ICIC Express Letters
Part B: Applications
Volume **15**, Number **5**, May **2024**

ICIC International ©2024 ISSN 2185-2766
pp. 515–523

APPLICATION OF INTERNET OF THINGS (IOT) FOR MONITORING OF THE FLOW INCENTIVE SPIROMETER

Naratorn Sangprasert, Keerati Inthavisas* and Kitisak Wattanakul

Department of Computer Engineering
Rajamangala University of Technology Srivijaya
1 Ratchadamnoennok Rd., Boyang Sub-district, Muang District, Songkhla 90000, Thailand
{ naratorn.s; kitisak.w }@rmutsv.ac.th
*Corresponding author: keerati.i@rmutsv.ac.th

Received September 2023; accepted November 2023

Abstract. *The pervasive nature and significance of Internet of Things (IoT) technology in routine existence are generally acknowledged. This research explored the use of IoT in monitoring and inspecting physical therapy activities of patients who have undergone thoracic or abdominal surgery, focusing on the application of IoT on a flow incentive spirometer. A laser distance sensor was utilized to measure the distance from the ball in the flow incentive spirometer during the research. The data was processed by the Node MCU 8266 V2 microcontroller to convert the distance into air flow rate (mL/s). Subsequently, the data was transmitted over the Internet and stored in a database. The calibration test confirmed the accuracy of the results, making them suitable for flow rate measurement. The experiment yielded an accuracy rate of 100% when comparing manually recorded values to those reported on our application page, over a total of 690 instances. To assess the efficacy of physical therapy using the flow incentive spirometer, particularly for patients, the system generates a summary report of basic statistical data and sends a daily Line sticker to them as a means of motivational enhancement.*
Keywords: Internet of Things, Incentive spirometer, Node MCU, Distance sensor

1. **Introduction.** Cardiovascular diseases are the primary cause of morbidity and mortality on a global scale, with a notable increase in occurrence and prevalence in low- and middle-income countries (LMICs). Recently, over 18 million people die each year from cardiovascular disorders; however, predictions show that number might rise to nearly 20 million by 2025 [1]. In the treatment of cardiovascular disease, patients typically undergo surgery, which can result in significant pain and anxiety. These factors can contribute to difficulties in movement for the patients. A decrease in patient mobility can lead to impaired functioning of the respiratory system. Furthermore, it is observed that cilia within the respiratory tract exhibit a tendency towards suppression. The condition leads to phlegm congestion [2] due to impaired lung expansion, resulting in restricted deep breathing and diaphragmatic dysfunction. As a result, patients may encounter a diminished ability to eliminate sputum as a consequence of their limited capacity to effectively expel sputum from surgical incisions. It is important to acknowledge that there is a possibility of lung infections [3].

Pulmonary exercise is recommended for patients who have undergone thoracic or abdominal surgery in order to facilitate a quicker recovery and reduce the risk of complications [4]. During the exercise period, patients are required to engage in independent practice without any assistance from others. The permissible tasks for assistants include providing guidance and coaching on breathing techniques, as well as organizing and coordinating physical activities for patients [2]. In order to facilitate the exercise of the lungs, medical professionals commonly employ a device known as an incentive spirometer. This

DOI: 10.24507/icicelb.15.05.515

tool assists individuals in practicing and enhancing their breathing abilities. The incentive spirometer is a device employed to augment lung capacity by a simple, self-administered, and safe method [5]. Physicians frequently endorse the use of the incentive spirometer as a preferred tool for patients undergoing physical therapy, citing its higher efficacy in comparison to alternative approaches.

One of the primary challenges associated with the utilization of incentive spirometers is the tendency of patients to neglect their prescribed lung exercise program. This neglect can lead to the development of more severe issues, such as a collapsed lung and other related complications. This research aims to integrate IoT technology into the design and development of a conventional spirometer. The objective is to enable the monitoring and display of data for patients, medical personnel, and family members of patients. The parties concerned will have access to monitoring and data recording services [6-8]. As a result, the patients will derive the greatest benefit from enhanced rehabilitation.

