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Use of Mobile Technologies in the Healthcare Industry and Business: The Case of Pulmonary Function or Breathing Test Supportive Care

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Abstract Digital spirometry, which is used to monitor and diagnose both acute and chronic lung diseases, has been the subject of research for many years. This research undertakes the initiative to build a novel mobile-based digital spirometry application helpful in diagnosing diseases such as asthma and Chronic Obstructive Pulmonary Disease (COPD). As part of the application's design, it consists of hardware and software components, including a pipe in which the user can breathe into, a pressure sensor that helps to collect patients' breaths, an Arduino board that is be responsible for processing patients' breaths received form the pressure sensor and convert the signal to the MIDI (Musical Instrument Digital Interface) message readable by the mobile application, and finally a spirometry application developed using android studio, JAVA programming language, as a user interface. Furthermore, the database applied in this project is SQLite which utilizes cloud-based storage technology rather than server-based models which might be costly. All parts work as a circuit unit that is capable of monitoring the user's breathing system, and processing to provide an appropriate report of its performance. According to the findings, digital spirometry based on mobile application and MIDI protocol is practical and offers all the fundamental metrics that are supported by conventional spirometers.

Keywords: *Mobile technologies, Mobile-based applications, Digital spirometry, Pulmonary function, Breathing test*

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1. Introduction

Mobile technologies have been proven a great potential in the healthcare industry during past decades. The development of medical mobile-based applications in the healthcare field has provided an appropriate replacement for traditional methods. The use of mobile applications by health care professionals has resulted in better support in clinical decision-making which improved patient outcomes subsequently. Moreover, these technologies have made a significant contribution to lower treatment costs. Governments are investing a huge amount of budgets transforming different manual work in healthcare industries

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into smart software and devices. Recording and processing the patient's data in the hospital systems have made tracking the patient's status much easier for medical professionals. Transforming medical practices into digital software enables doctors to connect to the patient's results simply in any future use and provide better care to them. Overall, lots of clinical practices have been transformed significantly through digitalization and mobile technologies.

Mobile health, or m-health, has been emphasized as a viable strategy to improve health outcomes as a result of the development of mobile technology and its quick entry into people's daily lives, particularly in developing nations. Numerous studies have been carried out to characterize the effects of m-health solutions in environments with limited resources and to evaluate their potential to enhance healthcare (Karageorgos et al., 2018).

Asthma and Chronic Obstructive Pulmonary Disease (COPD) are breathing-related lung diseases that cause difficulty in breathing. A person suffering from these illnesses must regularly undergo lung function tests and perform breathing exercises to understand their health status to manage it. Pulmonary Function Test (PFT) provides quantifiable measures of lung function. They are used to evaluate and monitor diseases that affect lung function (Hirai, 2021).

This research work combined hardware and software to design and implement a simple method of pulmonary function test in the form of a mobile application called 'Solo'. This application can help in diagnosing diseases such as asthma and COPD by measuring the level and quality of the breath blowing in and out of the lungs. It also can help patients who are treated for chronic lung diseases, such as COPD, asthma, or pulmonary fibrosis, to check out the progress of the applied medications to the disease. Normally, patients must wait a long period for visits and checkups due to the rise in asthma and chest infection cases. 'Solo' can solve this issue since periodic breathing reports can be reviewed through an online platform. It enables doctors to check and monitor their patients remotely in case of connecting the device to hospital systems. Besides, this application could be quite supportive for low-income patients who cannot afford expensive devices to follow up on their health condition online with the doctor. Furthermore, this application can be useful in testing lung function before commencing surgery. Experimental results represent this application as a successful and low-cost method for measuring respiratory rate that aids in the diagnosis of acute and chronic lung diseases.

The proposed model in this research work utilizes hardware, software, and cloud-based database technology. Applied hardware includes a pipe that the user can breathe into it, a kind of pressure sensor that helps to collect patients' breaths, and an Arduino board that will be responsible for processing patients' breaths received from the pressure sensor to convert the signal to the MIDI (Musical Instrument Digital Interface) message readable by the mobile application. The required software to develop the spirometry includes android studio, and JAVA programming language, supporting a user interface. Furthermore, the database applied in this project is SQLite which utilizes cloud-based storage technology instead of server-based models.

Maintaining digital records of patient information in the cloud has been proven to be a cost-effective storage solution for healthcare centers, unlike the costly record-keeping method of server-based databases (AbuKhousa, 2012). Utilizing cloud technology in the industries and services controlled by the government could save even more money based on the organization's scale and the extent of internal activities (Rashid et al., 2019). Cloud-based storage typically includes recovery and backup attributes that provide a high-quality level of protection and security in case of any system failure or attempt of a security violation such as a data breach, which will minimize the investment in damage control remarkably (Kaur et al., 2014).

2. Theoretical Framework

Many aspects of clinical practice have been transformed significantly using mobile devices. The prevalence of using mobile devices in healthcare fields has sped up the creation of medical software applications (apps) in these industries (Aungst, 2013; Wallace et al., 2012).

Healthcare professionals can now utilize a variety of apps to help them with lots of crucial tasks, including patient monitoring and management, clinical decision-making, time management, information gathering, health record access and maintenance, communication and consultation, etc. (Ventola, 2014)

Mobile health applications can facilitate relationship-centered healthcare by positively influencing patient and provider communication and relationships. Developing mobile health can enhance interactions between patients and providers in ambulatory and hospital settings, boost patients' self-efficacy, and improve access to healthcare services (Qudah & Luetsch, 2019).

