Wireless Personal Communications (2021) 117:337–353
https://doi.org/10.1007/s11277-020-07871-5

Design and Implementation of an Internet of Healthcare Things System for Respiratory Diseases

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Accepted: 29 October 2020 / Published online: 23 November 2020

Abstract
Internet of Things (IoT) paradigm broadens to several research fields. Thus, Wireless Body Area Network (WBAN) has been adopted as a standard to create an IoT scheme implemented on healthcare system. Furthermore, IoT can be employed to measure several diseases including stroke, diabetes, as well as respiratory diseases to monitor patient condition and environment change that might be harmful for patients. Implementation and realization of IoT for monitoring respiratory diseases is needed since in Taiwan the risk to get more severe symptoms by those diseases is relatively high considering the air pollution that is getting higher. In this study, IoT system is built based on the integration of several independent applications. In addition, our scheme consists of four main components such as environment sensing box, patient monitoring tools, android apps, and web Graphical User Interface (GUI). Web GUI is useful for health practitioners such as doctors and nurses to monitor the condition of patients obtained by patient monitoring tools. Moreover, patients and doctors can assess the status of weather and environmental condition whether it is safe or harmful for patients. Finally, android based apps is necessary for patients to connect all of schemes as well as monitoring all conditions including health and environmental status. The assessment of our tools indicates that the implemented scheme is consistent enough shown by low Root Mean Square Error (RMSE) and Mean Average Percentage Error (MAPE) achieved by our IoT system.

Keywords Internet of things (IoT) · Respiratory diseases · Monitoring · Sensors · Root mean square error (RMSE) · Mean average percentage error (MAPE)

1 Introduction

Modern world offers a flexibility for internet users on various fields. Agricultural, medical, and some other fields are laid on the application of Internet of Things (IoT), especially to monitor and control some specific purposes. IoT has changed and shifted the paradigm of internet future [1]. Ubiquitous technology offered by a new paradigm of Internet of Things

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Extended author information available on the last page of the article impacts the development of IoT infrastructure. Consequently, the construction of IoT infrastructure is inevitably massively made to accommodate the use of IoT in several fields. IoT concept for medical treatment has been studied by a lot of researchers and developed by several manufacturers. Some ideas to deal with the case or problems overcome by health practitioners are proposed, for instance building a smart system for monitoring athlete under mobile environment [2] or constructing Wireless Body Area Network (WBAN) to accommodate a highly appropriate communication between several devices [3]. [4] Also studied to securely protect user privacy by establishing a protection scheme called Privacy-Protector incorporating Slepian–Wolf-coding-based secret sharing (SW-SSS) as an encryption scheme along with patient data sharing.

As the main concern of modern people, healthy life is becoming a way of life to reach long age. Technology, in this manner is represented by IoT, could be massively implemented to deliver accurate and error-free treatments. By applying it, we can monitor the amount of pollutants [5] as well as UltraViolet (UV) [6] that might be very harmful for some patients. The exploration of IoT to be utilized as monitoring tools for hospitalized patients is shown by [7]. [7] Proposed an integrated scheme applied in certain hospital including health monitoring scheme of patients status, access control, and outdoor posture recognition. An Architecture of Narrowband IoT (NB-IoT) for smart hospital is introduced in this paper. Furthermore, authors [8] have studied the use of some sensors to detect patient health status. [8] Focused on Fog assisted-IoT to collect patient data and enable the 'smart homes' term. Some sensors have successfully attached on patients and detected environmental condition on smart home surroundings.

IoT is placed as the future of technology for healthcare, due to its flexibility for placement. Deployment of devices is one of useful research issues to be explored. Integration of several devices and sensors in IoT scheme plays an important role to create a robust model for monitoring health condition or even controlling healing stage patients. Deployment of IoT sensors for rehabilitation has been studied by [9]. [9] Proposed a scheme for sensor deployment implemented on rehabilitation engineering which can be a smart scheme. Furthermore, the proposed scheme is called a smart rehabilitation engineering. In this scheme authors scrutinized a proposal for ontology to be integrated to IoT and created an intelligent scheme based on implementation of IoT.

