, the sensitivity of Carbon Monoxide sensor was adjusted to exceed the danger level that would trigger Asthma attack for Children. When the sensor starts to measure the CO concentration, and it reaches the adjusted level, the second LED will turn to indicate that CO concentration is in the danger level. The sensor can measure between 20-2000ppm. Thus, this sensor can detect the danger level that set according to Table1. The CO sensor was interfaced to the Mbed MCU as shown in Figure 3. A program for Mbed MCU was written for calibrating the sensor and streaming its data. The results of testing this sensor are shown in Figure 2(c).



(a)



(b)

(c)

Figure 2: Measurements and Testing of a) Dust sensor PMS5003 b) Grove humidity sensor SEN51035P c) MQ-7 CO Sensor.

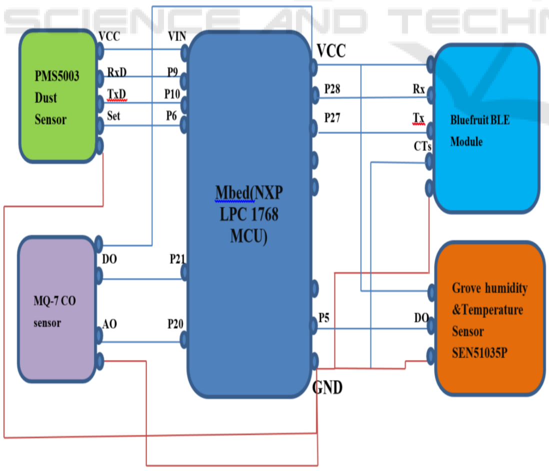


Figure 3: Illustrative block diagram for the Air-Quality Sensor Subsystem.

To enable the Air-Quality Sensing subsystem (AQSS) to send data wirelessly to the mobile App, a BLE module is used. The used BLE in this subsystem is Bluefruit BLE module. This Bluefruit LE is a low energy and has small footprint size. It can be interfaced with Mbed MCU using UART serial communication protocol. The hardware interfacing between the BLE module and Mbed MCU is demonstrated in Figure 3. A program for Mbed MCU was written to test the functionality of the BLE module.

After interfacing and successfully testing the functionality of each sensor module and the BLE module separately, all the modules were interfaced with Mbed microcontroller as shown in the illustrative block diagram of Figure 3.

The software part (program) of the AQSS is developed for Mbed MCU to initialize, calibrate (if needed), acquire raw data of the sensors, manipulate data and measurements, make decision, and send processed data and alarming messages wirelessly using Bluetooth module to a host computer for testing. The flowchart for the software part for AQSS is shown in Figure 4. The program was written using C++ language in Mbed online development environment. Thus, this program enables the AQSS to perform tasks from acquiring sensors' measurements until sending processed data and alerting message over the BLE module to the other subsystem (Mobile App).

3.2 Mobile App Subsystem

To inform parents of asthmatic children about the air-quality in friendly manner, we designed and implemented a mobile application that can communicate with the AQSS using the BLE technology. App Inventor program for Android was used to design the application which is an open source web application provided by Google. The designed application consists of Graphical User Interface (GUI) that the user can see, and programming blocks, which are hidden from the user. The designed GUI for the App is shown in Figure 5. The background of the screen was designed to represent the outdoor environment. To start the application, the user must click on the scan button that will search for available BLE devices. The user has to choose the AQSS to connect with and receive messages from it. After clicking on Adafruit Bluefruit LE, which is the device used for this project, the application screen will show the address of the connected device and a green tick, indicating the connection is done. A disconnect option could be used to disconnect the device. Figure 6 shows the GUI of the Mobile App after connecting with AQSS.

