Development of a Peak Flow Meter to Remotely Monitor Asthmatic Patients in Emergency Cases

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ORIGINAL RESEARCH

Abstract- There have been peak flow meter systems for monitoring asthma patients, however, there is a need to remotely carry out this monitoring to help the patients in case of emergency. This paper presents a mobile health device for tracking asthmatic patient locations during emergencies. The system design consists of nodeMCU microcontroller, MPX5010DP pressure sensor, and a power pack system. The system makes use of the following technologies; Wi-Fi, GPS, Google Maps, and SMS for communication of signals and messages between the user's device and devices of other components of the system. The system allows the involvement of the patient's next of kin and emergency personnel in the monitoring and tracking of asthmatic patients during emergencies. The C programming language was used to write code for the microcontroller, while the mobile application of the system was done using the Dart programming language. The expiratory flow rate value was used to measure the performance of the system. A prototype of the system was successfully developed, and tested. The system works as expected, with each component responding well to signals received. This system can be used to monitor asthmatic patients, especially during health emergency conditions.

Keywords- Asthma, Mobile Health, Peak flow meters, Android

1 Introduction

Asthma presents a worldwide public health challenge in both the adult and pediatric populations due to its widespread impact on over 300 million individuals and its chronic nature, leading to substantial levels of illness and mortality. (Holgate *et al.*, 2015). Asthma patient is projected to be 400 million by the year 2025 (Global Initiative for Asthma Strategy, 2022; Erhabor, 2010). Inflammation and constriction of the muscles surrounding the narrow airways in the lungs lead to a reduction in their size. Consequently, the individual will exhibit indications such as coughing, wheezing, difficulty breathing, and a sensation of tightness in the chest. (World Health Organisation, 2022).

According to World Health Organisation (2022), In 2019, asthma accounted for 455,000 fatalities. The degree of airflow limitation resulting from the condition's impact on the airways can be assessed using medical parameters like Forced Expiratory Volume (FEV) and Peak Expiratory Flow (PEF). Furthermore, global recommendations for self-management of asthma recommend the use of peak flow meters to effectively monitor lung function. (Global Initiative for Asthma, 2020). A peak flow meter is a small handheld device that measures how fast a person can blow air out of the lungs, when there is forceful exhalation, after maximum inhalation (VanZeller *et al*, 2019). Some of them have colour-coded zones that allow the user to alert the patient of his status. The peak expiratory flow rate (PEFR) is a straightforward, dependable, and widely recognized assessment of airway blockage.

This condition possesses distinctive features such as varying obstruction of airways, heightened sensitivity of the airways to specific triggers (viral infections, allergens, exercise, etc.), and chronic inflammation of the airways, which eventually results in structural changes in the airways known as airway remodelling (McCracken *et al.*, 2017; Reddel *et al.*, 2021).

The identification of asthma entails both recognizing a distinctive set of respiratory symptoms and observing indications of fluctuating airway obstruction during spirometry tests. (McCracken *et al.*, 2017; Reddel *et al.*, 2021). Peak Expiratory Flow (PEF) can be measured with a variety of pneumotachometers and spirometers, but they are complicated devices and difficult to understand. (Gerald, 2020). By identifying airway constriction even before the onset of noticeable symptoms, a peak flow meter can assist in monitoring asthma and providing patients with the opportunity to make medication adjustments or take other precautions before their symptoms deteriorate. (Motta *et al.*, 2021). This study suggests utilizing a compact and uncomplicated device called a peak flow meter to create an Emergency Mobile System specifically designed for individuals with asthma. The peak flow meter assesses the lung's ability to expel air by measuring the force in litres per minute. It provides a reading on an integrated numerical scale by directing a brief burst of air through a mouthpiece located at one end of the device.

The peak flow meter is connected to a smartphone and it is used to track a patient's record and notify emergency contacts, and a doctor when in a danger zone. Before usage, the patient is expected to meet with their doctor and get their highest peak flow rate; this would serve as a benchmark for the daily asthma management plan. If the patient's asthma is declared well controlled by the doctor, the peak flow meter can be used less frequently. If the

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doctor declares otherwise, then there might be a need to take peak flow readings more than once a day.

2 Related Works

Sakkatos and Williams (2022) introduced an innovative digital peak flow meter that synchronizes with a smartphone application, and its accuracy was assessed by comparing it to readings from a laboratory spirometer. The study aimed to evaluate the precision of this novel digital peak flow meter (referred to as SPF) when used in conjunction with a smartphone app in comparison to traditional spirometry measurements. The results showed that the SPF was able to provide accurate PEF values, and it was comparable to the lab spirometer. The SPF is a promising new tool for asthma self-monitoring, and it could be used in emergency settings to assess the severity of an asthma attack. The research was good to understand the concept of a digital peak flow meter.