Some combinations of several sensor implementations are possibly implemented to our scheme in order to monitor the environmental condition. Instead of constructing a solution for general healthcare, in this paper we offer a solution for patients with breathing-related disease. As the increase of pollutants around the world caused by industrialization, the advancement of monitoring system is essentially needed to be realized. Some works have successfully studied to build the IoT scheme related to monitoring system for pollution level. In this work, we mitigate an idea from [10] and put into our scheme for implementation and realization of our scheme. Air pollution is mainly the causal problem of respiratory diseases and those patients combatting breathing-related diseases are strongly recommended to avoid exposure from bad air. Moreover, the attachment of humidity and temperature sensors is also considered, since there are a lot of studies indicating that respiratory diseases are strongly related to humid and hot weather. Thus, considering the necessity to monitor the weather condition, humidity and temperature sensors as well as the attachment of UV sensor are applied in our scheme.

Thus, the rest of this article is written as follows. Section 2 discusses related work included with prior study as well as literature study for the fundamental idea of our implementation. The overview of proposed scheme is illustrated in Sect. 3. Furthermore, the Sects. 4 and 5 is the discussion of each part from the whole scheme. Then, we present the result in Sect. 6 and discuss the data in Sect. 7. Finally, we infer what we have done and list several possible future works in Sect. 8.

2 Related Work and Literature Study

2.1 Prior Study Related to Internet of Things for Healthcare

Overview of existing IoT applications on medical sector has been presented by [11]. In addition, broad survey related to healthcare based IoT is also conducted by [12]. [12] Discussed a new term for implementation of IoT in healthcare as Internet of Healthcare Things (IoHT). Detail explanation related to challenge and opportunities of IoHT is also presented. Since, the application of IoHT is comfortably accepted as a new emerging technique, [1] predicted that the use of IoHT will be flourishing in the next decade. However, some issues related to security and effectiveness to the patients are also needed to be addressed.

Some researchers deal with the realization of home health care, for example [13] proposed the platform for healthcare and secure scheme of IoT for healthcare using fog computing. Furthermore, [14] studied to collect data using smart wearable armband for stroke rehabilitation and proposed a machine learning scheme to predict stroke patients gestures. Besides, [15] also focussed on implementation of IoHT for stroke patients [15]. Created a smart cup for assessment of arm and hand activity of stroke survivors.

Previous studies for implementing of IoHT are widely accepted by users. 'Users' term is not only for patients or survivors of certain disease but also for hospital and doctors. Broadening the usage of IoHT is inevitable, since we can achieve a highly effective assessment of survivors' data. Therefore, a remote service for survivors can be provided by hospital.

2.2 Implementation of IoHT for Respiratory Disease

These days, air pollutants are rapidly increasing due to the impact of industrialization, high energy consumptions, and urbanization. Accepting poor air quality can be literally permitting the deterioration of human health. However, it is inevitably avoiding and prevalently becoming a habit for us to breathe in poor air. Sadly, the probability to suffer respiratory diseases is rocketing, especially in big cities. Some reports show that air pollution in some countries is strongly responsible to the worsening welfare and public health [16, 17]. Thereby, development of devices to monitor and report that the outside air pollutants are safe enough is essentially needed.

Among all air pollutants, fine particulate matter (PM2.5) is considered as the most culpable to the respiratory diseases. PM2.5 particles can be very hazardous to human health by penetrating to alveoli (lung regions to exchange the gas) and affecting other organs by entering our body via lungs [18, 19]. report that PM2.5 is firmly related to respiratory diseases, lung cancer, and premature death. Therefore, several studies to assess the hazard environment caused by PM2.5 have been proposed the development of particulate matter monitoring scheme [20–22]. It is worth notified that we gained several ideas for creating an IoHT scheme for respiratory diseases from papers presented in this related work.

2.3 Medical Background of Respiratory Diseases

Chronic obstructive pulmonary disease (COPD) is a long-term lung disease in which the airflow from the lungs is progressively reduced. The airflow limitation of the patient with COPD is associated with an abnormal inflammatory response of the lungs to noxious particles or gases, for example, air pollution and/or cigarette smoke. The World Health Organization (WHO) anticipates that COPD will become the third cause of mortality worldwide by the year of 2030, driven by an aging population, an increased prevalence of smoking and other environmental triggers [23]. Cough, dyspnea on exertion and fatigue are the most common symptoms reported by patients with COPD. Patients usually involve themselves in reducing physical activity participation to avoid symptoms. However, the less they perform physical activities, the more they worsen their physical conditioning and symptoms.