Pulmonary function tests (PFT) perform a quantitative assessment of physiological attributes in the respiratory system, which include the lungs and chest wall. Spirometry is the first step in exploring the existence and severity of the disease in the respiratory system (Hirai, 2021). Spirometry, is actually an office test used to assess how well the lungs work by measuring how much air is inhaled, how much is exhaled, and also how quickly it is exhaled (SC, 2018). Diffusion tests are complimentary with the Spirometer test. This test goes deeper into the process, where it explores and monitors oxygen movement taken from the air to the lungs till it moves through the patient's blood. Somehow, it is similar to spirometry; it includes a mouthpiece connected to a machine where you can breathe (Healthline, 2022). These are the main standard applied for diagnosing and staging Asthma and COPD. Such diseases can be worse over time, and their negative impacts can be remained on a patient's life for always. To avoid increasing the issues, patients need to conduct regular checks by spirometry at medical centers or buy expensive and portable devices to monitor and manage their disease at home. Therefore, COPD spirometry is costly in terms of both money and time (Zubaydi et al., 2017).

Some researchers developed applications to help these patients. For example, Xu et al. (2013) developed a mobile-based system for lung function diagnosis which was called MCOPD. In another instance, Larson et al. (2012) presented a low-cost mobile phone application named SpiroSmart. This application acts as a spirometer using a microphone.

Zubaydi et al. (2017) utilized the pervasiveness and advancement of smartphones and attempted to make use of their built-in sensors and ever-increasing computational capabilities to develop a mobile-based spirometer capable of diagnosing and managing COPD reliably and cost-effectively. That is while some other researchers worked on the interpretation of pulmonary function tests (PFTs) to diagnose respiratory diseases (Topalovic et al., 2019).

The use of portable spirometers is a more sophisticated alternative than measuring Portable Electronic Spirometers (PEF). As a measure taken at home, it helps healthcare organizations avoid coughing in the laboratory and reduce the risk of exposure to forced exhalation procedures in the workplace. A number of these products are now easily accessible, and users can download test results to their personal computers or mobile devices (Tovar, 2004). In addition, compared to PEF, these devices assist in accurate objective assessments of lung function. The majority of products have been developed to facilitate transfer and monitoring procedures by medical specialists.

Furthermore, electronic portable spirometry has become comparable to conventional laboratory spirometry, in a few chronic respiratory diseases, including chronic obstructive pulmonary disease, cystic fibrosis, asthma, hematopoietic stem cell transplantation control, and so on. Patients can check spirometry more regularly and weekly. Because of frequent testing, early detection of problems becomes an advantage (Global Initiative for Asthma, 2012).

Mobile health (mHealth) is considered another indirect digital alternative for formal PFT. If it has been put into practice during the COVID-19 pandemic, there would have been a chance to notice its contribution to improved management outcomes. Many advantages can prove its role in asthma care including education, symptom monitoring, and medication reminders as methods of self-management. mHealth applications can support patients' action plans to improve asthma control and have a better quality of life. An emerging mHealth option is mobile health for those with asthma and COPD. However, it is less likely to deal with new evaluations or situations of diagnostic doubt. It is more helpful for respiratory diagnostics and partnerships with mHealth-savvy healthcare practitioners. It's also critical to remember that there are currently not enough clinical efficacy trials available (Wang, 2005).

Pulmonary function testing (PFT) is essential to the diagnosis and management of patients with asthma, COPD, and other chronic lung conditions. It includes spirometry, lung volume, and diffusion capacity measurement. (Kouri et al., 2020). To develop a proper application to cover all those requirements, both traditional and innovative alternatives to PFT need to be explored first. Apart from this work, Expiratory flow devices, portable electronic spirometers, portable exhaled nitric oxide measurement, airwave oscillometry devices, and novel digital health instruments such as smartphone microphone spirometers and mobile health technologies along with the integration of machine learning approaches, all may include. (Kouri et al., 2020).

Hospitalization risk is less due to health interventions for COPD. Importantly, the main role of mHealth self-monitoring technologies is to digitize the transmission of medical care applications. Clinical information for medical professionals and virtual and remote patient management is just some basic examples of digital healthcare environment abilities. However, compared to traditional PFT, mHealth is still in its infancy, because it lacks to offer normal reference values. The revision of these paradigms is not the same as the adoption of smart technology.

3. Methodology

This section reflects the stages followed in the *design* and *implementation* phases of the project.

3.1. Project Design

To visually display the mental outcomes, a *system overview*, *device sketch*, *device 3D model*, *device pictorial circuit diagram*, *storyboard*, and *graphical user interface* (GUI) of the proposed system are designed and documented as follows. To facilitate the identification of the various components, some of the diagrams may include photorealistic images.

3.1.1. System Overview

As pointed out earlier, the proposed method in this research work is an incentive spirometer which measures the level and quality of the breath blowing in and out of the lungs. Therefore, there must be a combination of hardware to transfer the amount of the breath directory to the mobile application. Applied hardware to cover this includes:

- **Pipe/Hose:** For the user to breathe into
- **Pressure Sensor (Module MPX5010DP):** To convert the air pressure to the analog signal
- **Arduino boards (Leonardo/Micro ATmega32U4)**: To convert the signal to the MIDI message readable by the mobile application. Arduino has been programmed by using MIDI Library in Arduino IDE

Overall, the system works through two main sections; first, the *combination of the above hardware,* which receives, converts, and transfers the data to the mobile phone, and second, *the implemented mobile app software* that will receive and process the data and generate the final report. While blowing the air into the hose, the pressure sensor converts the air pressure to the analog signal. After that, the Arduino will convert the signal to a MIDI message in the application. Arduino is programmed using MIDI Library in Arduino IDE. All parts work as a circuit unit that is capable of monitoring the user's breathing system and processing to provide an appropriate report of its performance. Figure 1 shows the scenario and stages of how data transfer from the device to the application.

