Wearable Tool for Breathing Pattern Recognition and Exacerbation Monitoring for COPD Patients via a Device-to-Cloud Communication Model

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***Abstract*—**Chronic Obstructive Pulmonary Disease (COPD) has become one of the major causes of disability in the Philippines today. COPD is incurable and would also be one of the most painstaking diseases because it progresses over time. Patient self-monitoring, especially breathing patterns and frequency has become an increasingly recognized process which is beneficial for the ongoing care of COPD. Many potential technologies for the diagnosis and monitoring of COPD have been developed, but focusing on telehealth, imaging, and spirometry. This study has designed and created an IoT based system that could recognize and monitor the respiratory rate through breathing patterns and provide a means for doctors to remotely monitor the patient. The prototype device that has been developed was named X-Hale. X-Hale is a cost-effective and portable remote monitoring IoT-based tool, integrated within a wearable oxygen mask responsible for recognizing and recording accurate breathing frequency patterns. The system was designed to interweave underlying elements of Device-to-Cloud model for a straight-forward communication used in remote monitoring. The wearable device was tested using an HT50 ventilator that delivers machine-controlled dummy breathing in an actual hospital setting. Results show high accuracy in detecting breathing patterns in Slow, Normal and Fast respiratory rate per minute. X-Hale was also tested in actual patients to facilitate the remote monitoring of breathing patterns via the IoT communication model used.

***Index Terms*—**Wearable, internet of things, device-to-cloud communication, breathing pattern

I. Introduction

Chronic Obstructive Pulmonary Disease (COPD) is a common lung disease, characterized by obstructing airflow from the lungs that is due to airway abnormalities usually caused by significant exposure to noxious gases or smoke. Breathlessness is the most cited symptom that frequently manifests on both a daily and weekly basis. Other signs of COPD are irregular breathing patterns, coughing, fast heartbeat, weight loss, and fatigue [1].

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COPD has four stages, which range from mild to very severe. In the Philippines, COPD ranks 7th as the leading cause of death in the population. [2] Exacerbations, or acute events and worsening of disease happen one to four times a year on average [3]. Exacerbations are the cause of frequent hospital admissions and increased health care costs, especially in patients with more severe cases of COPD. Remote monitoring can reduce the frequency and severity of these exacerbations. The evaluation of patterns of breathing as part of regular monitoring could lead to improved care, and management of COPD patients, especially for non-ambulatory patients or those who are unable to walk or move around [4]

Efficient and practical remote monitoring can be achieved with the application of IoT or Internet of Things. In a study of health based IoT, network ecosystems and communication frameworks are based on a network of devices that connect directly with each other to capture, collect, and share vital patient data, and significant context information, through a secure service layer that connects to a central command and control server in the cloud [5]. The existence of an IoT-based remote monitoring device for COPD is a foreseen advantage for non-ambulatory patients, who most likely cannot accomplish self-management and follow-up checkups.

The study was geared towards provision of an applied technology, where health care practitioners and hospitals can be enabled to remotely monitor COPD patients' condition and determine the onset and offset of COPD exacerbations and the severity of the disease. Specifically, the study aimed to: (1) Provide a means of detecting respiratory rate by designing a wearable IoT device that can remotely monitor and recognize the different breathing patterns of COPD patients using breath-based temperature sensor to extract breathing patterns, (2) To develop a mobile application that can aid patients and doctors in self-recording, monitoring, and analyzing breathing patterns and (3) To provide a facility via a device-to-cloud communication model in executing

exchange of data that supports remote monitoring and software-based update pushing.

II. Literature Review

A. Gaps in Treatment and Monitoring of COPD

Effective treatment is available for COPD. However, not all health care systems are well set up to provide accessible clinical diagnostic pathways that can help in sustaining and executing manageable plans, especially for chronic non-communicable respiratory diseases. There is a need for both clinical and academic capacity that is well built on strong health systems research to underpin health service strengthening, policy and decision-making. Huge gaps and opportunity to integrate technological solutions for improving access to effective care for people with COPD is foreseen in this context [6].

Monitoring routines for COPD were recommended frequently, especially follow-up of lung function indices. However, evidence to support the guideline recommendations for the monitoring of patients with COPD is limited. An effective monitoring on care process and outcomes should be recorded, kept, and assessed, given that monitoring routines and recommended frequency for monitoring must be analyzed based on the guidelines [7].

Health Practitioners are monitoring vital signs, lung function, and respiratory sounds to predict exacerbations in non-ambulatory COPD patients. There are different devices for every type of monitoring. An example of such device is a spirometer which is used to measure the volume of air inspired and expired by the lungs as seen in Fig. 1.

Fig. 1. Three-Balls spirometer

Early introduction of treatment for exacerbations resulted in faster recovery of the [8]. Early introduction to treatment includes Self-management, early identification of breathing patterns, and timely treatment of COPD exacerbations. This is critical in order to slow down further deterioration caused by the disease and reduce health care costs.

