Development of Portable Electronics Incentive Spirometer for Patients Recovering from COVID-19 for Nakhon Nayok and Sa Kaeo Province Community

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Abstract: - After the COVID-19 pandemic, there has been an increasing demand for simple respiratory rehabilitation tools to assist patients in their recovery process. Among these tools, incentive spirometry is important in helping lung function and preventing complications such as pneumonia and atelectasis. Nevertheless, traditional spirometers are often bulky and confined to hospitals. These spirometers are not practical for home use which reduces patient safety and access to treatment. The development of a portable electronic incentive spirometer is specifically designed for patients recovering from COVID-19 in Thailand. This device contains small sensors, special microcontrollers, and a user interface with real-time measurements of inspiratory volume. It provides appropriate breathing techniques to Nakhon Nayok and Sa Kaeo patients. The spirometer has a wireless connection from the device to the main operator, allowing healthcare workers to monitor remotely and assist in telemedicine operations. With design refinements and volunteer user feedback, this portable electronic spirometer proposes an accessible and efficient solution for respirational rehabilitation in the post-COVID-19 era. Furthermore, the device can support patient engagement and improve clinical outcomes.

Key-Words: - COVID-19, Lung function, Small sensors, Microcontroller, Spirometer, Telemedicine operation, Patient engagement, Good health and well-being

Received: April 7, 2024. Revised: October 12, 2024. Accepted: November 13, 2024. Available online: December 17, 2024.

1 Introduction

The use of an incentive spirometer to test respiratory function is important to the diagnosing process. Typically, spirometers are large, immobile devices found mostly in hospital settings. However, recent advances in electronics and computer technology, especially medical sensor technology, have led to the development of portable spirometers. This development has many advantages such as accessibility, usability, and involvement for patients with long-term COVID-19.

The Portable Electronics Spirometer (PES) is an example of advancement in respiratory health monitoring since it is compact and user-friendly which allows people to perform lung exams at home, at work, or anywhere. The main aspects of the PES include the small size, simple user interface, and wireless connectivity. When the spirometer is used, the device is connected to a smartphone or other devices to transfer data to the physician or medical professionals in real-time. This method can save time and processes in predicting and diagnosing the problem by allowing the patient to look at the results and simultaneously send the results to the physician. These lung function results are important for patients who have chronic respiratory disease or cardiovascular problems [1], [2], [3]. Moreover, the patients do not need to go to the hospital often if they use the Electronic Spirometer [4]. Therefore, the patients have the freedom to use the spirometer themselves and monitor as well as track the outcome of the test anywhere and anytime.

2 Methodology

2.1 Conceptual Design

The objectives of the design are as follows:

Firstly, the spirometer is designed to enable an accurate measurement of lung function parameters such as Forced Expiratory Volume (FEV1), Forced Vital Capacity (FVC), and Peak Expiratory Flow Rate (PEFR). We use precise sensors and reliable calibration mechanisms for this high accuracy.

Secondly, the device is designed to be compact and portable. The spirometer is small and lightweight. The users can carry them anywhere for outdoor activities. The materials used are light materials with compact structured component arrangements.

Thirdly, the battery life must be long-lasting and can be operated without the need for frequent recharging or replacement. Fourthly, the user interface must be user-friendly and easy to use for the elderly or any layperson. Fifthly, easy data connectivity is an important design feature in which the spirometer is connected via Bluetooth or Wi-Fi to allow for easy data transfer and storage in Electronic Health Record (EHR) systems.

Sixthly, the design purpose concerns durability. The materials used must be strong enough to survive heavy usage, hazardous environmental risks as well as accidental falls. The seventh goal is safety. Safety measures such as disinfectant-resistant surfaces and compliance with medical device regulations are very important for patients. The eighth is the calibration capacity. The spirometer must have a user-friendly calibration process. The ninth is compliance with medical device standards. Any medical device must comply with specific regulatory requirements and standards such as FDA approval in the US or CE marking in the EU.

Having had the design objectives above, the electronic spirometer enables users to exercise the lungs, promote correct techniques, and give a positive user experience. This special electronic spirometer can also be connected to any health platform. With all the above, the device is compatible with current health monitoring systems and mobile applications. It will enable easy integration into users' daily routines to manage and monitor their health. Another advantage of the spirometer is its long operating lifespan with low battery consumption. This will make maintenance and repair easier for end users and allow them to do some simple preventive maintenance.