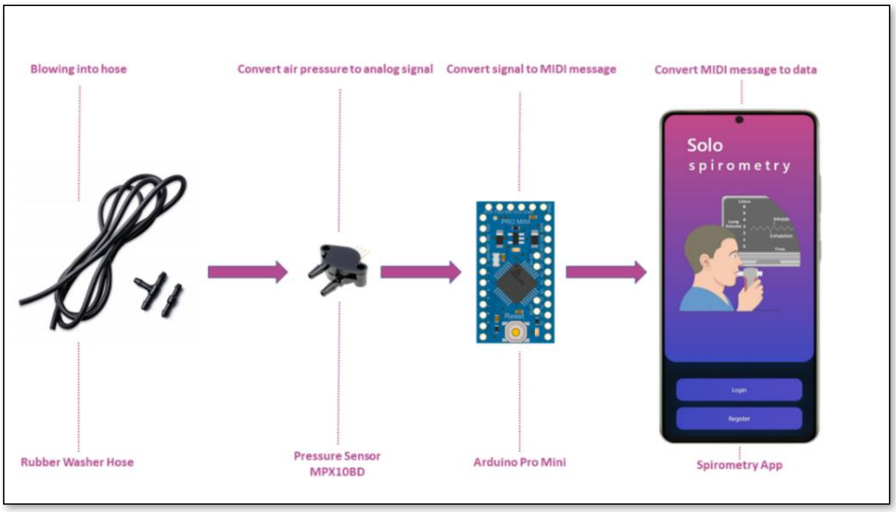

Figure 1
System Scenario for the Proposed Application in This Research Work

3.1.2. Device Sketch, 3D Model and Pictorial Circuit Diagram

Figure 2 represents a sketch of the device. It provides a clear view of the system (hardware face) designed for this project. Figure 3 provides a 3D design of the system (hardware face) proposed in this project. Figure 4 shows the pictorial diagram, which is used to depict part of a system assembly related to the Arduino Micro chipset and Pressure sensor module.

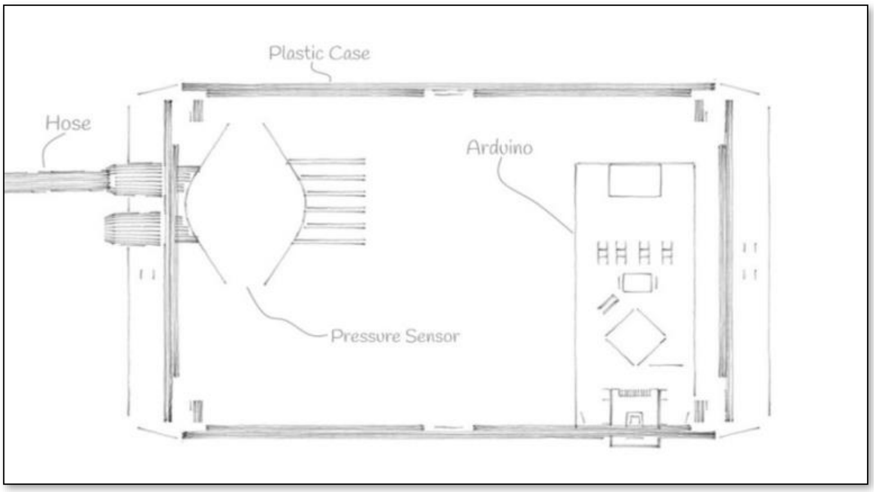

Figure 2
Device Sketch for the Proposed Application in This Research Work

3.1.3. Story Board and Graphical User Interface (GUI) Design

A storyboard is a crucial tool for communicating ideas in a visual format, especially for projects that involve creating mobile apps. It is a sequential collection of images that are snapshots or concepts of the final project. Figure 3a is the initial User Interface (UI) design of the proposed application in this research work.

Graphical User interface (GUI) design is a technique used by designers to develop user interfaces for electronic devices or applications that place a strong emphasis on appearance or style. Figure 3b is the final GUI system design which stands for the main functionalities that compose the whole system, including the home page, registration, user registration, and the actual functions of the system.

a b

Figure 3

a) Story Board for the Proposed Application in This Research Work, b) Application Design for the Proposed Application in This Research Work

3.2. Project Implementation

3.2.1. Software and Hardware Specification

Table 1 shows the used software and hardware, respectively, for developing the proposed system in this research work. The mobile application is developed in android studio and through the JAVA programming language. Arduino is programmed using MIDI Library in Arduino IDE. SQLite is applied to manipulate the data.

Table 1

Software and Hardware Specifications

Software Specification	
IDE/Operating System	Specification
Windows	64-bit version 8, 10, or 11
Android Studio	versions 2020.3.1 SDK version 2.7.0
Arduino IDE 2.0.1	versions 2.0.1
Programming language	Java
Database	SQLite
Hardware Specification	
Hardware	Specification
Computer	Core i3,5,7 HDD: 500GB RAM 4GB
Arduino boards	Leonardo /Micro ATmega32U4
Pressure Sensor	Module MPX5010DP
Pipe/Hose	Rubber Washer Hose

3.2.2. System Development Tools

a. Selected Programming Language: This project's application was developed through the Android development platform and Java programming language. Among the two most popular operating systems for smartphones that are Android and iOS, the Android operating system was chosen for developing this project due to its open-source attitude which allows developers to develop their applications at a free cost.

b. Database Requirements: This application will utilize SQLite as the required database. It enables developers to use a cloud-hosted NoSQL database that lets store and synchronize data between end users in real-time data at a global scale.

3.2.3. Requirements Elicitation and Specifications

a. Non-Functional Requirements:

- To guarantee a successful execution of the developed application, it is required to make it compatible with various Android devices available in the market, including their network bandwidth as well as application screen resolution in the market. If the application meets such requirements, it will function smoothly on all Android-powered devices and get better acceptance.