B. Breathing Frequency and Patterns

As mentioned in the gaps, breathing patterns is an important early introduction to COPD Treatment. Breathing frequency is the number of breaths per minute also known as respiratory rate. At rest, varies among individuals from about 10 to 20 per minute. While in heart rate, it is the speed of the heartbeat measured by the number of contractions (beats) of the heart per minute (bpm). Abnormal patterns of breathing are frequently caused by injury to respiratory centers in pons and medulla, use of narcotic medications, metabolic derangements, and respiratory muscle weakness [9]. While respiratory rate can be measured with exact values, patterns as seen in Fig. 2 can be easily used to monitor severity and can provide visual assessment of patients

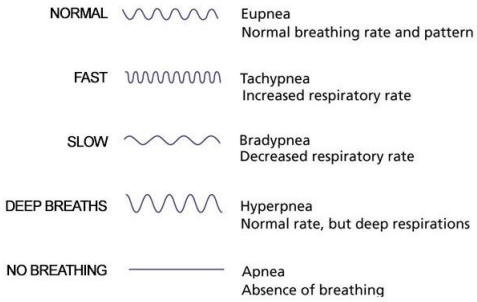


Fig. 2. Breathing patterns base on respiratory rate according to USMLEAid

In some studies, measim e wftc urements and extraction of breathing patterns are performed using magnetocardiography (MCG). This is done by bringing the chest closer to or away from the sensor array located inside a stationary liquid helium cryostat. The respiration rate is usually measured when a person is at rest and simply involves counting the number of inhalations per minute [10].

C. Wearables in Health Care and the Communication Model

Wearables can be used to track conditions of patients in cities or rural areas, thereby reducing the workload of healthcare providers, increasing efficiency, reducing costs of healthcare services, and improving patients' comfort. With remote monitoring, mortality can be reduced since introductory care can be provided to the patients at the right time [11]. Wearable systems and devices should also be able to provide real-time feedback not only to medical staff and patients. The capacity to detect body signals noninvasively can greatly facilitates the application of wearable monitoring devices [12].

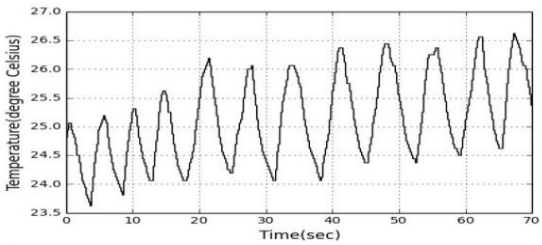


Fig. 3. Detection of changes of inhalation and exhalation using temperature sensor

For small devices that can be catered to wearables in a more appropriate way, the data collected from the preliminary experiments in a study demonstrates that the TMP102 temperature sensor, when accurately positioned,

can detect temperature changes corresponding to inspiration and expiration as shown in Fig. 3. As the size of the sensor is small and the computation required is minimal for non-contact breathing monitoring as compared to existing methods, this proposed method demonstrates the usefulness of this sensing modality [10]. The size makes it ideal for wearables that can be integrated in an IoT environment for remote monitoring

For these small devices in wearables to effectively execute in IoT environment, communication is the most critical element in producing IoT applications for it requires a means of transmitting data sensed at the device level to a cloud-based service for processing of data.

Device-to-cloud communication involves an IoT device or tool that can connect directly to an Internet cloud service like an application service provider. This is to exchange data and control message traffic. Oftentimes, this is done using traditional wired Ethernet or Wi-Fi connections but can also use cellular technology [13]. Wearables in Healthcare can depend on Cloud connectivity lets the user (and an application) to obtain remote access to a device. It also potentially supports pushing software updates to the device.

On a real-world example scenario, wearable implementation can be perceived where different sensors like thermostat from different locations are connected within a facility. Each of the thermostats is in communication model with a cloud-based application server whereby facility operations can view the temperature data using various interfaces. This scenario can be depicted in Fig. 4 by which the thermostats may communicate with the cloud server such as HTTP, TCP, UDP, CoAP [14].

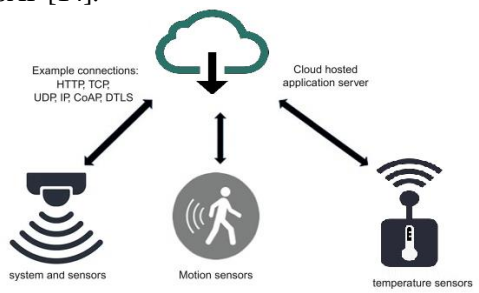


Fig. 4. Device-to-Cloud communication model

III. Methodology

The methodology that was used in the study was a modified prototyping based on Nurun Process, a prototyping methodology that is well suited for developing projects that is under Internet of Things [15]. Fig. 5 shows the stages that were performed in the study.

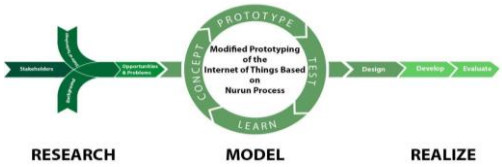


Fig. 5. Modified Nurun-Based methodology for IoT

There are 3 main stages in this methodology, Research, Model, and Realize. In the Research Stage, the study created an insight and developed areas of opportunities. The study understood the nature of the problem, learned the state of the COPD patients here in the Philippines and the technologies that are currently being used. To have a better understanding of these, the team visited a Rural Health Unit in the Philippines and conducted an interview to gather information about their current state in assisting COPD patients in the area. In the Model Stage, a rapid and iterative process was conducted to conceptualize and learn within a given time frame. The model stage allowed the researchers to iteratively perform different tests including Sensor and Data Transmission Tests, Hospital Machine Test in a Private Hospital, and Device/Mobile Functionality Test before the complete development. Finally, the prototype was developed and evaluated by the health workers and patients of a selected Rural Health Unit under the Realize Stage. This also include a machine test performed in a selected private hospital.

A general Communication Framework was followed in the Model Stage, integrating the Device-to-Cloud Communication Model. The Framework can be viewed in Fig. 6.