2.2 Product Design and Development

2.2.1 Hardware Design and Creation

This research divided the format for installing sensors to receive small electrical signals with a wavelength of 632.80 nm into two formats. The number of sensors was installed according to all three groups, each installed independently and using an Arduino microcontroller. The input signal received from the sensor will be digital. When the laser light hits, it will receive a logic of "1", which is 5 volts, when the three balls move through the sensor installed outside the plastic tube of the spirometer. The sensors on the three tubes will have three pulse signals from the sensors and feed these signals to the preamp circuit that amplifies the signal 100 times, as shown in Figure 1, [5].

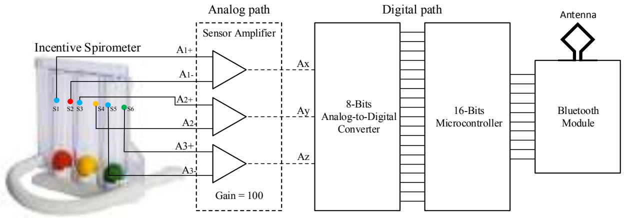

Fig. 1: The concept of sensor placement is as a group of three weak points on a spirometer

The concept of positioning the sensors is based on the ball's highest point rising to the highest point of the spirometer device, as shown in Figure 1 and Figure 2, which will position three sensors with a diameter of approximately 6/8"—divided into three groups, including a total of 18 sensors installed, consisting of nine LDRs receiving sensors and nine photodiodes transmitting sensors. Because of the low output voltage (50 mV), amplifying the signal to 5 Volts is necessary. The analog signal is then converted to a digital signal by the 8-bit analog-to-digital converter. Then, the signal is fed to the 16-bit microcontroller for processing and communication via Bluetooth to Smartphone.

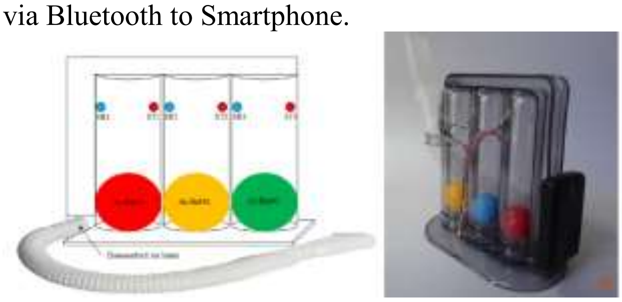

Fig. 2: The installation of sensors on the three plastic tubes of the spirometer

Using the LF353, the signal can be amplified to gain 100 times to 5 Volts. However, for converting signals from Analog to Digital signals, a microcontroller board with an 8-bit A-to-D converter circuit is used. It accepts 8 Analog inputs each, as shown in Figure 3 and Figure 4.

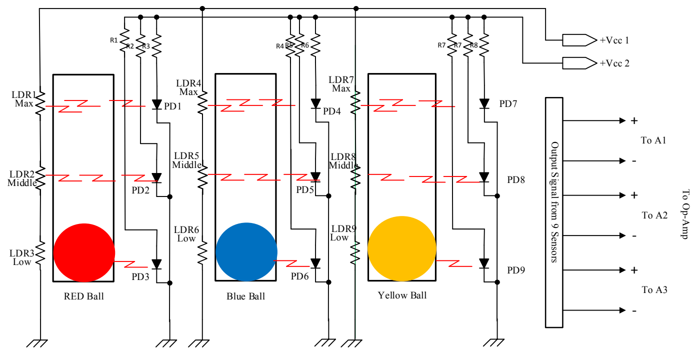

Fig. 3: All sensors send a 50 mV electrical signal to the voltage preamp circuit

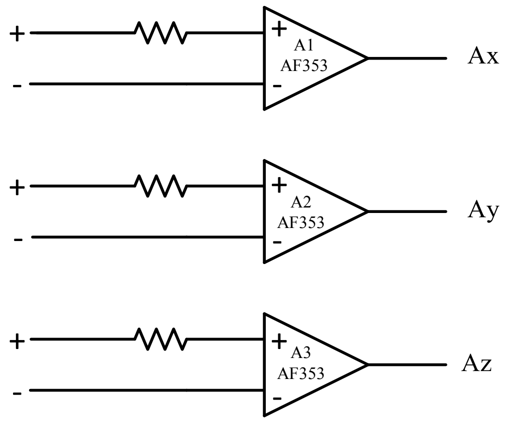

Fig. 4: The input of the circuit preamp will receive the signal from the sensors to provide a voltage gain of 100 times

Figure 4 illustrates the design and development of a circuit to amplify the voltage signal received from LDR sensors to have an amplification rate of 100 times (the input of the circuit preamp will receive the signal from the sensors to provide a voltage gain of 100 times or amplifier from 50 mV into 5V at output of all Integrated Circuit, IC) using a MOSFET IC No. LF 353. This component is used because it is a Low Noise Amplifier IC with low power consumption, [4]. This device prepares the output to be fed into the circuit to convert the signal from an analog to an 8-bit digital signal, as shown in Figure 5.