Several research studies have been conducted in relation to our proposed system. In [9], the authors proposed an algorithm designed to address the issue of sample extrusion phenomenon in the IoT system. This phenomenon occurs when a sample collected by the source node is not fully transmitted to the base station due to being stored in the buffer, and the source node subsequently collects a new sample. The algorithm utilizes a greedy strategy to effectively gather data from multiple source nodes by taking account of both the Age of Information (AoI) and sample extrusion. The results of simulation experiments demonstrated that the proposed algorithm outperformed existing algorithms in terms of comprehensive performance. The research on the application of IoT to an incentive spirometer was presented in [10]. The main objectives of these studies were to develop a flow-based incentive spirometer that aided patients in their post-operative lung rehabilitation after surgery. The proposed system offers patients the ability to monitor their breathing status and securely store their daily records. This is achieved through the implementation of IoT technology. A novel IoT-based incentive spirometer design has been introduced by Jantaraprim and Sangkaew [11]. The primary function of the system is to process data acquired from three distance sensors and an air flow sensor. The experimental results demonstrated a strong correlation between the flow rate measured by the digital flow meter and the distance sensors. Regarding the aforementioned studies, there is a lack of research or literature specifically addressing the topic of data acquisition. In this research, we have designed the system and put forth several steps in the process of data acquisition in order to achieve optimal outcomes, as detailed in Section 2.5.

The paper is organized as follows. Section 2 presents a comprehensive overview of the system design pertaining to device installation, the controlling component, and the data acquisition procedure. Section 3 presents the experimental results. The discussion is presented in Section 4, while the conclusion can be found in Section 5.

2. Material and Method.

This section presents the design and implementation of a recording and reporting system for an incentive spirometer, employing IoT technology. Specifically, the detail is as follows.

2.1. System architecture.

The system's architecture primarily comprises the IoT-based incentive spirometer, the interaction web page, and the notification unit facilitated by the Line application, as depicted in Figure 1. The primary component of the system is the IoT-enabled incentive spirometer, which is equipped with a distance sensor for the purpose of measuring data. The data is acquired from the distance sensor and subsequently processed by the Node MCU. The outcome is transmitted over the Internet utilizing the MQTT protocol as a means to transfer data to a web server. Users can access the main page of MySQLi to view the report and receive notifications sent by the Line application. The system is equipped with a liquid crystal screen for the purpose of displaying the

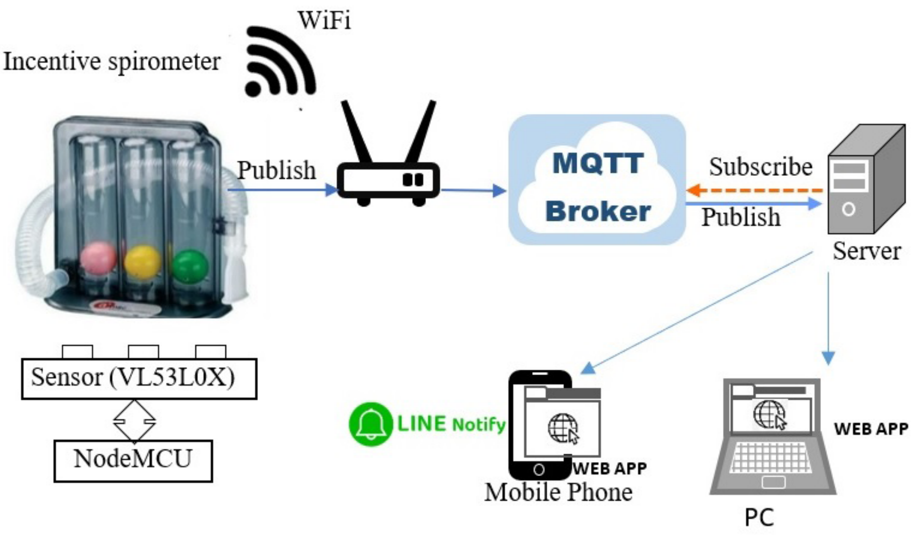
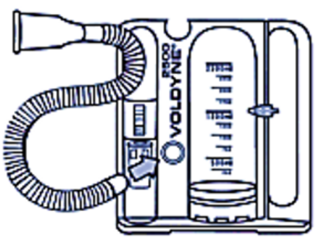