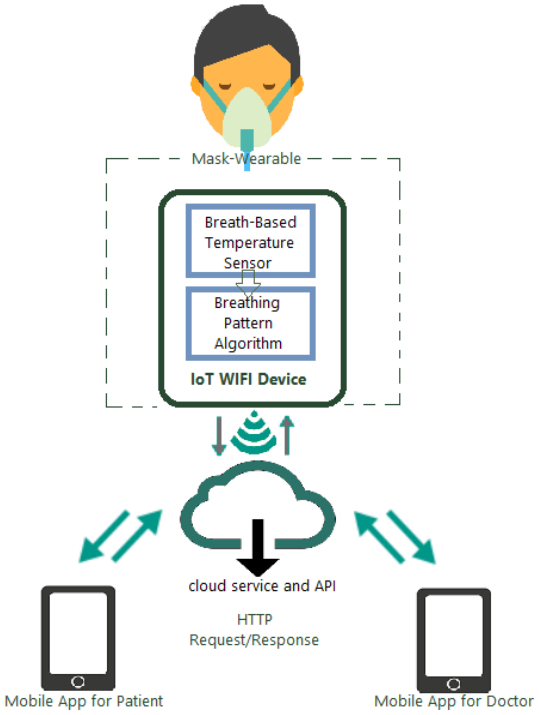


Fig. 6. Communication framework.

In the Communication Framework, an oxygen-based mask design was conceived for the wearable design. A breath-based temperature sensor is integrated within the mask, which receives breath signals from patients' nostrils. This is fed into a Breathing Pattern Algorithm which is based on an equation that counts breath cycle per minute. Dedicated IoT WIFI device (Wemos) is used to connect the device directly to the cloud where application APIs are residing. Data including the

inhalation and exhalation count are collected and processed within the hosted API, which is then computed and displayed in a mobile application through the Request-Response process of HTTP.

IV. Results and Discussion

A. System Diagram and Actual Prototype

Actual components and system diagram of the Prototype. WeMos D1 Mini, a WIFI enabled Microcontroller, serves as the core of the device which is also where all the hardware components are connected into [16]. The WeMos D1 Mini also serves as the hardware component that enables the device to connect to the internet and send or receive data from the Web API using the Device-to-Cloud communication Model. A power supply in the form of a power bank is utilized to provide the needed power and voltage of the WeMos D1 Mini. The power bank is utilized as a power supply for the device to be portable. To be able to capture the breathing pattern from the patients, MLX90614 Temperature Sensor was utilized and converted into an improvised breathing pattern sensor [17]. All the temperature data that the MLX90614 reads are sent to the WeMos D1 Mini to be processed and send to the Web API. The Web API serves as the hub where all the data that has been sent is processed and stored into the database. The Web API is also capable of sending cross-platform data that enables the mobile and/or web view application and the device to receive sent data from the Web API. The mobile application serves as another end device tool in the communication model, to enable the user to access and send data to the Web API. (See Fig. 7).

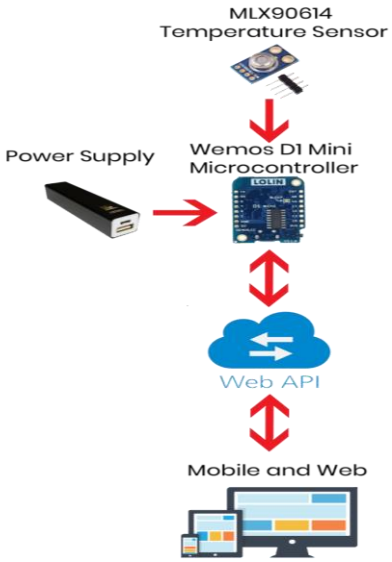


Fig. 7. System diagram

As seen in Fig. 8, a wearable mask has been developed using an oxygen mask attached with an MLX90614 sensor and a WeMos D1 Mini. The setup has been done by attaching an MLX90614 sensor to the tubing area of an oxygen mask. The close-up version of the tube can be seen on Fig. 9.

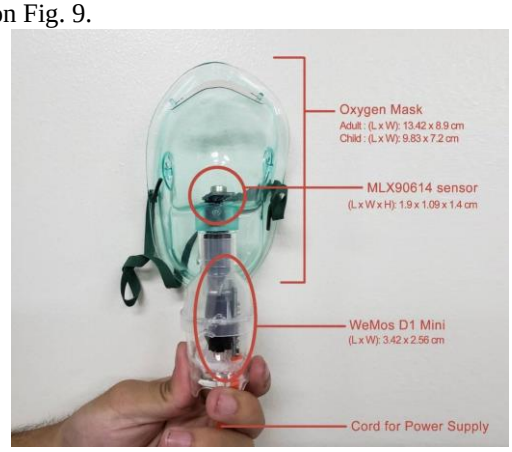


Fig. 8. Actual Image of the Prototype with Labels

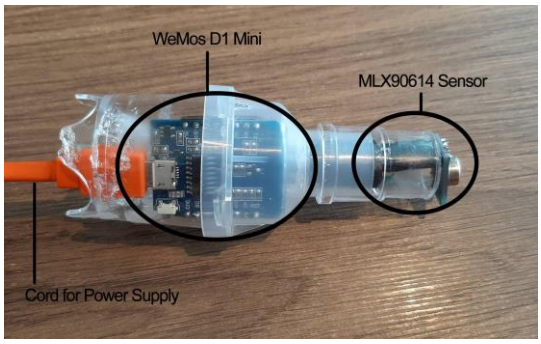


Fig. 9. Close-up of tube containing Sensor and WeMos

The objects used in designing the device seen in Fig. 9 are very small, with the Wemos being only 3.42 x 2.56 cm and the MLX90614 sensor at 1.9 x 1.09. 1.4 cm. The developed device is also very lightweight, with the sensor at 2 grams, the WeMos at 3 grams, and oxygen mask itself at around 61 grams. This setup allows patients to use the device without inconvenience by not making them feel the burden of using a heavy machine whenever they need to test. All objects are connected and placed inside a tube which can attached to the connector hole of the oxygen mask. Aside from an oxygen mask, patients may also use a nebulizer mask if they feel more comfortable using the other or if it is more accessible. Both oxygen and nebulizer masks come in two sizes – one for children and one for adults.