Once the Analog signals (Ax, Ay, and Az) are received from the preamp circuit in Figure 4, they are converted into digital signals. The microcontroller module processes the signals and sends them to the smartphone with a 2.47 GHz Bluetooth module. This type of IC can receive up to 36 channels of Analog signal input by the system's operation, [6]. When the signal is received, the sensor amplifier circuit converts the signal into a digital signal to be fed into the microcontroller. The working flowchart (Block Diagram) in Figure 5 shows that the computer program will process and display the signal results and record them on a storage memory card (Secure Digital Card, SD Card) using an Arduino microcontroller.

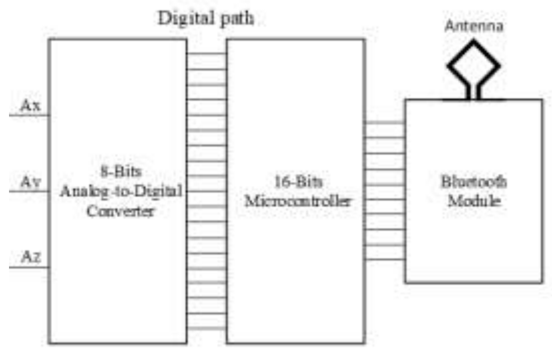

Fig. 5: Analog to digital signal conversion Circuit

2.2.2 Microcontroller Platform

In this research, we used a particular microcontroller consisting of two main parts. The first part is the Arduino module, a piece of hardware. When we create our own object-oriented, the second part is Arduino software, which we use on the computer/notebook. We use the Arduino IDE to code the sketch program, which we upload to the Arduino module. This is normal when making hardware applications for all circuits, especially wired circuits. When making changes to the circuit, we have to waste time cutting wires or cutting copper wires to connect the solder. Digital technology and microprocessors, whereby these functions that were once performed on wires, have been replaced by software programs. The circuit that the research team designed and developed uses one Arduino module. However, this circuit still consumes up to 120 mA, and the battery will run out very quickly because there is still an active device, namely a transistor, which still consumes high current, [7], [8]. In addition, the size of the circuit board is significant (not suitable for actual use). Therefore, we designed the sensor circuit to leave only the sensor and one resistor in each group using only a single Arduino module. Then, we wrote a program for the Arduino to receive values. The required number of Analog inputs is eighteen. The circuit consumes only 6mA of current, as shown in the circuit in Figure 6.

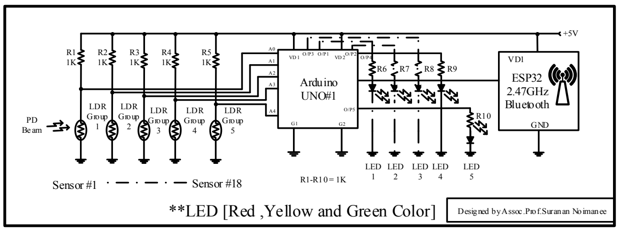

Fig. 6: A new overall circuit that uses no transistors or capacitors

2.2.3 Software Platform

The program receives the name, date of birth, weight, height, and gender according to the designed flow chart, which receives patient information and sets breathing goals according to the characteristics of each patient, the operation algorithm of the lung exercise machine or electronic spirometer as shown in Figure 7. The operations are as follows:

a. The patient connects the mouthpiece to a cylindrical spirometer equipped with a cylindrical sensor.

b. The patient takes a deep breath and slowly exhales into the cylinder with the sensors installed. The device detects airflow and converts it into an electrical signal using a flow sensor.

c. Electronic spirometers measure the air a patient breathes in and out and display the results on a smartphone's screen.

d. The software reviews the results and determines whether the patient's lung function is adequate. The device records the patient's inhalation and exhalation data and stores them in memory.

e. If the patient's lung function is insufficient, your healthcare provider may recommend treatment or additional treatments to help improve your lung function.

f. The patient continues to use the electronic spirometer regularly, as the doctor has advised. This is to monitor progress and ensure lung function improves. If the patient achieves the specified exhalation goal, the device will emit an audible alarm or generate a visual signal to signal test success.

g. The patient may repeat inhalation and exhalation as often as directed by the physician or therapist.

h. Patients can view their progress over time by accessing data stored on the device.

i. The patient removed the device and turned it off after the test.

j. End of the experiment.