The Global Initiative for Chronic Obstructive Lung Disease (GOLD) strategy recommends that all patients with COPD should participate in daily physical activity [24]. Maintaining a sufficient amount of daily physical activity is critical for the patients' prognosis, quality of life and mortality. There is a large body of evidence that demonstrates health benefits from physical exercise in patients with COPD, including decreases in exertional dyspnea, fewer disease exacerbations, and improved exercise tolerance [24]. Persons with COPD who wish to become more physically active at home need to be evaluated by an office graded exercise testing with ECG, blood pressure and SpO_2 (oxygen saturation measured by pulse oximetry) monitoring [25]. Following appropriate prescreening, daily physical activity participation should be recommended to patients, who are on a stable drug regimen, known to be stable in their respiratory function, and absence of untoward conditions during active physical activities [25]. Wearable devices that continue monitoring physiological data (heart rate, blood pressure, SpO_2) provide the patients with behavioral strategies such as self-monitoring, goal setting and feedback during their daily physical activities at home.

In addition, COPD symptoms are closely related to the environmental conditions. To minimize disease symptoms, the patient should avoid risky environment (e.g., indoor and outdoor air pollution) and bad weather that may increase the irritation of the respiratory tract. A sensor device that monitor environment conditions including temperature, humidity, and air dust particles (e.g., PM2.5) concentration may detect risky environments for COPD patients during their daily activities [26].

3 Proposed Platform

As we discussed earlier that our study is to create and realize a platform for respiratory diseases, in this section we extensively review our IoHT scheme for respiratory diseases. General overview of our scheme is provided in the beginning, then we will explain each component in our scheme.

3.1 General Overview

Figure 1 illustrates our proposed IoHT scheme. In general, we divide our scheme into three parts. Sensing part takes a place on the front of our scheme. There are three different devices employed to observe the environment. First, environment sensing box

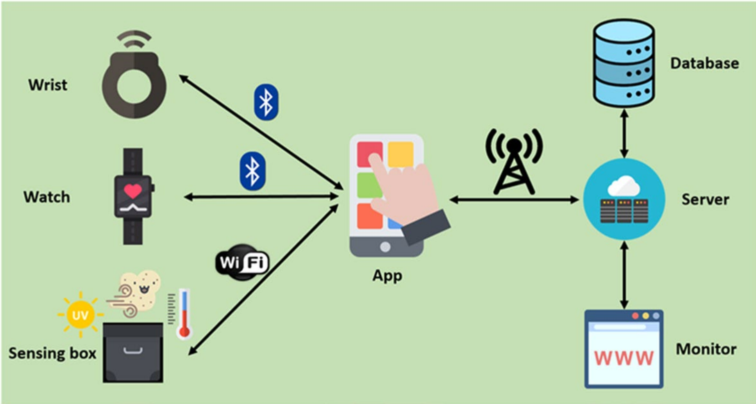

Fig. 1 General overview of our proposed scheme

is placed outside to give us information related to surroundings. The assessment using this box is very useful to declare either the patients can go outside or they need to stay at home due to the harmful environment for them. We separate the sensing box to have a flexibility for monitoring environment. Therefore, users can be easily used and utilized our platforms. Second, wrist and watch are tied on patient surface skin in order to sense and monitor biosignal of patients. We further create user-friendly apps on android to monitor current status and data of patients as well as to connect with server.

In order to collect all of data from sensing units, we gather patient and environment data using smartphone. Apps based on android platform is established. Wrist and watch are connected to smartphone through Bluetooth. In addition, data from sensing box is acquired using WiFi connection. All of collected data are fully stored to server that has been designed as the storage of our database and can be monitored by users or analysts.

3.2 Detail Implementation

Figure 2 is the detail implementation of proposed scheme. To assess the current status of patients, we collect the heart rate and blood pressure using watch used by patients. SPO_2 sensor is also employed by attaching the sensor on the wrist of each subject. All of data are gathered and sent to smartphone using Bluetooth then passed to server through internet connection using smartphone.