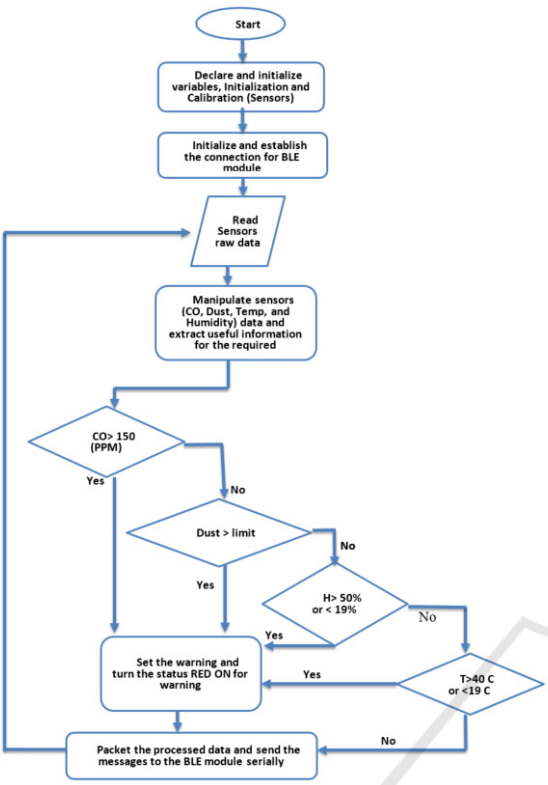


Figure 4: Flowchart for Air-quality Sensing Subsystem (AQSS).

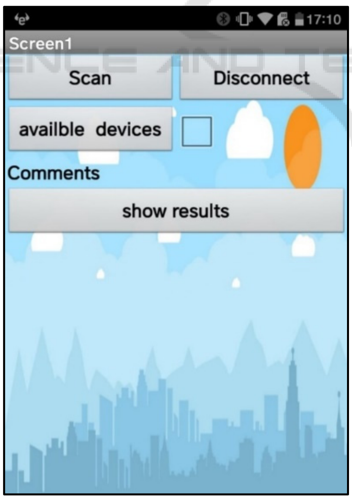


Figure 5: Start GUI of the mobile App.

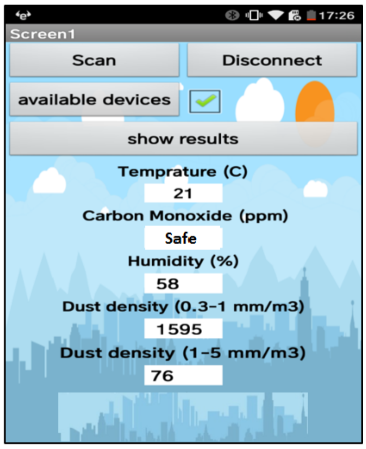


Figure 6: GUI of App after connecting with AQSS.

4 SYSTEM INTEGRATION AND DISCUSSION

For the final presentation, a PCB board was printed, and all the components of The Air-Quality sensing subsystem were assembled on it. The PCB for the sensor's subsystem was designed using DipTrace Software. The PCB design is shown in Figure7. In the designed PCB board, the circuit wiring connections for PMU were added, and the circuit wiring connections for two status LEDs (RED and GREEN) were added. Furthermore, to control turning the Air-Quality Subsystem ON/OFF, the required wiring connections were added.

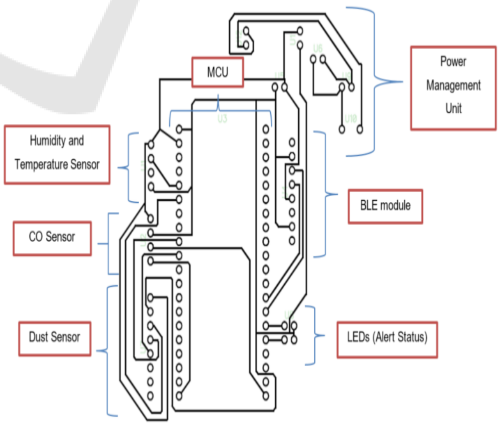


Figure 7: PCB design for the Air-Quality Sensor Subsystem.

As the AQSS should be portable, the PMU was interfaced with Mbed MCU and all other modules and components to manage power the whole AQSS using rechargeable battery as well as charging the battery.