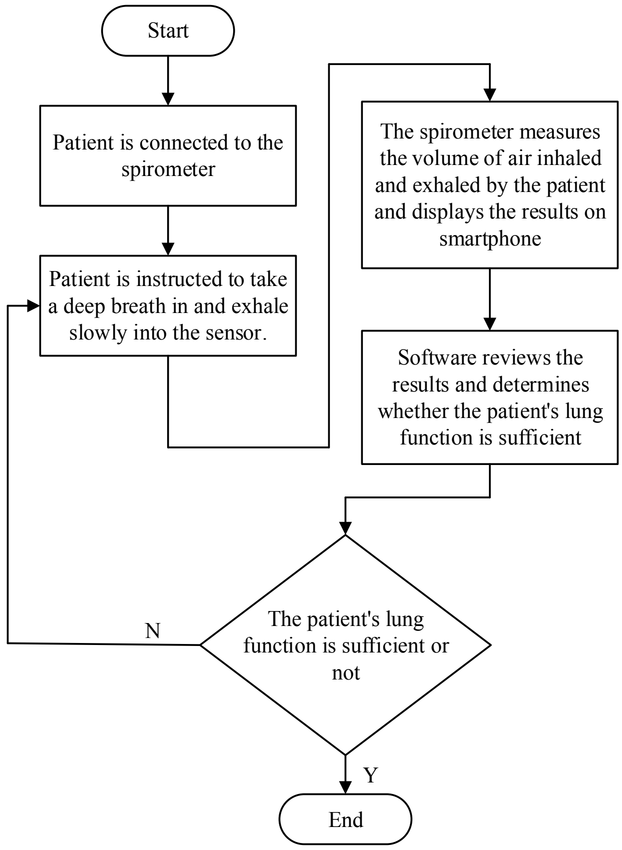

Fig 7: Overall working diagram of the electronics spirometer device

3 Results and Discussion

Testing the functionality of lung exercise equipment or electronic pyrometer equipment is done by installing a total number of sensors. To receive light, 18 sensors must be completed first. As mentioned above, nine laser light sensors must be installed and divided into three groups. Ready to transmit data in hexadecimal format from the ESP32 Bluetooth board to a smartphone, the smartphone will analyze the breathing rate and the lungs' strength by measuring the height of the three colored balls. The destination must install the application program named Bluetooth 2.apk before it can connect to the sensor on the spirometer. When Bluetooth is connected to the smartphone with all 18 sensors, the program developed by the researcher can be opened, and the working menu can be selected by selecting the Bluetooth device connected to it. The Arduino board is connected first. After that, it can be used automatically next time.

When the patient/user blows or sucks on the spirometer device, the three balls will gradually rise. So, the three balls cut off the light sent from the PD to the LDR sensor, and the LDR sends a signal to the smartphone and displays it.

Fig. 8: The first volunteer is suctioning on the electronics spirometer

Fig. 9: The second volunteer is suctioning on the electronic spirometer

(a) (b)

Fig. 10: The volunteers are suctioning on the electronic spirometer. (a)The third volunteer, (b)The fourth volunteer

Fig. 11: The fifth volunteer is suctioning on the electronic spirometer

Fig. 12: The sixth volunteer is suctioning on the electronic spirometer

Fig. 13: The seventh volunteer is suctioning on the electronic spirometer

Fig. 14: The eighth volunteer is suctioning on the electronic spirometer

Fig. 15: If the volunteer stops exercising the lungs, the three balls will fall back down to the same level

Referring to Figure 8, Figure 9, Figure 10, Figure 11, Figure 12, Figure 13, Figure 14 and

Figure 15, the results of the different volunteers demonstrated that lung function is normal with different values of lung function parameters. The range of the values is within the normal ranges.