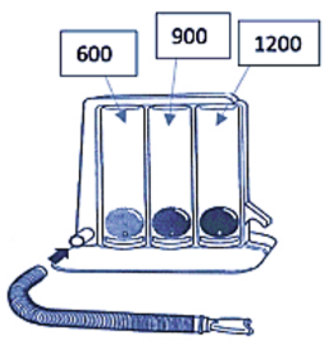
Figure 1. Proposed structure of the system

results. The device is powered by a rechargeable lithium-ion battery, providing an electric power of 5 V.

2.2. **Incentive spirometer.** An incentive spirometer is a device designed to help take slow, deep breaths in order to expand the lungs and prevent atelectasis (the collapsed lungs). The incentive spirometer consists of a cylindrical box, which serves as an air chamber. The chamber contains a ball and is connected to a flexible breathing tube that can be adjusted to facilitate the intake of air. The tube is designed with a flat shape at its end to serve as a mouthpiece, facilitating the user's ability to take deep breaths gradually and to their maximum capacity. The ball contained within the chamber serves as an indicator. The patients are required to inhale in order to elevate the ball. The volume of inhalation can be assessed by means of a numbered scale, enabling the patient to evaluate the outcome and enhance their respiratory function. There are two types of spirometers: volume displacement and flow-dependent devices. For the first type, it serves to gradually increase the air volume in the lungs by inhaling or exhaling. The measurement is indicated by the level of air volume, as shown in Figure 2(a). For the second type, it is a device that controls the air flow through the mobile apparatus into the lungs. For this type, it does not directly increase the pulmonary air capacity. The measurement is indicated by the air flow rate, as shown in Figure 2(b) [5,12].



(a)



(b)

Figure 2. Type of spirometers: (a) Volume displacement device; (b) flow-dependent device

For this study, the air flow device was selected as the preferred option. This particular type of device is known for its affordability and is widely recommended by physicians as a means for patients to engage in breathing exercises. This exercise aids in the development and strengthening of the muscles in the rib cage. As a result, the respiratory rate of patients demonstrates improvement [13]. In this research endeavor, the installation of a sensor was carried out with the utmost care, ensuring that it did not impede the device's functionality or internal structure. Consequently, the operation of controlling the air flow remains unaltered and undistorted.

2.3. **VL53L0X V2 laser ranging distance sensor.** VL53L0X V2, as shown in Figure 3, is a laser distance sensor that can measure distance with a laser beam with a wavelength of 940 nm, which is invisible to a human observer. The principle is based on the time measurement of an infrared laser from a transmitter to a receiver, called time-of-flight. For this sensor, the distance is obtained directly without a mathematical function. The sensing and processing units are connected using the I^2C bus, which can measure a maximum distance of 1.2 m with a 1 mm resolution and an accuracy of 96% [14], depending on the environment and the color of the object [15]. It can be applied to measuring the displacement of the ball in the incentive spirometer without damaging or changing the structure of the apparatus.