- Since this application connects to the network it must be able to connect to all sorts of networks, including 2G, 3G, 4G, and Wi-Fi.
- It must react to a variety of sensors that may attach to smartphones, including the fingerprint, accelerometer, rotation, iris scanner, and GPS. Gaining permissions depends on the functions that the program does.
- To use the application on Android smart devices, it must be able to obtain the permissions of device resources, and the user has to accept those permissions to start the application; otherwise, the application fails to complete the work.
- The applications that require large resources to work well will affect phone speed and drain the battery charge which can cause of damaging the smartphone. Therefore, the number of required resources must be restricted as much as possible.

b. Functional Requirements:

- Registration function which allows the user to create a new account.
- The user can access a window of choices at logon.
- Show the options menu for admin usage and allow admin login.
- A special page called “About Us” provides information about the features of the program.
- A separate page that explains details of the sections and their contents.
- The test page provides various levels of pulmonary tests for the user.
- Utilizing the different colors to indicate different breathing levels visually.
- Using an internal database that includes the patient records.
- Elegant and simple design for a unique user experience.
- The unique shape of the buttons to start the application.

3.2.4. Hardware Assembly for Spirometry

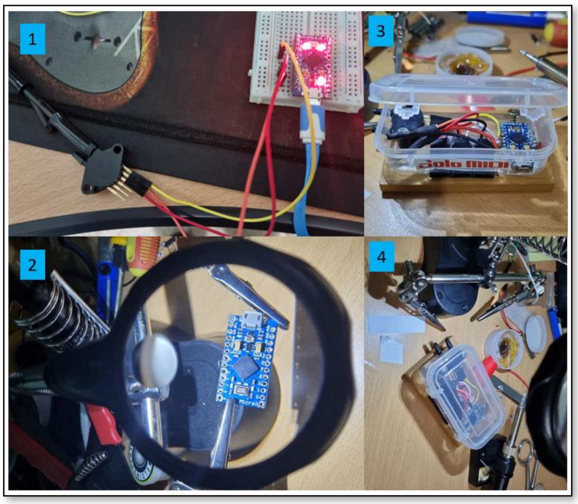

Figure 4
Assembly for Spirometry

Figure 4 shows the assembly steps of the hardware components. At first, the component assembly was done on the breadboard to make sure it works well. Then the pressure sensor soldered with the Arduino board by setting the pins A0, and 5V, of the Arduino.

3.2.5. Screenshots and Discussion of the Implemented Functions

As pointed out earlier, the mobile application is developed in the Android studio environment, using the JAVA programming language. Below are the screenshot taken of the various part of the implemented application, along with a brief discussion of the functionality defined for each.

Figure 5a is a screenshot taken of the designed ‘Home Screen’ page. When the user opens the application, the main screen appears with a simple design, having two options, log in and create a new account. Figure 5b shows the designed ‘Edit Profile Screen’. On the registration page, there are three fields, which are the username, email address, and phone number. The user must fill in these fields to be able to create a new account, and as shown in Figure 5b, if one of the fields is empty or the email already exists a warning message will appear to the user. Once the user finishes creating a new account, he will be transferred to the home page to sign in to the application. A screenshot taken of the Login Screen is shown in Figure 5c. If the email or password is wrong, an alert message will appear for the user. Otherwise, it will move to the main page, and the user’s email will appear at the top of the screen with a message indicating that the login has been successful. This page gives the user four options, which are logout, about the app, instructions, and test. Once the user presses the logout button as shown in Figure 5d he will log out and go to the main page. When the about app button is pressed, information about the application will be displayed. The GUI design of the ‘About Us Screen’ is provided in Figure 5e. When the instructions button is pressed, the application will display a video tutorial on how to use the device to measure spirometry as shown in Figure 5f.