The MLX90614 produces two temperature measurements: object temperature and ambient temperature. The object temperature is the non-contact measurement from the sensor, while the ambient temperature measures the temperature on the die of the sensor. In the developed system, the temperature values received via object reading of the patient's breathing, which makes the sensor breath-based, are collected and calculated to show the breathing pattern and respiratory rate. The MLX90614 sensor can produce a wide range of object readings from -70 to 382.2 °C, and can collect multiple temperate values in less than a second. For the breath-based setup, the sensor would be calibrated to collect temperate values of non-contact elements such as

the air flow in between inhales and exhales every half a second within a time frame of one minute.

The WeMos D1 Mini is used to give the device Wi-Fi capabilities, to enable the device to connect to the internet, where the data gathered by the sensor can be fetched by the mobile application through the API.

B. *Respiratory Rate (Breathing Pattern) Calculation*

The respiratory rate is the rate at which breathing occurs. This is usually measured in breaths per minute. Respiratory rate is typically measured when a person is at rest and involves counting the number of breaths for one minute.

$$\frac{\textbf{(Total Inhale + Total Exhale)}}{\textbf{1 minute}} \quad (1)$$

Equation 1. Calculation for Respiratory Rate

Equation1 shows the calculation for the respiratory rate. By getting the number of times a person breathes in a minute we can calculate the respiratory rate of the person. A breath counts as one inhale (breathe in) and exhale (breathe out). Instead of manually observing and counting the inhalation and exhalation of the person, the study used a temperature sensor to detect temperature changes corresponding to inhalation and expiration as shown in Fig. 10.

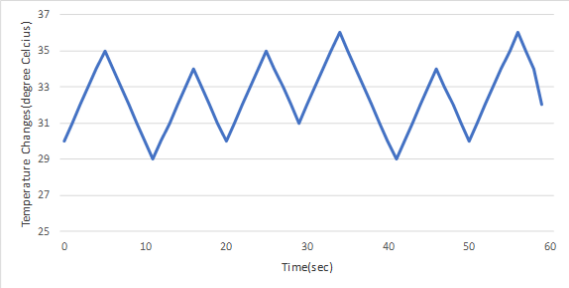


Fig. 10. Change in temperature near nostril during breathing

C. *Breath-based Sensor and Data Transmission Test*

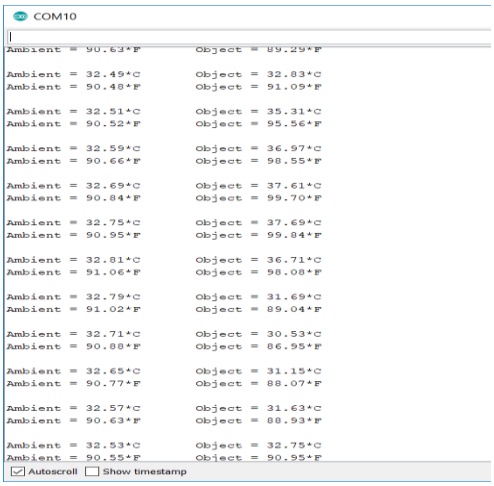


Fig. 11. Output of sensor readings

Sensor test was done in order to verify if the breath-based temperature sensor can accurately detect temperature values and get the values at proper time intervals. By connecting the setup to a computer and viewing the output of readings on Arduino COM, we can determine if the sensor can successfully fetch temperate values every half a second.

In Fig. 11, the terminal result successfully shows that the sensor is capable of reading temperature of air flow at a given set time intervals, which is every 500 milliseconds. It can be noticed that temperature values do not remain constant because of the presence of air flow. This test was conducted five times, and all passed the test cases.

Data Transmission Test

In Data Transmission Test, the study followed the Communication Framework of device-to-cloud model. Each inhalation and Exhalation will be sensed by the temperature sensor as inputs. For each change in temperature near nostrils, a breath count will be recorded and calculated as Respiratory Rate using the Formula. Data exchange and transmission is pushed via HTTP request and response directly to the cloud. Data is in form of date/time stamp and actual numerical temperature, which are logically stored as series of records in the database. Dedicated Web API controls the traffic of data by providing response in each HTTP request (transmission) and therefore waiting one at time per record. Separate HTTP responses were dedicated for the collation and processing of entire data. In the actual Data Transmission Test, breathing is used as input data and corresponding Breath Pattern in graph formed following each 20 seconds of breathing. The basis of which is the process done in collecting breath data using hospital machines in selected Rural Health Unit. (See Fig. 12)

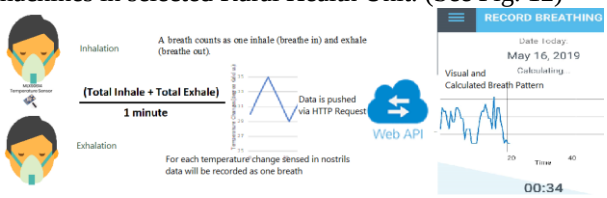


Fig. 12. Data transmission using Device-to-Cloud model

TABLE I: DATA TRANSMISSION TEST CASE

Test Case		
Test Title: Testing for Data Transmission	Test Executed by: Developers	Impact: High
Module Name: Data Transmission	Executed on: April 15, 2019	

Test Description: This will test if the WeMos can successfully deliver data to the API, and display results on the mobile app.
Pre-Requisite/s: The WeMos must be powered on and already connected to a Wi-Fi network with internet. Tester must be online and logged in to a patient account and go to add record page.