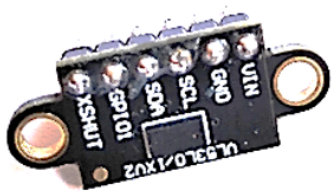


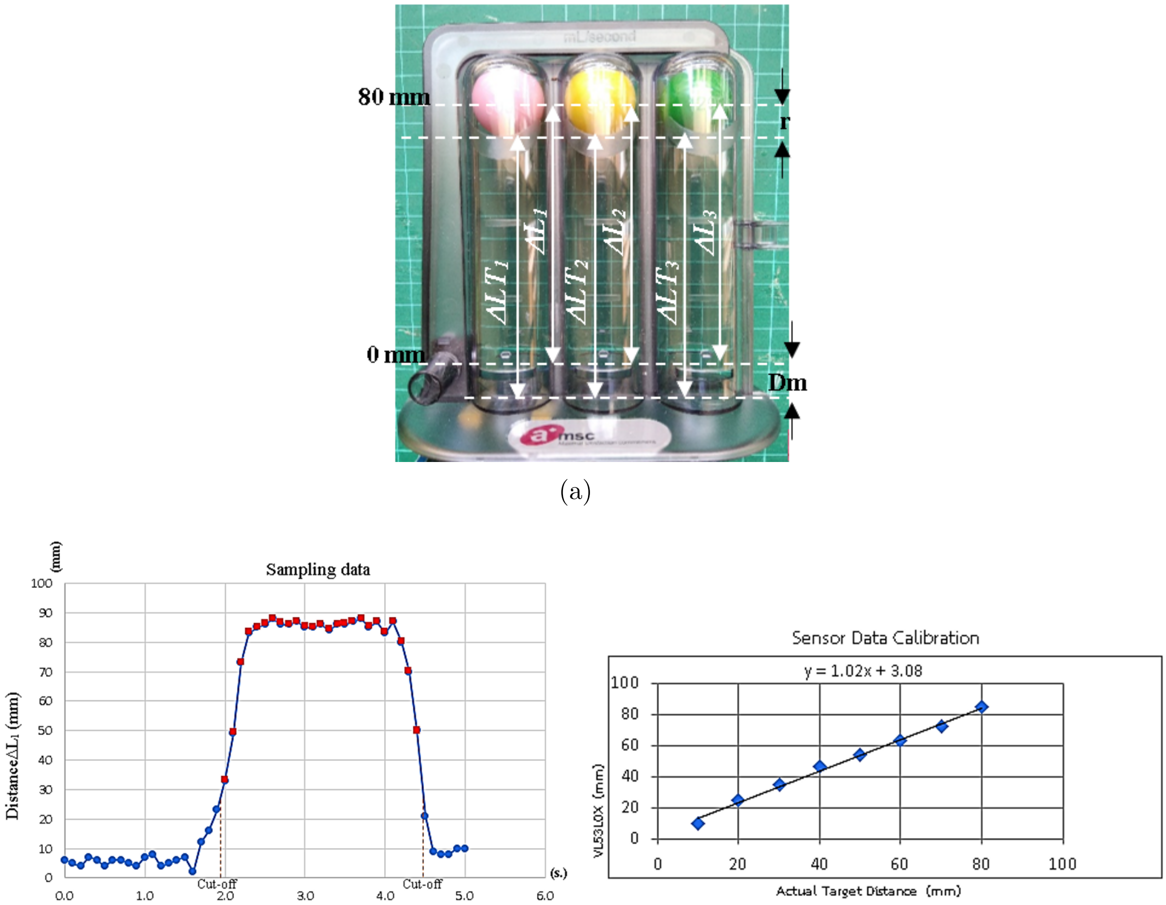
Figure 3. VL53L0X V2 laser ranging distance sensor

2.4. **Node MCU ESP8266 V3.** The Node MCU 8266 Generation 3 is a microcontroller that combines the advantages of the Arduino board and the Wi-Fi module (ESP8266). So, it has input and output pins that can be directly programmed with the C language to control devices and make the Node MCU truly support the Internet of Things technology. It is convenient to use and affordable. There are also facilities such as voltage regulators, a micro-USB port to upload instruction sets and supply electric power, and pins for converting analog signals to digital [16].