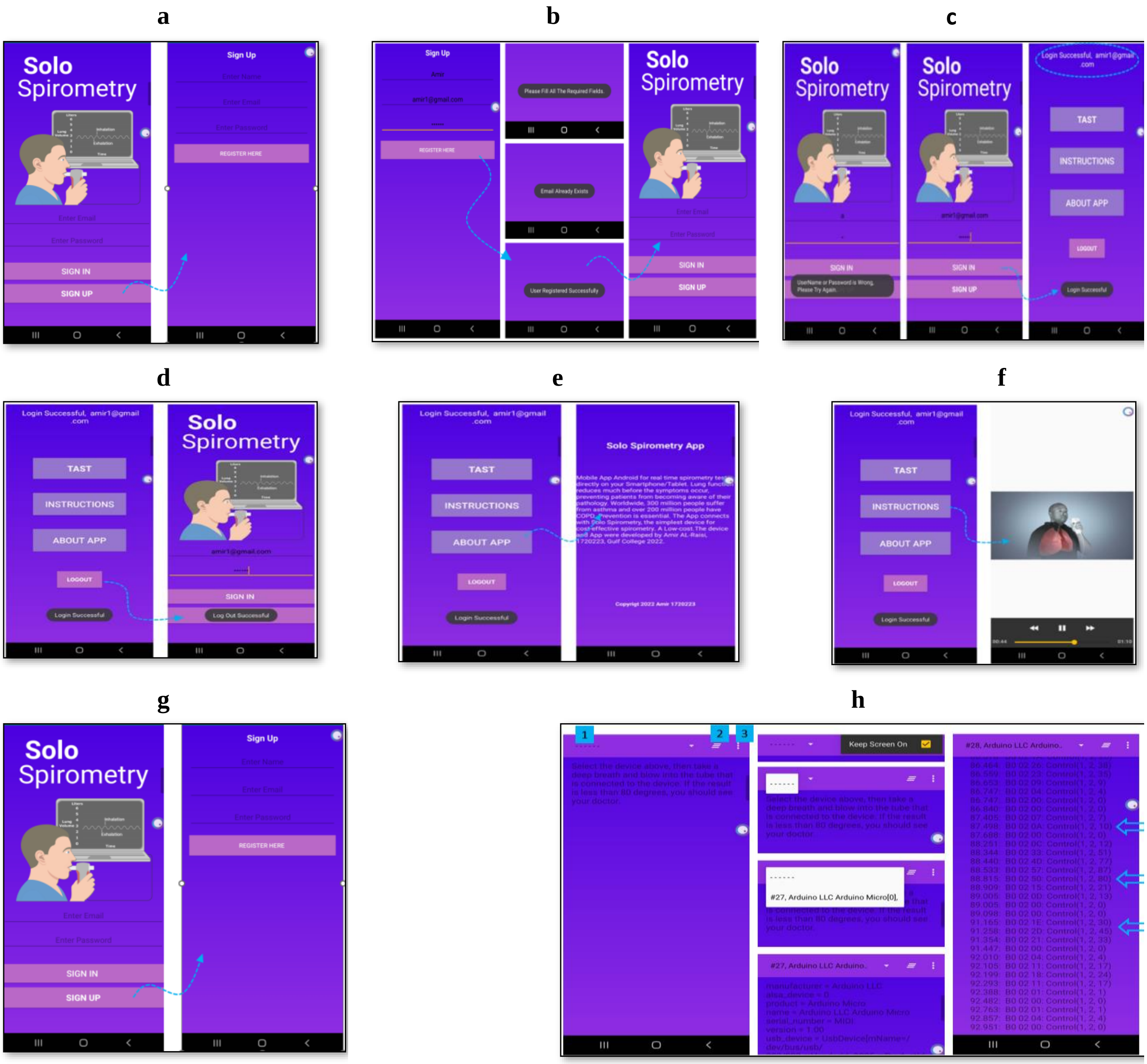

Figure 4

a) Home Screen, b) Edit Profile Screen, c) Login Screen, d) Logout Screen, e) About Us Screen, f) Instructions Screen, g) Test Screen, h) Results Screen

Finally, the main part of the application which works as a spirometry appears by pressing the test button. This button will navigate the user to the Spirometry page shown in Figure 5g, and once the page is opened, it will display some of the task steps before starting the test. The result screen shows in Figure 5h. At the top of this page, there are three options; the first is to choose the device, the second is to clear the screen, and the last option makes the screen work non-stop. Once the device is connected to the phone via a USB port, the device name appears at the top of the page, and when the user blows into the hose, the results appear directly on the screen.

4. Results

To test the performance and accuracy of the developed system, we applied alpha testing to all sections of the application. Test cases are reported in the rest of this paper.

4.1. Test Case 1: Testing Sign-up Option Provided on the Home Screen

Figure 5 is a screenshot taken of test case 1, visually describing the test result of the sign-up option on the app’s home screen. As can be seen, this option would navigate a new user to a registration page where a new account credential could be defined. The action taken by the tester, expected output, and actual output of this test case are reported in Table 2.

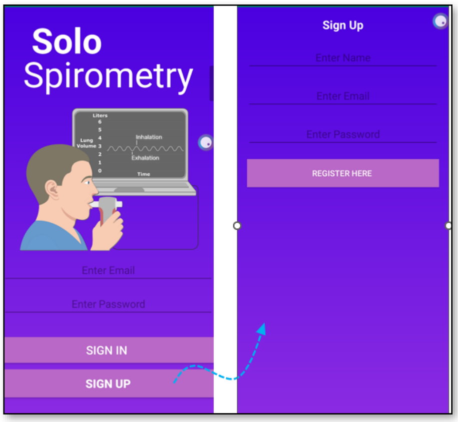

Figure 5
Test Case 1

Table 2
Test Case 1

Test Case 1				
Name- Menu Screen Functionality				
T. No	**Action**	**Expected Output**	**Actual Output**	**Remark**
1	Pressing sign up button	To navigate the user to the registration page	Clicking the sign-up button resulted in opening the registration page successfully.	Pass

4.2. Test Case 2: Creating a New Account Credential for Any New User

Figure 6 is a screenshot taken of test case 2, which visually describes the various test results of the application registration page. As can be seen, the application provides the right output to any valid or invalid input from the user. The action taken by the tester, expected output, and actual output of this test case are reported in Table 3.

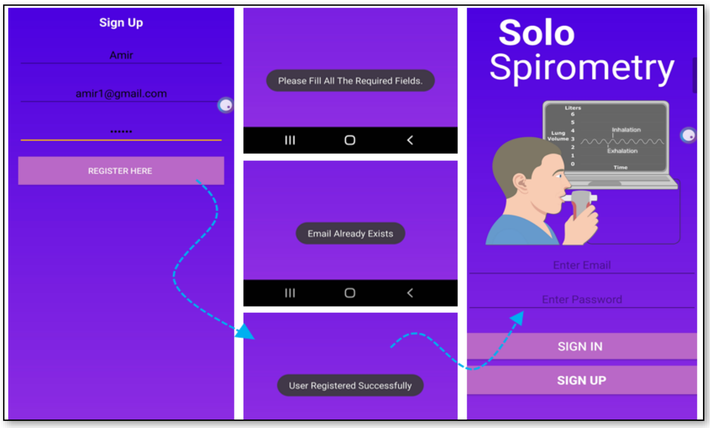

Figure 6
Test Case

Table 3
Test Case 2

Test Case 2				
Name- Registration Functionality				
T. No	**Action**	**Expected Output**	**Actual Output**	**Remark**
1	If the register button is pressed and one of the required fields is empty	To stop the user with a clear guidance message of filling the required fields.	A message appeared as “Please fill all the required fields”.	Pass
2	If the register button has been pressed and the email already exists	To stop the user with a clear guidance message of providing a valid email address.	A message appeared as “Email already exists”.	Pass
3	If the register button was pressed and the registration was successful	To confirm a successful registration, and then navigate the user to the Login Page.	A message appeared as “User registered successfully” The user navigated to the Login Page.	Pass

4.3. Test Case 3: Testing the Login page

Figure 7 is a screenshot taken of test case 3, which visually describes the various test results of the application Login Page. As can be seen, the application provides the right output to any valid or invalid input from the user. The action taken by the tester, expected output, and actual output of this test case are reported in Table 4.