In our scheme, pollution level is monitored using PM2.5 sensors. Temperature and humidity as well as the UV level as key factors influencing the healthiness of patient is also assessed during certain day. Attached WiFi on our sensing box transmits collected data to server. Microcontroller Atmega 32U4 is primarily used to collect data from each sensor. The microcontroller is also utilized to process analog signal from UV sensor, get the data from PM2.5 sensors using UART communication, and gather the temperature as well as humidity data through I2C connection. Watch with embedded sensors inside is attached to patients. Furthermore, it will send heart rate and blood pressure data using WiFi.

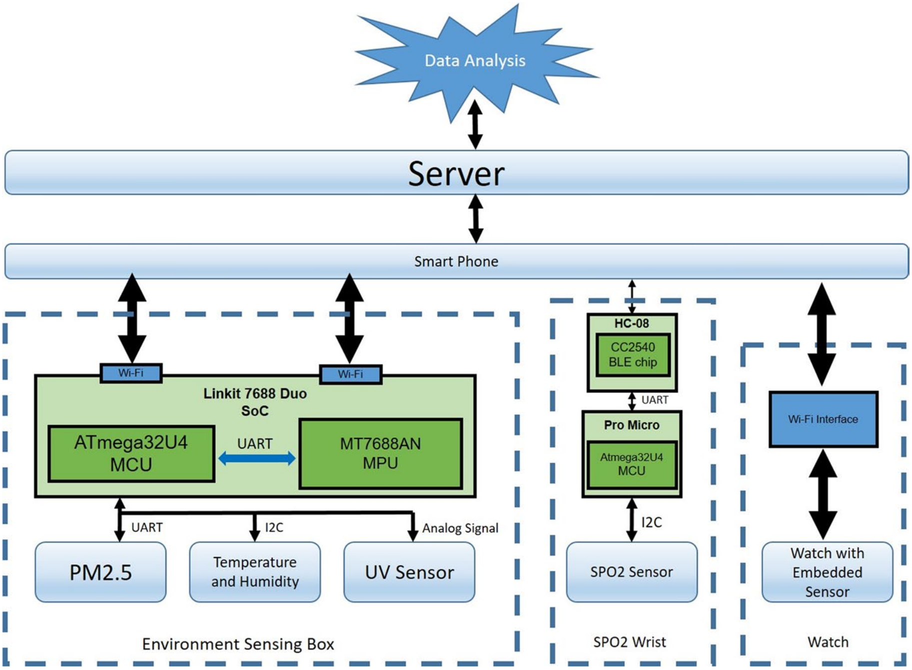

Fig. 2 Proposed scheme implementation

3.3 Data Flow from Sensor Nodes to Server

As illustrated in Fig. 3, in the beginning, the proposed framework is started by collecting the data from available sensors. Then, the data is transmitted to smartphone to be displayed and presented in our APP. Eventually, data is sent and stored to the server.

4 Device Development and Placement

To give a usage flexibility for users, wristband and watch are used and attached to users' surface skin. In addition, environment sensing box is connected to user's smartphone, thereby they can monitor the environmental indicator. Therefore, decision can be made whether the weather is safe enough or not.

4.1 Environment Sensing Box

As depicted in Fig. 4, sensing box can be placed outside or inside buildings as long as the smartphone is able to reach the WiFi signal transmitted from the box. Supply is provided from Li-ion battery, thereby it will be very convenient and can be put as the preference of users.