The battery-life for (AQSS) was also calculated for different scenarios. It was found that the battery-life (68000 mAh) is 12 hours if this system works continuously. To prolong the battery-life of this system, a switch was added to turn it ON/OFF. Thus, the system can run for longer time before it needs to be recharged. Moreover, to make this system capable of informing the parent if the air-quality is safe or not for their asthmatic children with using mobile app, alert status LEDs were added which will turn green LED on when the air quality is in good level and turn red LED on when the air quality is dangerous for asthmatic children. Furthermore, a 3-D box was also printed using 3D printer to host nicely this AQSS.

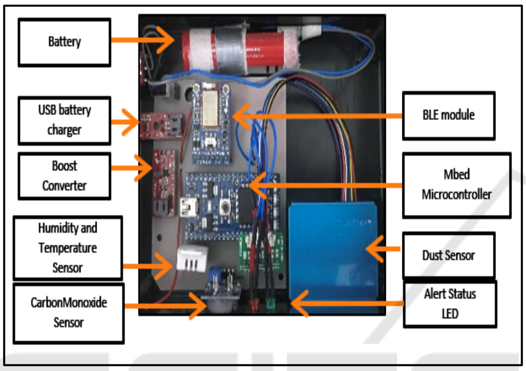


Figure 8: Final assembled prototype for AQSS.

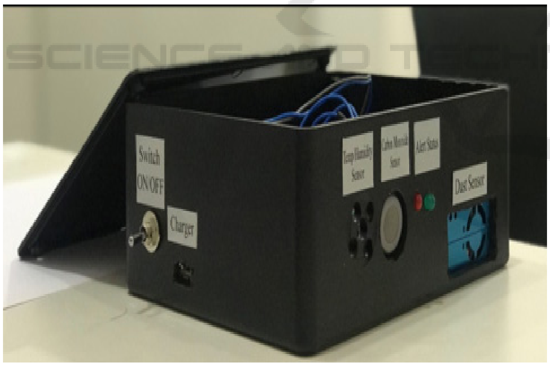


Figure 9: Final packing for the prototype of AQSS.

The final prototype for AQSS was assembled on the produced PCB board and hosted in the 3D package as shown in Figure 8 and Figure 9 respectively. The developed app works on android devices (Mobile phone or tablet). The Air-Quality Sensing Subsystem and the Mobile App subsystem were tested together. After turning ON the Air-Quality Sensing Subsystem, the Mobile App was opened and connected to AQSS. The sensors' measurements are shown on the Mobile App as demonstrated in Figure 6. The final prototype (shown in Figure 9) was tested with the Mobile application in different environment settings (dust, heat, and humidity). To test the whole system in measuring the CO, the flame of lighter is used in proximity to the CO sensor of the AQSS. The developed prototype for the Air Quality monitoring and alerting system works successfully and shows real time measurements (on the mobile app) that are received from the Air-quality sensing subsystem over the BLE. For CO sensor module, it shows a warning when the concentration of the CO exceeded the set point. As it was mentioned previously, the set point can be changed by varying the variable resistor on the CO sensor. For our system, the set point was set to the dangerous level for asthmatic children (150ppm). In Figure 6, there was no warning message as the system was tested indoor in a normal environment setting.

5 CONCLUSIONS

The developed prototype system, in this work, can collect data about environmental factors that trigger asthma attacks in our region (Qatar). It shows the collected measurements on mobile app and alert the user when the out-door air quality degrades to a level that trigger asthma attacks especially in children who are more sensitive to asthma trigger factors. Therefore, the developed system will help in managing and avoiding asthma attacks for asthmatic children by informing their parents in a real-time manner. Thus, the life-quality for asthmatic children will be improved as well as avoiding un-necessary costly hospitalization. The developed system is portable and user friendly. Thus, parents can use it anywhere to check the surrounding air-quality and avoid exposure of their asthmatic children to polluted and unhealthy out-door environment. This work will be extended by providing each sensing subsystem with GPS and GSM modules to form IOT infrastructure. Thus, the sensor subsystem can send the collected data to the cloud database. The cloud services can be used to analyze the environmental sensor measurements data. The Air Quality Sensing Subsystems(AQSSs) can be distributed in different locations. All the AQSSs can send their data to the cloud by utilizing the available IOT infrastructure. Therefore, parents of asthmatic children can access the cloud webserver and get updated information about the air-quality level in a specific location at a specific time.