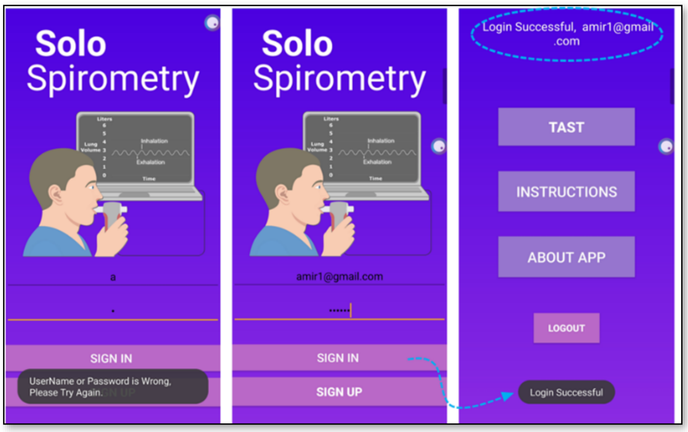

Figure 7
Test Case 3

Table 4
Test Case 3

Test Case 3				
Name- Login Functionality				
T. No	**Action**	**Expected Output**	**Actual Output**	**Remark**
1	If the login button is pressed and the username or password is incorrect	To stop the user with a clear warning message of the wrong username or password.	A message appeared as “Username or password is wrong. Please try again”.	Pass
2	If the login button is pressed and the username and password are correct	To confirm a successful Login, and then navigate the user to the Main Page.	A message appeared as “login successful”. The user navigated to the Main Page.	Pass
3	Trying the system with another valid account credential	To confirm a successful registration, and ten navigate the user to the Login Page.	A message appeared as “login successful”. The user navigated to the Main Page.	Pass

4.4. Test Case 4: Testing the Logout Option on the Main Page

Figure 8 is a screenshot taken of test case 4, which visually describes the test result of clicking the Logout option on the app's Main page. As can be seen, the application logout the user successfully once the user clicks this option. The action taken by the tester, expected output, and actual output of this test case are reported in Table 5.

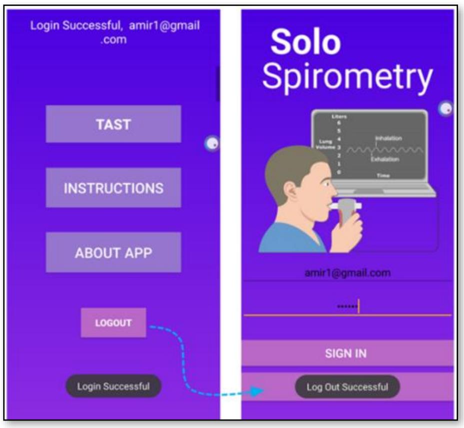

Figure 8
Test Case 4

Table 5
Test Case 4

Test Case 4				
Name- Logout Functionality				
T. No	**Action**	**Expected Output**	**Actual Output**	**Remark**
1	If the logout button is pressed	To log out the user, and show a message of the successful logout and back to the sign-in page.	The user logged out, and a message appeared as "logout successful". The user backed to the sign-in page.	Pass

4.5. Test case 5: Testing the About App option on the Main page

Figure 9 is a screenshot taken of test case 5, which visually describes the test result of clicking the About App option on the app's Main page. As can be seen, the application navigates the user to the About app page successfully once the user clicks this option. The action taken by the tester, expected output, and actual output of this test case are reported in Table 6.

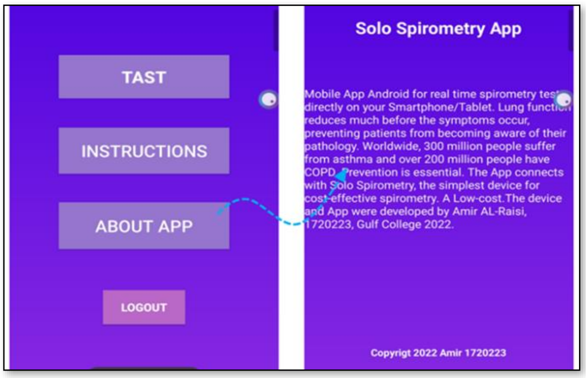

Figure 9
Test Case 5

Table 6
Test Case 5

Test Case 5				
Name- About App Button Functionality				
T. No	**Action**	**Expected Output**	**Actual Output**	**Remark**
1	If the About app button is pressed	To navigate the user to the About App page	The user navigated to the About app page.	Pass

4.6. Test case 6: Testing the Instruction Option on the Main Page

Figure 10 is a screenshot taken of test case 6, which visually describes the test result of clicking the Instruction option on the app's Main page. As can be seen, the application navigates the user to the Instruction page, where an animation video is provided to guide the user on how to use the app. The action taken by the tester, expected output, and actual output of this test case are reported in Table 7.

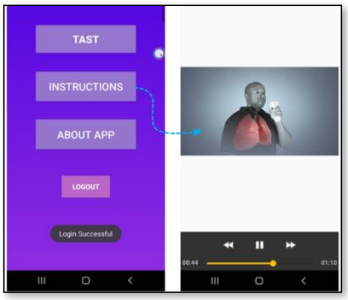

Figure 10
Test Case 6

Table 7
Test Case 6

Test Case 6					
Name- Instructions Button Functionality					
T. No	**Action**	**Expected Output**	**Actual Output**	**Remark**	**Date**
1	If the Instructions button is pressed	To navigate the user to the instruction page and enable the user to watch the animation illustrating how using the app	Instructions page opens	Pass	15-6-22

4.7. Test case 7: Testing the Instruction Video on the Instruction Page

Figure 11 is a screenshot taken of test case 7, which visually describes the test result of the video performance provided on the app's Instruction page, which guides users about how to use the app. As can be seen, the video's play, stop, skipping forward, and skipping backward options are all working well. The action taken by the tester, expected output, and actual output of this test case are reported in Table 8.