Ghodsi *et al.*, (2022) evaluated the feasibility of using a smartphone-based peak flow meter (SPFM) for asthma self-monitoring. The SPFM was found to be easy to use and accurate, and it was well-received by the participants. The SPFM has the potential to be a valuable tool for asthma self-monitoring, and it could be used in emergency settings to assess the severity of an asthma attack. Chelabi *et al.* (2021) devised a Portable Game Controller aimed at evaluating Peak Expiratory Flow in children. The study aimed to assess the agreement between PEF values obtained using the game controller and various measurements derived from conventional pulmonary function tests, such as spirometry. Additionally, the researchers sought to gather feedback from the participants. A total of 158 children, ranging from 8 to 15 years old, diagnosed with or suspected of having asthma, underwent spirometry and engaged in the game at one of two hospital university centres. Garvey *et al.* (2021) developed Postable peak flow meters to enhance remote patient monitoring from home. They designed a portable peak flow meter called DigiPeak, which can be easily disassembled and reassembled into multiple components. These components can then be conveniently packaged for shipping through regular mail services. The researcher further recommends smart measuring and portable peak flow meter measures for asthma patients. Antalffy *et al.* (2020) introduced a promising method to enhance compliance with peak flow diaries through the use of an electronic peak flow meter and a connected smartphone application. The Smart Peak Flow (SPF) device and accompanying app enable individuals to self-measure and self-monitor their Peak Expiratory Flow (PEF) levels. This research work serves as a benchmark for our work.

3 Methodology

An experimental approach was used in this work, with both hardware construction and software development. Figure 1 shows architectural overview of the developed system. Components are discussed in Sections 3.1 and 3.2.

3.1 Hardware Design

The design of the system contains four (4) major units with three (3) individuals involved in the use of the system. Peak flow meter - this component consists of MPX5010DP pressure sensor and the nodeMCU microcontroller. The MPX5010DP is an integrated differential pressure sensor with a linear analogue output, which can be easily interfaced with microcontrollers. It was chosen because of its low cost, fast response time and ease of interfacing. The pressure sensor which measures the pressure difference of a user was connected to the nodeMCU microcontroller through input pin A0, and power pins V_{in} and V_{out}. The microcontroller controls all the activities of the device. it was programmed to upload the digital values to the database created for the system.

The power section consists of a lithium-ion battery which is capable of charging up to 5V but only discharges 4.2V to the Microcontroller in the peak flow meter via a USB cable. The NodeMCU Microcontroller unit operates at 3.3V; the NodeMCU receives the 4.2V from the power pack via Micro USB jack. To balance the voltage at 3.3V there is already an LDO voltage regulator inbuilt into the microcontroller to keep the voltage steady at 3.3V.

3.2 Software Design

In the course of this system development, two software applications were developed; The Arduino application which controlled the microcontroller was developed with the C programming language, and the mobile application. The mobile application was developed with Dart programming language.

The flowchart implemented in the mobile app is given in Figure 2. The app contains the following interfaces database section, application section, emergency section, patient section and mobile device section. The database section consists of a central location where the essential information such as the patient's peak expiratory values, and other health-related information. The database was designed using the Firebase cloud database and Firebase real-time database.

The microcontroller converts the analogue signal given to a digital signal and sends the data through a wireless connection from the Arduino API to the Firebase real-time database. The user details are transmitted via a wireless connection to the cloud firebase after registration. When the software is being used, the software requests data from the real-time database and the real-time database transmits the data gotten from the Arduino API to the software application. The software required for the database is null as the database is hosted in the cloud.

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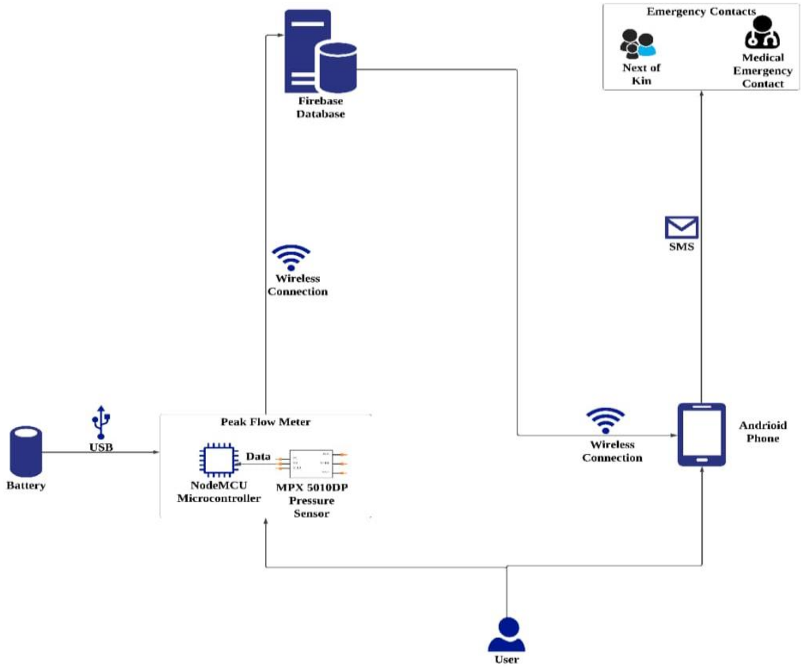