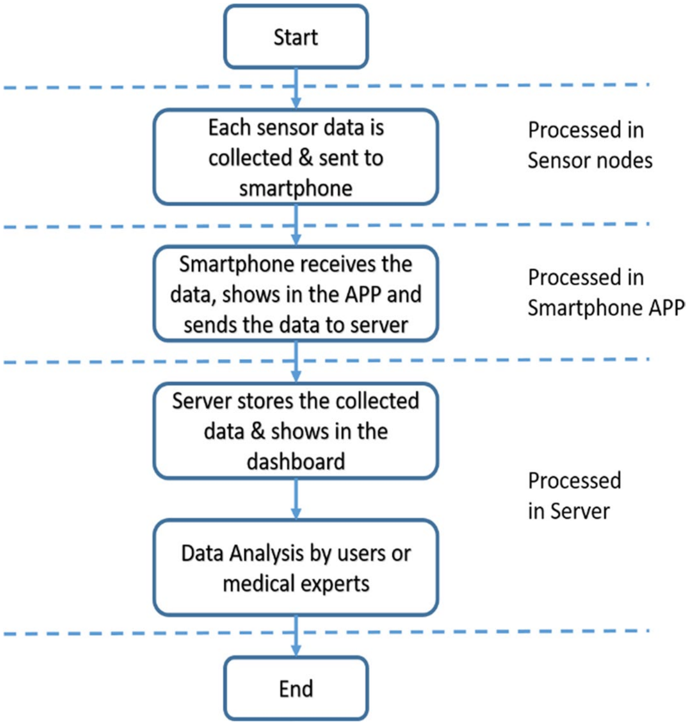

Fig. 3 Data flow from sensor nodes to server

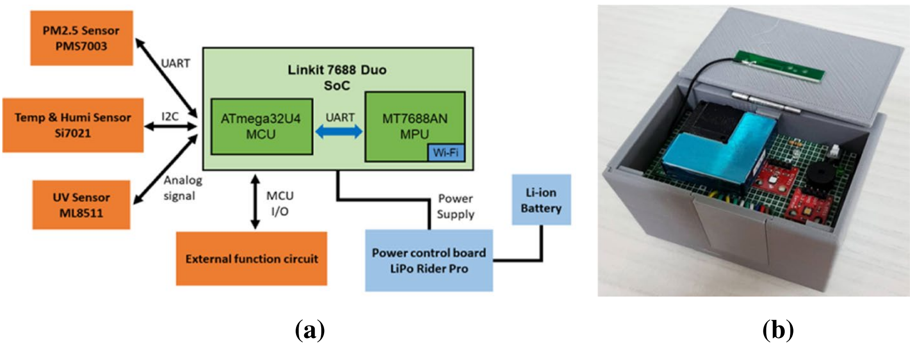

Fig. 4 **a** Environment sensing box block design **b** sensing box chase

4.2 Development of Wristband and Watch

4.2.1 Wristband Detail Structure and Implementation

The wristband constructed in our platform is illustrated in Fig. 5a while the chase design is shown in Fig. 5b. SPO_2 sensor used in our platform is MAX30102 as depicted in Fig. 5c and connected to Atmega32U4 through I2C. Furthermore, data from MAX30102 is

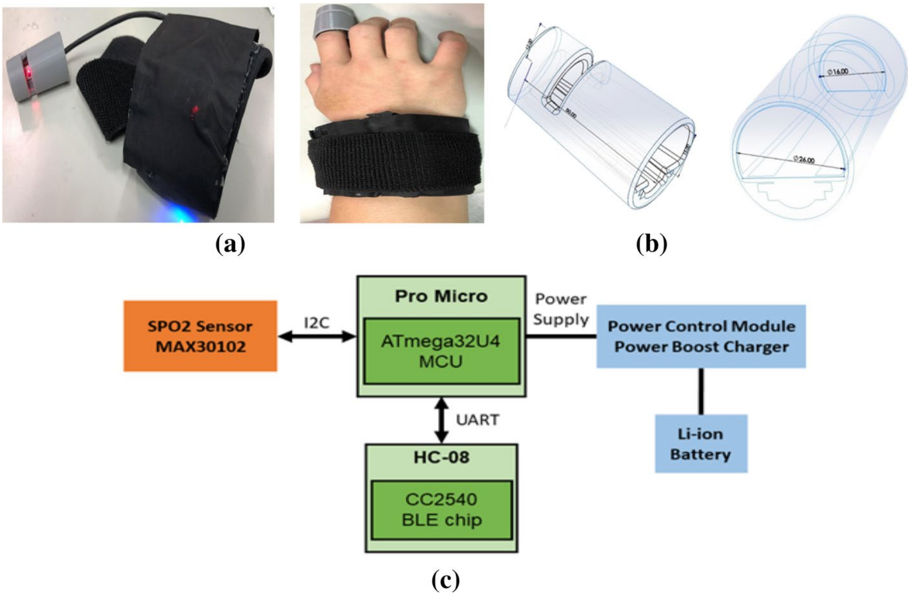

Fig. 5 **a** Placement of wristband, **b** Design of chase for SPO2 sensor, **c** wristband circuit design

transmitted to smartphone via Bluetooth module HC-08. Li-ion Battery is used as a source for SPO2 sensor circuit.