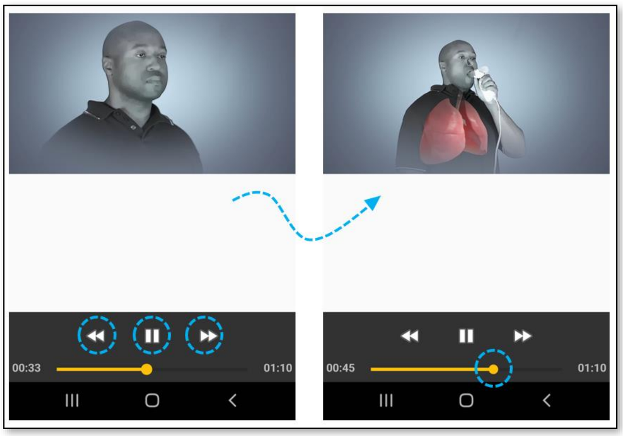

Figure 11
Test Case 7

Table 8
Test Case 7

Test Case 7				
Name- Video Controls Functionality				
T. No	**Action**	**Expected Output**	**Actual Output**	**Remark**
1	If the play button is pressed	Provided video to be played	The video played	Pass
2	If the pause is pressed	Provided video to be stopped	The video stopped	Pass
3	If skip forward is pressed	Provided video to be skipped forward	The video skipped forward	Pass
4	If skip backward is pressed	Provided video to be skipped backward	The video skipped backward	Pass

4.8. Test Case 8: Testing the Pulmonary Test Function

Figure 12 is a screenshot taken of test case 7, which visually describes the test result of the pulmonary test function provided on the Main page. As can be seen, the application navigates the user to the spirometry/pulmonary test function once this option is selected. The action taken by the tester, expected output, and actual output of this test case are reported in Table 9.

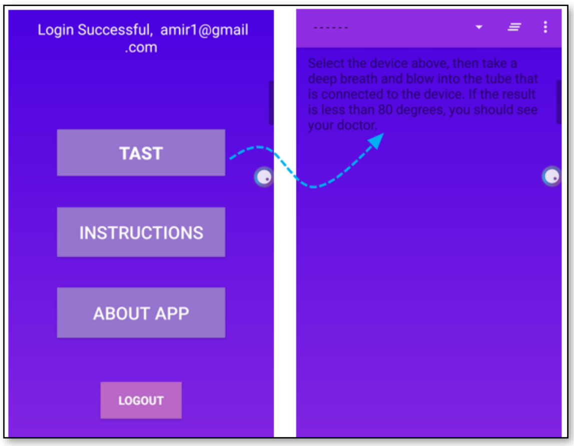

Figure 12
Test Case 8

Table 9
Test Case 8

Test Case 8				
Name- Test Button Functionality				
T. No	**Action**	**Expected Output**	**Actual Output**	**Remark**
1	If the test button is pressed	To navigate the user to the pulmonary test section of the app.	The user navigated to the pulmonary test section of the app.	Pass

4.9. Test Case 9: Testing the Options Provided in the Pulmonary Test Function Page (Making Screen On)

The “Three vertical dots → (⋮)” option (highlighted in Figure 13) was added to protect the screen from switching off during the test. Once the user clicks it, the “Keep Screen On” option will be activated which makes the mobile screen ready for the test. Figure 13 is a screenshot taken of test case 9, which visually describes the test result of the “Three vertical dots → (⋮)” provided on the pulmonary test function. The action taken by the tester, expected output, and actual output of this test case are reported in Table 10.

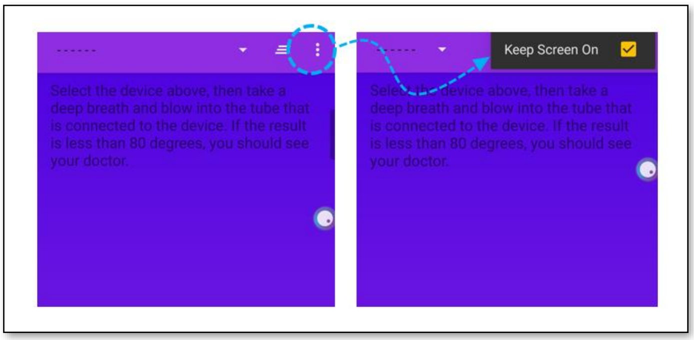

Figure 13
Test Case 9

Table 10
Test Case 9

Test Case 9				
Name- Keep Screen on Functionality				
T. No	**Action**	**Expected Output**	**Actual Output**	**Remark**
1	If the three-dot menu is pressed	To “Keep Screen on” appears, and protect the mobile screen from switching off during the test.	The option “Keep screen on” appeared and kept the screen on.	Pass

4.10. Test case 10: Testing the Options Provided in the Pulmonary Test Function Page (Clearing the Screen)

The “Horizontal lines → (≡)” option (highlighted in Figure 14), was added to clear the screen and prepare the page for the pulmonary test report. Once the user clicks it, the screen will be cleaned and ready to show the pulmonary test function report. Figure 14 is a screenshot taken of test case 10, which visually describes the test result of the "Horizontal lines → (≡)" provided on the pulmonary test function. The action taken by the tester, expected output, and actual output of this test case are reported in Table 11.