Fig. 1: Architectural Overview of the System

The emergency section consists of the patient's next of kin, the medical consultant's contacts and ICT gadgets such as smartphones. During emergencies, a notification message is received by the emergency unit and next-of-kin via mobile devices, when the peak flow rate is lower than a particular preset threshold value for the user of this system. The message contains the name, id_number, and information saying the patient is in a critical condition and needs medical care immediately. The medical consultant utilizes ICT devices to monitor the peak expiratory value of the patients for management and quick medical attention. In this system, the patient's next of kin was introduced to ensure that non-medical caregivers are allowed to know the health status of their subject and to ensure that, the patient takes their medication as scheduled.

With the next of kin being intimated with the patient's health condition, the patient can be adequately encouraged and supported to adhere to the prescribed drugs and lifestyle. In this system, the patient's next-of-kin unit consists of a smartphone number on which the patient's next-of-kin receives information through SMS service, in cases of emergency. It is expected that the patient has been clinically trained on how to use the peak flow meter and the application before usage. In this system, the mobile application built runs on the patient's smartphone and the data used were obtained from the peak flow meter. This data determines whether the patient's condition is being properly managed.

The mobile device section of the system is the mobile device. The pressure data transmitted on the wireless link can be received by a mobile device using an Android operating system. For experimentation, Samsung A12, which operates on the Android operating system with 4GB RAM was used to display the data. The Android application was developed to receive the data, compare it with the patient maximum peak expiratory value, and send emergency notifications to emergency contacts if the value is below the $Peak_{max}$.

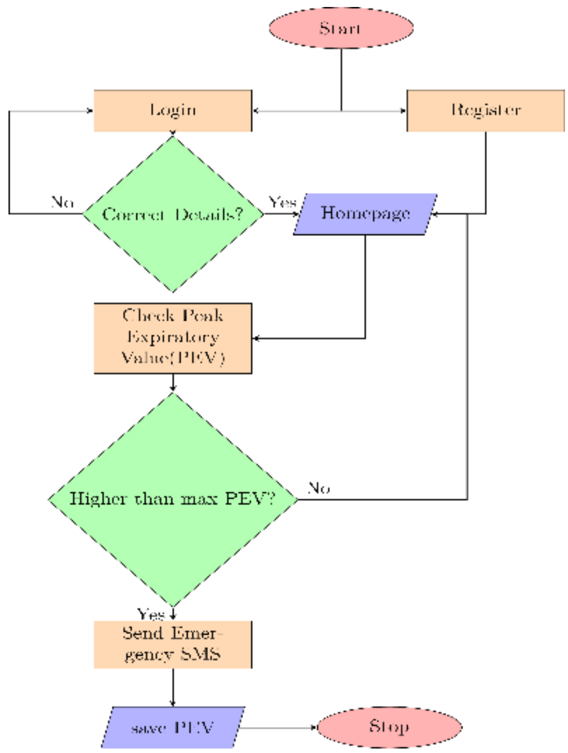

Fig. 2: The flowchart implemented in the mobile app

3.3 Computation of Expected Lung Performance Values

Peak Expiratory Flow Rate (PEFR) is a key parameter utilized in the diagnosis of asthma. It represents the maximum flow rate achieved during a forceful exhalation that begins from a full inhalation. PEFR predominantly reflects the flow in larger airways and is influenced by factors such as lung elasticity, voluntary exertion, and the muscular strength of the individual. The highest airflow

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is typically observed during the portion of the exhalation that requires effort, meaning that low PEFR values can be influenced by factors such as the patient's physical strength, age, and the size of their lung airways. For this reason, it is paramount for patients to visit a doctor to determine the maximum and minimum PEFR suitable for them.