4.2.2 Watch Detail Structure and Implementation

Instead of constructing a watch from the scratch, in this project we employ the existing watch platform for medical use namely Zoetek watch. Some features are offered and embedded in this watch, as illustrated in Fig. 6a and b, Zoe watch system has Bluetooth chip inside and several sensors, such as ECG, Heart Rate, as well as monitoring the blood pressure of users. All of users' data will be transmitted to smartphone apps via the Bluetooth or Wi-Fi chip inside the watch.

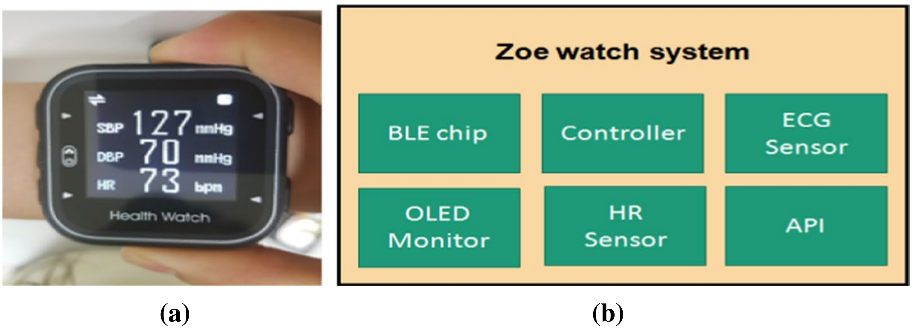

Fig. 6 **a** Zoetek watch**b** available features on Zoetek watch

4.3 The Flowchart and Processing of Sensing Data

Environment data is simultaneously and parallelly collected through several available sensors as shown in Fig. 7. PM 2.5 is transmitted through UART whereas the UV data is interfaced by Analog to Digital Converter (ADC) and I2C is used to get the temperature and humidity data. Furthermore, the collected data is concatenated using json structure in the MCU and sent to smartphone through WiFi. The oxygen saturation is monitored by an SPO_2 sensor attached on the wristband and sent via Bluetooth to the smartphone APP. Besides, the heart rate and blood pressure are sensed by Zoetek Watch. All of the data are transmitted to the smartphone and concatenated before sending to server.

5 Development of the Smartphone App and Server Dashboard

5.1 Overview of Smartphone APP and Server Dashboard

Practically, we need to evaluate and monitor the COPD survivor status in real time. Moreover, in order to realize the scheme, we develop an android based app to be integrated in our monitoring scheme. Through developed app, all of data are wirelessly collected. Assessment and monitoring can be conducted via all data transferred from our monitoring devices. To visualize data streaming from all connected devices, we create a web based monitoring system on our local server. All of collected data are recorded and stored to local server. Moreover, visualization is also updated once sensors send users collected data.

Figure 8 depicts the development dashboard of data management center. As can be seen, users of our platform can also import the data as the excel format. Considerably, this feature is provided due to the need of health practitioners to analysis patient data and they