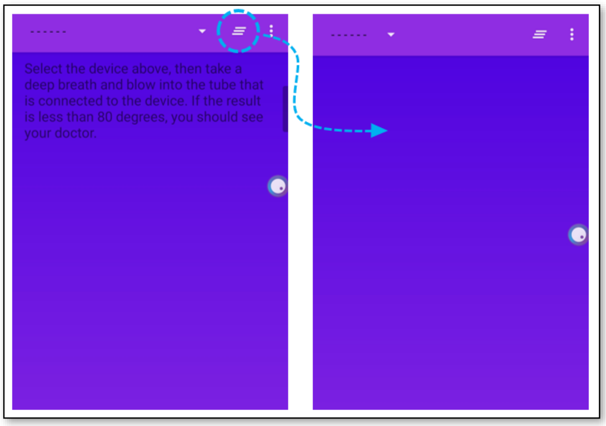

Figure 14
Test Case 10

Table 11
Test Case 10

Test Case 10				
Name- Clears The Screen Functionality				
T. No	**Action**	**Expected Output**	**Actual Output**	**Remark**
1	If horizontal lines are pressed	To clear the screen and make the page ready for the pulmonary test function report	The screen cleared.	Pass

4.11. Test case 11: Testing the Options Provided in the Pulmonary Test Function Page (Hardware Connection)

The "Dash line option → "(`````)" embedded in the top left side of the screen (highlighted in Figure 15) was added to test the hardware connection. Once the user clicks it, the name of the hardware connected to the device will appear in the case of the right connection. Figure 15 is a screenshot taken of test case 11, which visually describes the test result of the "Dash line option → (```````)" provided on the pulmonary test function. The action taken by the tester, expected output, and actual output of this test case are reported in Table 12.

Figure 15
Test Case 11

Table 12
Test Case 11

Test Case 11				
Name- Connect the Device Functionality				
T. No	**Action**	**Expected Output**	**Actual Output**	**Remark**
1	Pressing the "Dash line option → (```````)"	To show the hardware name connected to the mobile device in the case of the right connection	The device name appeared when the device was connected correctly.	Pass

4.12. Test Case 12: Testing the Pulmonary Test Function Report

Figure 16 is a screenshot taken of test case 12, which visually describes the test result of the testing of the pulmonary test function report provided on the pulmonary test function page. As can be seen, clicking the name of the device provides the attribute of the device, and blowing on the connected pipe connected to the mobile (Hardware side) will generate the report of the pulmonary test function. The action taken by the tester, expected output, and actual output of this test case are reported in Table 13.

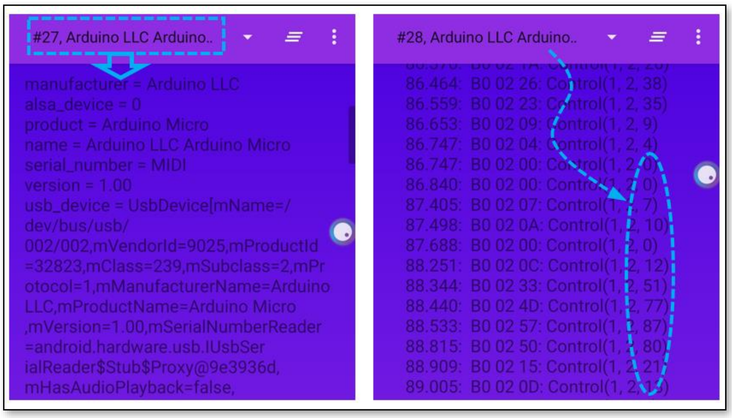

Figure 16

Test Case 12

Table 13

Test Case 12

Test Case 12				
Name- Connect the Device Functionality				
T. No	**Action**	**Expected Output**	**Actual Output**	**Remark**
1	Clicking the name of the device at the top left side of the screen	To appear the device attributes	The device attribute appeared	Pass
2	Blowing to the pipe connected to the device	Pulmonary test function to be reported	The report generated	Pass

5. Discussion

Computerized approaches, due to their abilities, are able to facilitate and optimize the healthcare industry and businesses smartly and responsively. Information technology provides fast and reliable solutions for medical procedures (Paul et al., 2023). Mobile applications and cloud-based solutions as part of these technologies are continuously used in the healthcare industry and businesses due to their numerous advantages, such as operational cost reduction, enabling remote communication, simplifying medical approaches, increasing accuracy, providing efficient time management, and everything in between (Ventola, 2014). These help clinics, hospitals, and medical centers save a huge amount of funds. Not only the medical centers get profit from the advantages of such technology, but mobile solutions could also provide enormous benefits for patients by reducing healthcare costs in terms of money and time (Divall, 2013).

The outcome of this project is a novel mobile-based application called ‘Solo’, which is designed and implemented for diagnosing diseases such as asthma and COPD. This application can help patients who are treated for chronic lung diseases, such as COPD, asthma, or pulmonary fibrosis, to check out the progress of the applied medications to the disease without visiting the hospitals or clinics. The proposed method has utilized a combination of hardware, software, and cloud-based database technology to design and implement a simple way of pulmonary function test. Furthermore, this application can be useful in testing lung function before commencing surgery. This application enables doctors to check and monitor their patients remotely in case of connecting the device to hospital systems.

Experimental results prove this application is a successful and low-cost method for measuring respiratory rate that aids in the diagnosis of acute and chronic lung diseases. Tracking such vital health data at home, enabling online access to digital records, and providing remote communication with medical practitioners are some of the attitudes of this app that provide patients with a cost-effective solution for managing their healthcare expenditure. Besides, maintaining digital records of patient information in the cloud has provided a cost-effective storage solution for healthcare centers, unlike the costly record-keeping method of server-based databases.

Utilizing cloud technology in the industries and services controlled by the government could save even more money based on the organization's scale and the extent of internal activities. Cloud-based storage typically includes recovery and backup attributes that provide a high-quality level of protection and security in case of any system failure or attempt of a security violation, such as a data breach, which will minimize the investment in damage control remarkably (Kaur et al., 2014; Rashid et al., 2019).

Future research may focus on improving the quality of breathing signal readings, utilizing more accurate pressure sensors or functionalities if applicable. Furthermore, the developed project might be extended to the next level by proposing and connecting it to the clinic and hospital systems where its remote's benefits attitudes could be fully utilized.

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