No.	Test Case	Test Data	Expected Result	Actual Result	Status
1	On the Record Breathing page on the mobile application, click on START button.		The button must change into a timer.	Button changed into a countdown timer	PASS

2	Continue breathing using the mask for one minute.	Breathing	Every 20 seconds of recording using the mask, the graph on the mobile application must contain new values.	The graph values increase every 20 seconds, and stops after the recording period.	PASS

Table I shows the test case that the study used to determine if the prototype can transmit data from the readings of its sensor to the Web API in the cloud. Passing this test case is also very crucial because having a failed data transmission test might lead to unforeseen errors and/or inaccurate data on other test cases. Based on the results shown in Table II, the prototype has passed all the cases and was able to successfully deliver data to the Web API and display the results on the mobile app via internet connectivity. This testing was conducted five times, which all passed.

TABLE II: DATA TRANSMISSION TEST CASE

Name	Age	Date of Recording	Recorded CPM	Breathing Pattern
Patient A	32	May 2, 2019	20 (Normal for Adult)	
Patient B	52	May 12, 2019	18 (Normal for Adult)	
Patient C	77	May 15, 2019	30 (Higher than Normal for Adult)	
Patient D	2	May 13, 2019	22 (Normal for Children)	

D. Hospital Machine Test

This test is done in order to verify the accuracy of the device. With the guidance of an expert in the medical field, hospital machine testing was conducted in a private hospital using an HT50 Ventilator. The HT50 Ventilator is capable of delivering machine-controlled dummy breathing through values set by the health workers. The breath-based temperature sensor was used to detect the respiratory rate outputted by an HT50 Ventilator. The respiratory rate (RR), also called cycles per minute (CPM), is the number of breaths a person does in a minute, with one breath or one cycle being equivalent to one inhale and one exhale. This is a vital sign used to determine the condition of the lungs or difficulty in breathing. The testing was conducted 45 times (15 per category), each with different set of breathing values on the ventilator. The setup during testing can be seen on Fig. 13-Fig. 15. Transmission of data results of these tests is perfomed with both the actual cloud server that required internet connectivity and a local cloud server as backup.

Fig. 13. Setup of hospital machine testing before recording

Fig. 14. Nurse and doctor attaching X-Hale device to the HT50 ventilator

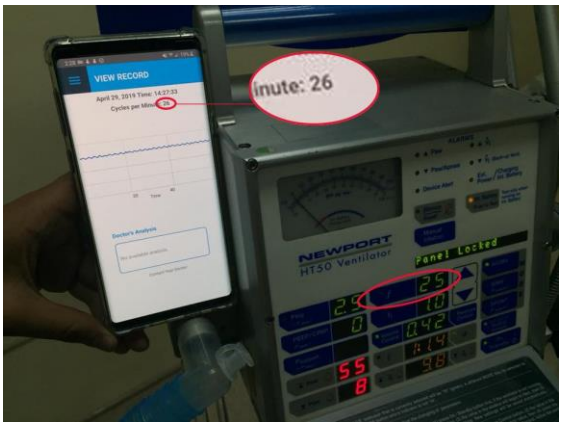


Fig. 15. Result of recording using X-Hale device and app

The use of the HT50 Ventilator machine can be seen in Fig. 15. The f value on the machine shows the number of breaths per minute delivered by the ventilator, which is recorded by the device. On the smartphone being used for recording, it is shown that the recording resulted in a CPM value of 26, which only bears a difference of 1 from the actual CPM value delivered by the machine. The result is verified to be accurate by the doctor and nurse in the private hospital.

E. Breath Pattern Accuracy

The hospital machine testing was split into three categories in terms of output of breaths per minute or

respiratory rate (RR). The first run of tests was for the slow respiratory rate output, which consists of values lower than 12. In the line chart of Fig. 16, it can be seen that the X-Hale reading does not go far off the actual output of ventitalor. There were only three instances out of 15 that the device had a reading difference of ±2 from the actual HT50 Ventilator output. The highest percentage accuracy reached 100%, and the lowest was 75%. The average percentage accuracy for the testing for slow respiratory rate is 88.06% accurate.

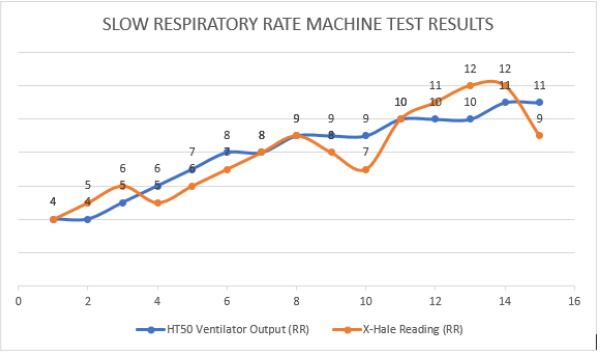


Fig. 16. Comparison of ventilator output and X-Hale reading for SLOW RR.