ACKNOWLEDGEMENTS

This work was supported in part by the Qatar University Student Grant under Grant number QUST - 1 - CENG - 2019 - 12.

REFERENCES

M. Guarnieri, J. R. Balmes, and S. Francisco, 'Outdoor air pollution and asthma', *Lancet*, vol. 383, no. 9928, pp. 1581–1592, 2015

Holgate, Stephen. (2010). A Brief History of Asthma and Its Mechanisms to Modern Concepts of Disease Pathogenesis. Allergy, asthma & immunology research. 2. 165-71. 10.4168/aair.2010.2.3.165.

Haughney, J., Winders, T. A., Holmes, S., Chanez, P., Saul, H., Menzies-Gow, A., & PRECISION Improve Access to Better Care Task Force (2020). Global Quality Standard for Identification and Management of Severe Asthma. Advances in therapy, 37(9), 3645–3659. https://doi.org/10.1007/s12325-020-01450-7.

Diette, G. B., McCormack, M. C., Hansel, N. N., Breysse, P. N., & Matsui, E. C. (2008). Environmental issues in managing asthma. Respiratory care, 53(5), 602–617.

A. Alassi et al., 'Development of innovative indoor/outdoor air quality monitoring for environmental impact assessment in the State of Qatar', WIT Trans. Ecol. Environ., vol. 183, no. April 2016, pp. 103–115, 2014.

A. Lal and G. A. Kulkarni, 'Detection and Monitoring of Asthma Trigger Factor using Zigbee', vol. 3, no. 7, pp. 134–137, 2016.

Betts, A. (2020b, March 23). The 7 Best Apps and Sites to Check Air Quality Anywhere. MakeUseOf. https://www.makeuseof.com/tag/check-air-quality-apps/ [Accessed: 5-Apr-2020].

AIR MENTOR. (2019). Https://Www.Air-Mentor.Com/. https://www.air-mentor.com/web2017/product/air_mentor_8096ap [Accessed: 22-Mar-2019].

Bottrell, J. (2009). High and low humidity not good for asthma - Minimizing Triggers - Asthma. Everyday Health. https://www.healthcentral.com/article/high-and-low-humidity-not-good-for-asthma. [Accessed: 04-Nov-2018].

Vann, Madeline R., et al., 2012, Heat, Humidity, and Asthma Symptoms: Everyday Health." EverydayHealth.com, www.everydayhealth.com/asthma/heat-humidity-and-asthma-ymptoms.aspx. [Accessed: 04-Nov-2018].

Airveda team. (2017). Measuring Data - Understanding Particulate Matter and How It Impacts Our Health. Https://Www.Airveda.Com. https://www.airveda.com/blog/Understanding-Particulate-Matter-and-Its-Associated-Health-Impact. [Accessed: 22-Apr-2019].

Kidde. (2018). 'Carbon monoxide Levels that Sound the Alarm. Https://Www.Kidde.Com. https://www.kidde.com/home-safety/en/us/support/help-center/browse-articles/articles/what_are_the_carbon_monoxide_levels_that_will_sound_the_alarm_.html [Accessed: 04-Nov-2018].

E Instruments. (2018, April 27). Health Effects of Nitrogen Dioxide (NO2) in Homes. E Instruments | E-Inst.Com. https://www.e-inst.com/applications/adverse-effects-of-elevated-no2/ [Accessed: 04-Nov-2018].

CATA. (2018). Ozone Action Season | Clean Commute | Rider Information | CATA. Www.Cata.Org. https://www.cata.org/Rider-Information/Clean-Commute-Options/Ozone-Action-Season [Accessed: 04-Nov-2018].

Z. Yong and Z. Haoxin, 'Digital universal particle concentration sensor PMS5003 series data manual', 2016.

O.US EPA, 'NAAQS Table'. [Online]. Available: https://www.epa.gov/criteria-air-pollutants/naaqs-table. [Accessed: 04-Dec-2018].