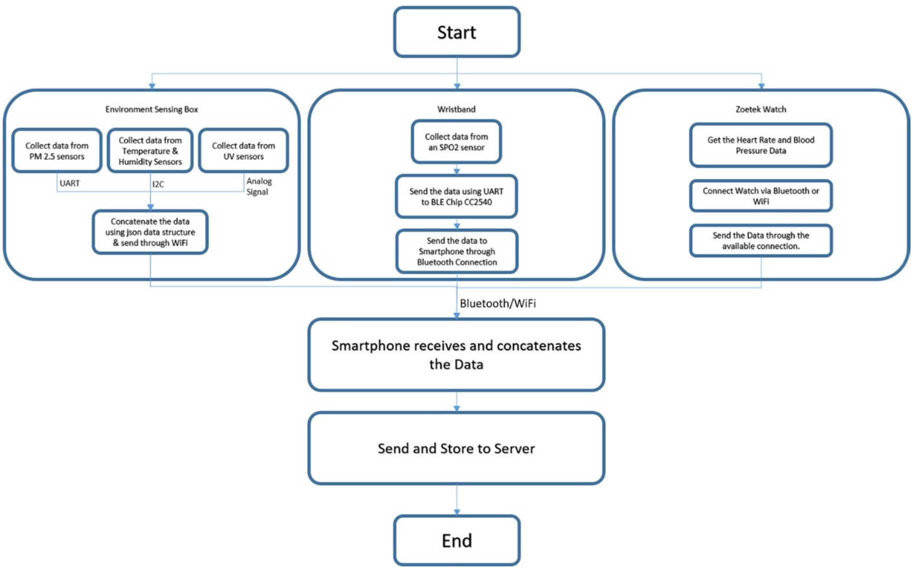

Fig. 7 Data collection: flowchart

Fig. 8 Data management center for COPD patients

might use different tools to analyze it. The ease of our platform usage is to transfer data provided by our scheme to others by converting collected data from patients to excel or csv file. In addition, health practitioners (doctors and/or nurses) can also monitor patient data through our platform user interface.

Besides, to make our app publicly available, we have put COPD monitoring app developed by our research team on Google Play Store as depicted on Fig. 9a. Android based real-time measurement system for COPD patients is illustrated on Fig. 9b. In the beginning, the scheme records patient blood pressure before doing exercise. Therefore,

(a) (b)

Fig. 9 **a** COPD app on play store **b** Monitoring patients using our app medical data during exercise or patient activity are not only simultaneously recorded and stored to server but data streaming is also visualized by plotting the graphic of recorded data.

5.2 APP Service Flow

The APP service flow (depicted in Fig. 10) is started by sensing all of the related data then the real-time data is displayed by the APP. Once users press the save button, the APP is going to check whether there is the connection through server. Therefore, the data is stored to server when there is the connection. Eventually, users can stop the service by pressing the stop button.

6 Performance Evaluation

To validate our scheme, we conducted 15 experiments using our platform. As illustrated in Table 1, our tool to monitor patient status is quite consistent indicated by low Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). Furthermore, the performance assessment of environmental sensing box is shown in Table 2. From the data, our scheme is also achieving low RMSE and MAPE indicating that our scheme is consistent enough in order to record the patient and environmental condition data.