The second run of tests was for the normal respiratory rate output, which consists of breathing values in between 12 to 20. As seen in Fig. 17, the X-Hale reading also does not go far off the actual output from the HT50 Ventilator. The readings were more accurate during the second run. There were only two instances out of 15 that the device had a reading difference of ±2 from the actual HT50 Ventilator output. There was one test that produced a reading with difference of 3 from the ventilator output however, upon further inspection, the developer determined that the machine was started first before the device started to read, leading to the additional difference between the output of the machine and the reading of the device. It can also be seen that for this test run, exact matches of output and reading were produced. The highest percentage accuracy reached 100%, and the lowest was 85%. The average percentage accuracy for the testing for normal respiratory rate is 93.27% accurate.

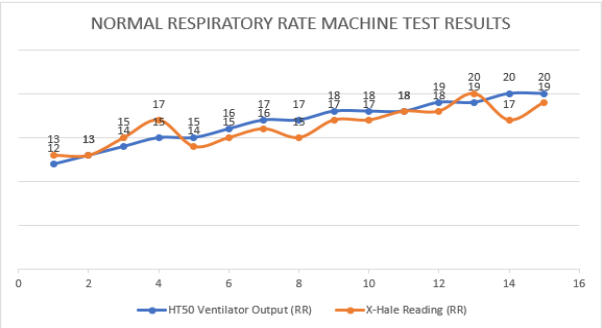


Fig. 17. Comparison of ventilator output and X-Hale reading for NORMAL RR.

The last run of tests was for the fast-respiratory rate output, which consists of breathing values higher than between 20. For the tests during this run, the X-Hale Device produced better accuracy, as seen on Fig. 18, where the line representing the X-Hale Reading rarely goes far from the ventilator output and were almost identical. The highest percentage accuracy reached 100%, and the lowest was 93.33%. The average percentage accuracy for the testing for fast respiratory rate is 96.55% accurate.

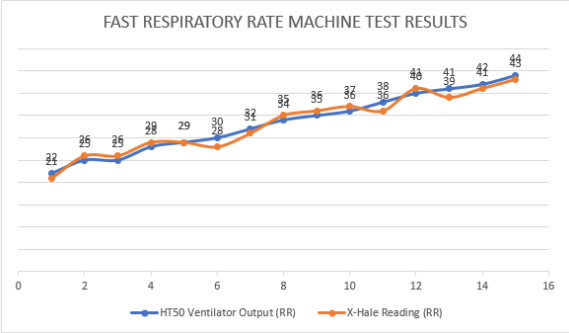


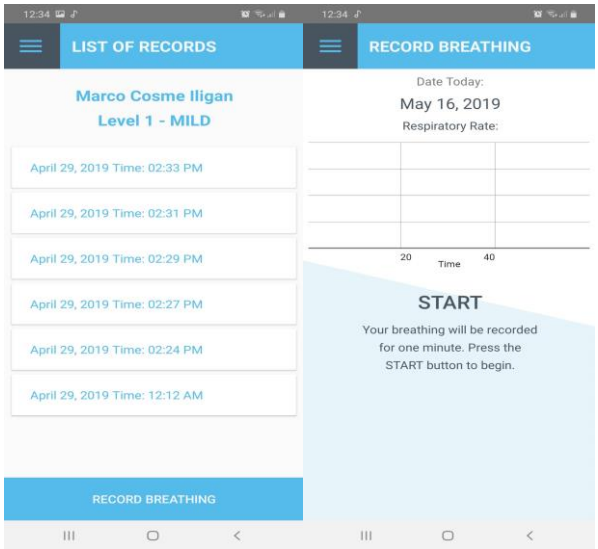
Fig. 18. Comparison of Ventilator Output and X-Hale Reading for FAST RR.

F. *Mobile Application for Patients*

A mobile application for patients was also developed. The application provides features such as account management, recording of respiratory rate, viewing of records and doctor's analysis, and getting notifications.

X-Hale Mobile Application Screenshots (Core Modules)

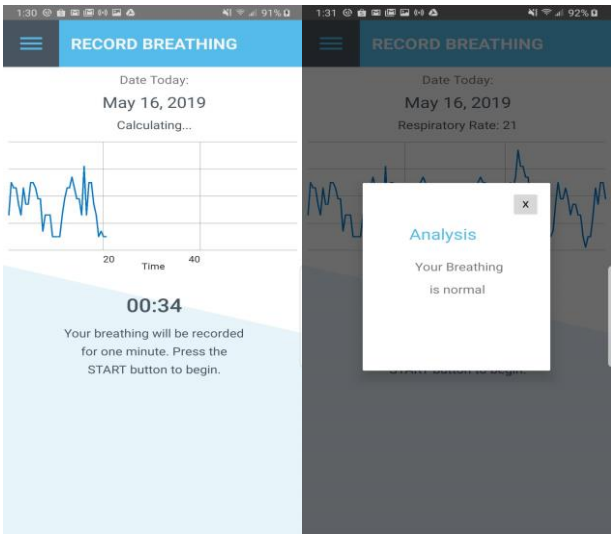
The core module of the X-Hale application is the viewing and recording of breathing patterns and respiratory rate.



(a) (b)

Fig. 19. (a,b) Screenshots of records page and adding of record

The records can be seen by navigating to the 'My Records' page of the mobile app. As shown in Fig. 19(a), the records are displayed in chronological order. For the recording of breathing, the patient will be shown in the display as seen in Fig. 19(b). The patient will then have to click on the START button and wait for one minute and 25 seconds, for the inhales and exhales to be counted, and for the data to be calculated.