4 Conclusions

The development of an electronic spirometer device is significant for managing the lungs of patients after they recover from COVID-19 because patients themselves will know whether they have been cured or continue to have Long-Term COVID-19; biomedical engineering researchers must work hard to design and implement it. It is important for patients who are recovering from COVID-19. Long-term Coronavirus syndrome, also known as post-acute sequelae of SARS-CoV-2 infection (PASC), is a condition in which patients experience symptoms that continue long after initial COVID-19 infection. Even if the patients are well, this is to consider whether the patient has long-term COVID-19 disease or not. Recent research has demonstrated many exciting findings and considerations that may come from the initial COVID-19 infection [9]:

a. Persistence of symptoms: If a patient continues to experience symptoms related to COVID-19, such as fatigue, shortness of breath, joint pain, or brain fog. for weeks or months after the initial infection, it may indicate long-term COVID-19. These symptoms can persist even after the acute phase of the illness has passed.

b. Diagnostic criteria: No universally diagnostic criteria for long-term COVID-19 are accepted. However, researchers and healthcare providers may use guidelines like those from the National Institutes of Health (NIH) or the Centers for Disease Control and Prevention. Disease Control and Prevention (CDC) has measures to help identify and characterize the condition.

c. Clinical Assessment: Healthcare providers conduct a thorough assessment of patients who report ongoing symptoms. This may include a physical examination to rule out other possible causes and assess symptoms' severity and impact on daily life. Laboratory tests, imaging studies, and other diagnostic procedures are also used.

d. Patient History: A detailed patient history is essential in diagnosing long-term COVID-19.
The healthcare provider asks about symptoms, their duration, and progression. This includes risk factors or comorbidities that may affect symptoms.

e. Exclusion of other conditions: Long Covid-19 is an exemption diagnosis. This means that other possible explanations for the symptoms must be ruled out. Healthcare providers may investigate other medical conditions that may cause similar symptoms, such as chronic fatigue syndrome. Postural orthostatic tachycardia syndrome (POTS) is an autoimmune disorder or mental health condition.

f. Follow-up care: patients who have recovered from COVID-19 need the following up. Acute cases may undergo periodic follow-up evaluations with a healthcare provider to track their symptoms and overall health status. Continuous monitoring allows for continued long-term assessment and management of COVID-19 symptoms.

g. Research studies: Researchers are conducting studies to understand the long-term effects of COVID-19, improve them, and identify patterns and risk factors related to long-term COVID-19. Participating in such studies can help advance knowledge and understanding of this condition. It is important to note that our understanding of long-term COVID-19 is still evolving. Healthcare providers and researchers continue to study the causes, risk factors, and optimal management strategies. If there are continued symptoms after the COVID-19 infection, one must seek medical advice for proper evaluation and management.

Therefore, the development of electronic lung exercise equipment is only creating a tool for patients to know their status and how many disease symptoms they still have. The strength of the lungs will determine this. For the hardware side, the researcher used the device as a model. The surface mount makes the device's size smaller and allows it to fit a printed circuit board (PCB) under the base of the spirometer. The direction for future research can be divided into the hardware side to make it smaller, e.g. a hand-held device. The application can be developed further for the software to use Artificial Intelligence (AI) to predict or uncover underlying diseases or symptoms. Technological advancements during the COVID-19 pandemic can be seen in many applications, including the design of a hybrid drone system to measure human body temperature, [10]. Such advanced development is another example of COVID-19-related research.

For future work, hardware should be developed further to make it affordable. The working part of the entire circuit has a current consumption rate of only 5.5 mA, equivalent to 27.5 mW of electrical power at a direct current voltage of 5 volts only. The experiment using a 0.5Ah battery enabled the transmission of data while being used by the patient; the maximum number is 12,000 times. The circuit under this device's base can be used for approximately 240 hours or ten days.

Acknowledgments
The author would like to thank Strategic Wisdom and Research Institute Srinakharinwirot University and the financial support from the Faculty of Engineering, Srinakharinwirot University, through the research grant No. 202/2023 acknowledged.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the authors did not use AI tools/services. The authors reviewed and edited the content themselves and took full responsibility for the content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Wongwit Senavongse conceptualized the study and research design, carried out the literature review and theoretical framework development, and performed statistical analysis of collected data, data analysis, and interpretation. He also took care of project administration and funding acquisition.
- Suranan Noimanee organized the experimental protocol, hardware integration, and testing, executed the experiments, refined the methodology and validation as well as software development, manuscript drafting, and revision.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

Financial support was received from the Faculty of Engineering, Srinakharinwirot University, through the research grant No. 202/2023 acknowledged.

Conflict of Interest

The authors have no conflicts of interest to declare.