Although the standard expected value for PEFR is also useful in the management of asthma disease. Equations (1) and (2) can be used to calculate the PEFR for males and females respectively.

$$PEFR_{Males}: e^{(0.376\ \ln(\text{age}) - 0.012(\text{age}) - (58.5/\text{height}) + 5.63)} \quad (1)$$

$$PEFR_{Females}: e^{(0.544\ \ln(\text{age}) - 0.051(\text{age}) - (74.7/\text{height}) + 5.48)} \quad (2)$$

3.4 System Layers

The developed system architecture has four (4) layers; the user layer, the application layer, the service layer and the server layer.

The user layer includes all of the system's human users. The asthmatic patient, the patient's next of kin, and the medical consultant are all part of it. The application layer is located between the user and service layers. The user communicates with other services integrated into the system via the application's user interface. The service layer receives application layer input and communicates with the system's backend. This system includes services such as Short Message Service (SMS), authentication service and internet service. The application started the services based on the data it received from the user layer. The Global System for Mobile Communication (GSM) was used to provide short message service, while the internet services were provided by the internet service provider. The service layer communicates with the server layer directly.

4 Results and Discussion

In this section, the system's features and evaluation were reported. This includes the hardware component and the mobile app components of the system.

4.1 System Features

The physical outlook of the peak flow meter: The physical outlook of the peak flow meter during coupling and after coupling is shown in Figure 3. The mobile application allows the user to add information to their profile, as well as update the profile. It authenticates the user so external access will be prevented. The application also allows users to read their peak expiratory value using the developed peak flow meter and store the value in local database. The app has emergency feature that allows users to send a distress message to Emergency and Next-of-kin contacts via GSM.

Fig. 3: The physical outlook of the peak flow meter

4.2 Result of Evaluation

After the completion of the system, different tests were carried out on the system, and the results are reported in this sub-section. Some parameters of interest were tested and the results are reported in Table 1. The table indicated the parameter tested, response time in seconds, observation about the parameter, and the remark on the test conducted. From the response time of parameters tested, the time taken to fetch data from the sensor to microcontroller is almost immediate with a response time of 0.05 seconds. This response time is adequate for the operation considered. The time taken to send an SMS alert to the patient's next of kin and emergency contacts is 120 seconds. This response time depends on the GSM services of both the sender and the receiver. But on average, the response time is between 1-2 minutes. The time to fetch data from cloud storage to display it on mobile app, and fetch the data from sensor to microcontroller are 0.5 seconds and 0.05 seconds. The response time of all the variables considered indicates fast response which is sufficient for emergency team and next of kin to remotely monitor asthmatic patients during emergencies.

Peak Expiratory Flow Rate Value-The developed peak flow meter was used to test user and the value recorded by the device were reported in Table 2. The table indicates the date the values were recorded, the PEFR value and its implication for an asthmatic patient.

5 Conclusion

In this paper, the development of a peak flow meter to remotely monitor asthmatic patients, especially during emergencies has been reported. The developed system can help reduce the mortality rate caused by gradual and sharp attacks on asthmatic patients by aiding response time from emergency and next-of-kin teams. This is achieved by the remote monitoring of asthmatic patients by an emergency team and next of kin. The system consists of hardware components and applications. The hardware components have plastic tubing which was attached to the hose on the pressure sensor and fitted into a plastic case. The mobile application of the system consists of the following features authentication, profile, update profile, breathe, and emergency. The system was successfully implemented and tested. The prototype of the system is available and ready, and waiting for mass production on demand. This device is portable and can be easily carried around by asthmatic patients to different locations, as they go about their normal day-to-day activities.

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Table 1. Results of the system's parameter tests

S/N	Parameter Tested	Response Time(s)	Observation	Remark
1	Time taken to send sensor data to Firebase real-time database in the cloud	30.00	The response time depends on the quality of available internet service.	Optimal performance
2	Time taken to initialize Wi-Fi module to identify network and enable internet	90.00	The time to initiate the connection is about an average of 90.00s. This is required once during system setup in a day.	Optimal performance
3	Time taken to fetch data from the cloud and view it on the mobile device.	0.50	The response time depends on the quality of internet service within the user's coverage area.	Optimal performance
4	Time taken to fetch data from the sensor to Microcontroller	0.05	This time is almost immediate.	Optimal performance
5	Time taken to send SMS alert to Emergency and Next-of-Kin	120.00	This depends on the GSM services of both the sender and receiver coverage areas.	The performance was ok.

Table 2. Values of the Peak Expiratory Value based on different time

Date	Peak Expiratory Flow Rate Value (Litres/Min)	Implication
15th July 2022	465	Value is normal; hence the user is in a safe zone.
16th July 2022	342	Value is below the minimum range hence emergency notification is to be sent.
17th July 2022	405	Value is normal; hence the user is in a safe zone.
18th July 2022	496	Value is normal; hence the user is in a safe zone.
19th July 2022	389	Value is below the minimum range hence emergency notification is to be sent.

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