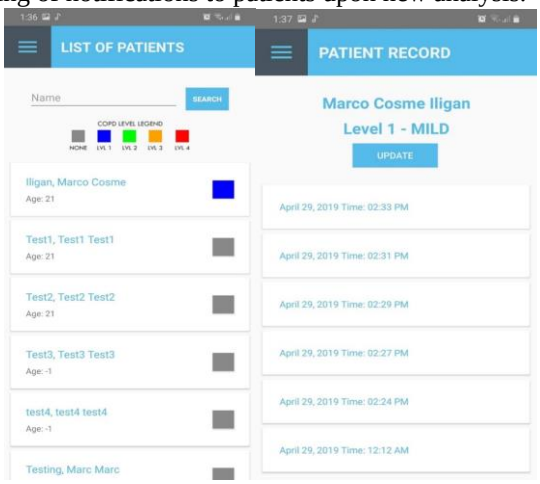
(a) (b)

Fig. 20. (a,b) Screenshots of actual recording and basic analysis after recording.

While recording, the graph will update from time to time to show the pattern of the already collected data values. After the entire recording is completed, a pop-up will appear showing a basic analysis of the respiratory rate as base on the visual breathing pattern.

G. Mobile Application for Patients

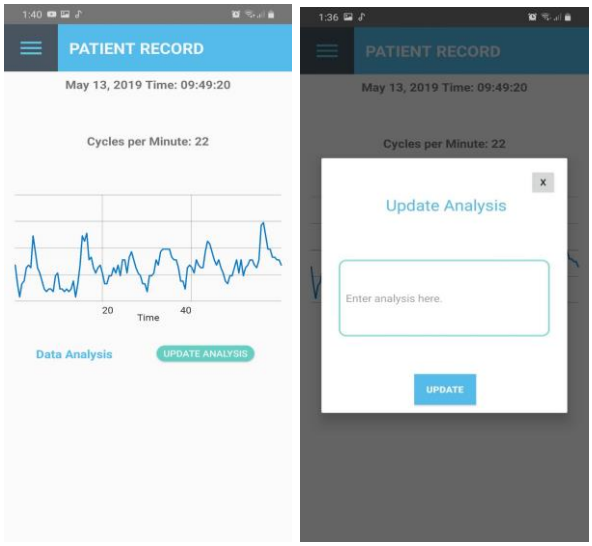
A different version of the app was also developed for doctors. For the doctor's mobile app, functionalities include account management, viewing of patients, viewing of patients' records, adding analysis to records, receiving notifications for new records, and automatic sending of notifications to patients upon new analysis.



(a) (b)

Fig. 21. (a,b)Screenshots of list of patients page and a patient's records page

The doctor can view a list of patients as seen in Fig. 21(a). Upon clicking on any patient, the doctor will be redirected to the records page of that patient, as seen in Fig. 21(b). The doctor may then click on any record, which will then redirect the app layout to the page showing the breathing pattern and CPM for that record in Fig. 20.



(a) (b)

Fig. 22. (a,b) Screenshots of viewing of record and adding analysis

Patient's record and visual breathing pattern can be viewed by the doctor in Fig. 22(a). Upon clicking on the 'UPDATE ANALYSIS' button, a pop-up area will appear, as shown in Fig. 22(b), where the doctor can type his/her analysis of the breathing pattern. After the doctor finishes in providing the analysis, a notification will be sent to the patient with the doctor's added analysis.

H. Actual Patients Testing

Functionality tests were also conducted among patients to further verify the capability of the device and application to monitor and record respiratory rates.

Four (4) respondents were selected to perform the actual testing. These respondents were selected by recommendation of health workers, and tested the device and application in the comfort of their own homes. Two respondents from the sample do not have COPD and the other two are diagnosed with COPD.

Fig. 23. Patient A exploring the features of the mobile application

Fig. 23. Patient B wearing the X-Hale mask and using the mobile app

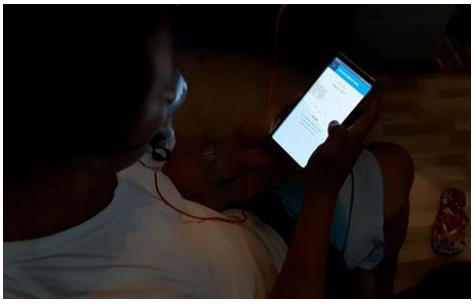


Fig. 24. Patient A recording his breathing

In Fig. 23, Patient A can be seen using the mobile application while wearing the mask, and in Fig. 24, it can be seen that Patient A is recording his breathing while looking at the graph being updated as he is recording.

The second person who tested wearable mask and mobile application is a 52-year old female (Patient B)

Two other tests have been conducted, with people diagnosed with COPD, who were called Patient C and Patient D. Patient C is a 77-year old male diagnosed with Stage IV COPD, and the Patient D is a 2-year old male with mild COPD, whose guardian mainly used the mobile app to record the child's respiratory rate, while the child is assisted in equipping the mask. The summary results of actual testing can be found in Table II.

From the results seen on Table II, it can be viewed that different breathing patterns and CPM have been recorded for each person which can indicate severity of their situation. The breathing patterns on the rightmost column of the table are actual screenshots of the patterns recorded by the device during the time of testing. These indicate that the device and mobile app can record different respiratory rates and display its corresponding pattern. Complete tests were also conducted to test all the modules of the system and all results are documented.