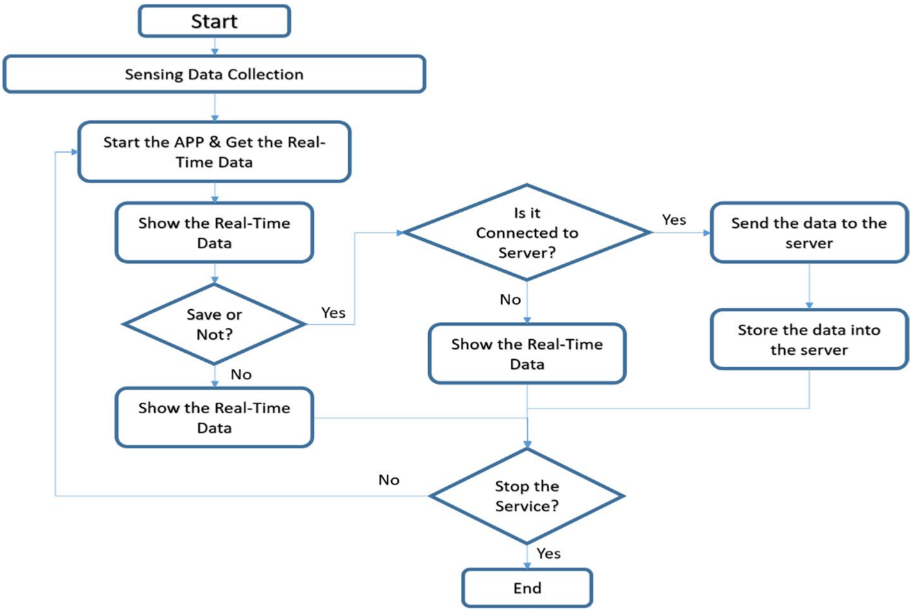

Fig. 10 APP service flow

Table 1 Patients monitoring tool performance

Name	Experimental group			Control group		
	MAPE	Correlation coefficient	RMSE	MAPE	Correlation coefficient	RMSE
Heart Rate	3.17 ± 3.85	0.913 ($p < 0.001$)	2.891	3.52 ± 2.61	0.950 ($p < 0.001$)	3.824
SBP	4.85 ± 4.38	0.819 ($p < 0.001$)	7.867	3.14 ± 2.93	0.855 ($p < 0.001$)	4.489
DBP	5.96 ± 7.85	0.923 ($p < 0.001$)	7.303	6.45 ± 6.33	0.833 ($p < 0.001$)	6.984
SPO_2	1.15 ± 1.47	−0.374 ($p = 0.408$)	1.254	1.17 ± 0.70	0.271 ($p = 0.556$)	1.155

Table 2 Environmental monitoring box performance

Name	A002 control group		RMSE	A003 Control Group		RMSE
	MAPE	Correlation coefficient		MAPE	Correlation coefficient	
Temp	10.92 ± 5.18	0.867 ($p < 0.001$)	4.333	9.04 ± 4.19	0.904 ($p < 0.001$)	3.162
Humid	11.35 ± 4.43	0.791 ($p < 0.001$)	10.846	11.05 ± 5.08	0.818 ($p < 0.001$)	8.341
PM2.5	12.63 ± 10.5	0.994 ($p < 0.001$)	3.596	$14\ .34 \pm 8.61$	0.992 ($p < 0.001$)	3.756

7 Discussion

In this study, a prototype of wearable sensor devices connected with a decision support system was developed to facilitate daily activity of patients with COPD. This tool consists of: (1) wearable sensing devices (physiological sensor and environmental detector; (2) a smartphone App for physical activity decision support system; and (3) a cloud infrastructure. The feature of this prototype was designed to reduce harmful exercise environment by increasing access to safe and personal goals focused activity. The main procedures for the use of this tool are:

1. An environment detecting box is placed in the location of individual patients to give information surrounding them. Decision support will be provided from the smartphone App for individual patients whether the regional weather and environment (outdoor or indoor) is appropriate for their physical activities. Identification of risk conditions is performed by evaluating ambient conditions (e.g., high temperature or low humidity) or using thresholds (e.g., PM2.5 concentration more than 50 μg/m^3) [26].
2. Physiological sensors were worn on the wrist of each patient that measure real time heart rate, blood pressure, and SPO_2. Readings from the physiological sensors will be assessed by the decision support system of the smart phone App. For example, if patients with COPD have SpO_2 values of $\geq 95\%$ at rest, they are recommended to preform physical activities. On the contrary, if they have SpO_2 values of $< 95\%$ at rest, they are recommended to evaluate their COPD symptoms before physical activities [25, 27].
3. The real time physiological readings provide patients with an instant feedback to them during active physical activities. The smart phone App further comprises a physiological data management system and a physical activity data analysis processing unit. The patients could see their real-time activity results and history of daily steps on the mobile phone App. All of collected data are recorded and stored to local server.

Before testing the system measurements in relation to COPD patients, our research team conducted a preliminary test to confirm the function of the sensor systems and data processing software of this device. Rates of the technical problems, detection of physiological and environmental data, and functions of decision support system were the key evaluation parameters and we adjust the program of this system accordingly.

8 Conclusion and Future Works

While many mobile technology interventions for patients with COPD are currently discussed in a Cochrane Database System Review [28], to the best of our knowledge, our study is the first one that incorporate environmental and physiological sensors with personalized exercise decision-support system for COPD population. This tool developed in our study added value of pre-exercise environmental and physiological assessment to exercise monitoring and feedback features to help preventing symptoms during active physical activity of patients with COPD. This tool were recently tested for its accuracy in our lab environment and a pilot study will be performed to evaluate the system in terms of usefulness, friendliness and user acceptance in COPD patients. Our next step in the evaluation of the system is to integrate this tool with the home-based program and evaluate the effectiveness of the system on daily activity facilitation by running a plot with COPD patients. We hope that the tool developed in our study can be taken into consideration for the initial design of an integrated care system of COPD patients to encourage self-management of their conditions at home.

Acknowledgement This work was supported by the National Yang-Ming University-National Taiwan University of Science and Technology Joint Research Program (NTUST-NYMU-106-02).

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