I. *User Acceptance Test Results*

Finally, a User Acceptance Tests were performed in the last stage of the Methodology for both patients and doctors. Following a 4-point likert scale, The Results of tests can be viewed in Fig. 25 and Fig. 26.

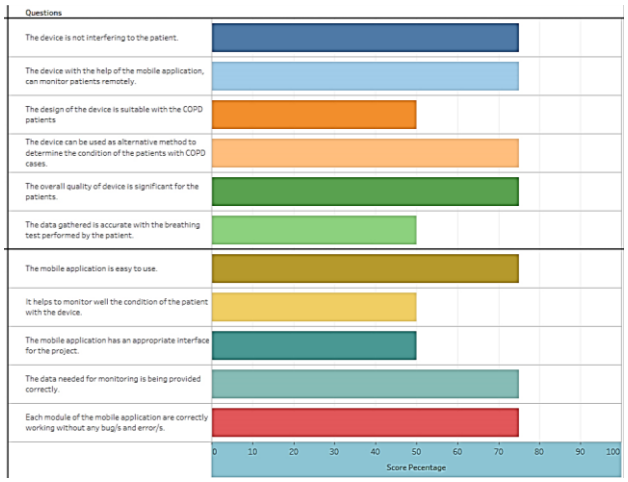


Fig. 25. Results of Likert scale survey for doctors/ health officer

The result of the 4-point Likert scale survey for (2) doctors and (1) health worker concluded a total score of 2.87 out of 4 or a percentage value of 71.75%. Most of the respondents answers fall under 'Agree' Interprettaion given the Likert Scale.

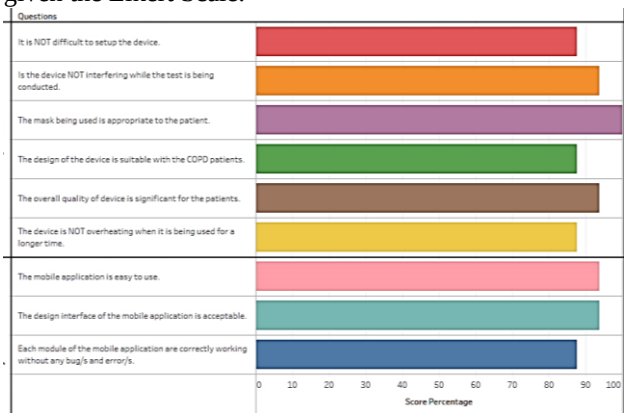


Fig. 26. Results of Likert scale survey for Patients

The result of the four-point Likert scale survey for actual testing with patients concluded a total score of 3.67 out of 4 or a percentage value of 91.75%. It showed that in real-life usage of the device and application, people are satisfied with the outcomes, and are able to properly utilize the device and mobile application.

V. Conclusion and Recommmendations

An improvised temperature sensor-based device integrated in an IoT communication model can provide an alternative tool that can introduce monitoring of exacerbations among COPD patients. Following the device-to-cloud communication model, breathing data can be transmitted and processed to remotely recognize and monitor respiratory rate and frequency patterns, thereby may help in reducing frequent hospital check-ups for analysis.

Testing performed in the device using an actual Hospital Breathing Machine, posed 92.63% accuracy in combining all Respiratory Rate Modes (slow, normal, and fast). Test runs have passed the standard set by the doctor for accuracy check, which is ±2 difference reading from the actual machine output. The ±2 value is the allowable difference of reading since in actual setting, that change in value does not indicate whether a patient is already exacerbating or not. While doctors and health workers of the private hospital validated that the device can possibly be used as a tool in determining the respiratory rate of COPD patients, it was not indicated to replace high end facilities and hospital machines but rather, to provide alternatives that can be done remotely even without going to the hospital. However, with the results of UAT of about 91.75% among patients with different demographics and severity of COPD, the study revealed that the device and the application have met its desire in aiding patients in recording and monitoring breathing patterns, which are critical as inputs in assessment of COPD severity.

With respect to the communication framework, required elements of device-to-cloud model were implemented. As breathing data may vary on the inhalation and exhalation process of the patient, the transmission is done based on the changes on temperature in the subject area. The test case for transmission of 20 seconds was made for validation purposes. However, exact breathing patterns can be achieved for longer time which was done more than a minute for each patient in the testing. This however will not matter when it comes to analysis of doctors since patterns are read graphically to show breath rate given a time and not base on exact values for every instance of breath. In the design of the communication model, breath data is directly sent in a straightforward manner within the IoT environment through HTTP therefore, exact time stamp for each breath count are transmitted and recorded for verifying purposes without validation.

With this, the study recommends that the breath counts are validated within the communication model. This is to avoid spikes and filter out sudden differences of transmitted data in the cloud. It may also pose possible changes to HTTP response processing as it was designed to performed one at a time for each request.

Series of strategic positioning of the sensor is also advised to compare breath counts and achieve reading with few errors. In providing a more reliable results, the prototype must be tested with more patients of different severity, and possible analysis to non-COPD patients for baseline data. Additional doctors and health practitioners are also recommended to assess the accuracy.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

D.A Martillano is the main author and responsible for the overall technical and hardware set-up, general analysis processes, and evaluation of procedures. M.C. Iligan is in charge of executing the hardware setup including the development of algorithm. A.R. Ramos led in performing tests and completing each executing cycle for Data Collection and Analysis. J.P Daraman concentrated in the development of the utility application while M.F. Abadines assisted in the integration of communication module. Conclusion, Recommendations overall integration were conceived and performed by the whole research team.

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