2.5. **Data acquisition.** In this work, a number of steps are necessary to produce an accurate representation of the data. Subsequently, the computed air flow rate is converted from the data, ensuring its precision and proximity to the actual values. The steps are as follows.

***Step 1*: Sampling data.** The data is obtained through a random sampling method. The process of randomization commences when the system enters the waiting state and becomes prepared to retrieve data from the detector. When the system identifies data that exceeds 30% of the maximum distance, it initiates a continuous data collection process for a total of 25 iterations (Figure 4(b)). Next, the collected data is filtered using a median filter. The outcome is employed to indicate the distance between the ball and the sensor for each tube, denoted as ΔLT_1, ΔLT_2, and ΔLT_3 for tubes 1, 2, and 3, respectively.

***Step 2*: Compensation and offsetting.** Due to the VL53L0X sensor being positioned beneath the spirometer's base, as illustrated in Figure 4(a), the reflective distance reading from the sensor to the object does not represent the absolute distance. These details require compensation and offsetting.



(a)

(b) (c)

FIGURE 4. (a) Distance measurement of the ball in each chamber, (b) sampling method and (c) data calibration of VL53L0X measurement result

The distance margin (Dm) is equivalent to the distance between the sensor and the lower edge of the ball at the reference position (0 mm), as illustrated in Figure 4(a). Thus, it is necessary to deduct this margin from the output. Furthermore, it was noted that the incentive spirometer reading is obtained at the midpoint of the ball, which is elevated relative to the lower perimeter of the ball by the radius r (see Figure 4(a)); this additional radius should be incorporated into the calculated values. Let the distance be used as the raw data (the readout) denoted by $\Delta LT_{1,2,3}$, the absolute distance, denoted by $\Delta L_{1,2,3}$ is calculated as indicated by Equation (1).

$$\Delta L_{1,2,3} = (\Delta LT_{1,2,3} + r) - Dm \tag{1}$$

***Step 3*: Data calibration.** After determining the absolute distance, the calibration of the VL53L0X data begins. Calibration is done under particular circumstances; it is positioned beneath the base of the incentive spirometer tube. This VL53L0X's distance is compared to a manual ruler-based approach. The test findings in this particular circumstance revealed that the VL53L0X measurement values did not differ considerably from the ruler-based approach. The data was then calibrated using a linear regression equation and the least squares fitting approach. The linear equation yields $y = 3.08 + 1.02x$, where x is the VL53L0X reading and y is the calibrated data. The plot is depicted in Figure 4(c). The obtained results demonstrate a satisfactory level of accuracy and exhibit potential for utilization in spirometers.

***Step 4*: Convert distance data to air flow rate data.** The experimentation involved the measurement of distances ranging from 0 to 80 mm using the detector. The subsequent procedure involves converting them into the air flow rate through the utilization of a linear equation. There are three distinct air flow chambers. The airflow rates for the first, second, and third chambers are 0-600 mL/s, 600-900 mL/s, and 900-1200 mL/s, respectively. These air flow factors are linearly related to the distance from the displacement of the ball. Hence, the total air flow rate can be calculated by Equation (2), where Fr is an air flow rate (mL/s), ΔL_1, ΔL_2 and ΔL_3 are the absolute distances between the reference position (0 mm) and the midpoints of balls 1, 2 and 3 (Figure 4(a)). The constant values of 7.5, 3.75, and 3.75 are derived from the correlation between the distance from the displacement of the ball and the air flow rate as determined by the SFM3300-D air flow sensor [11].

$$Fr = 7.5(\Delta L_1) + 3.75(\Delta L_2) + 3.75(\Delta L_3) \tag{2}$$

3. **Main Results.** The system's implementation is depicted in Figure 5. The system, as described in the preceding section, comprises electronic devices, a microcontroller, and components of the incentive spirometer, as illustrated in Figure 5(a). All components were assembled and subsequently installed into the incentive spirometer, as illustrated in Figure 5(b).

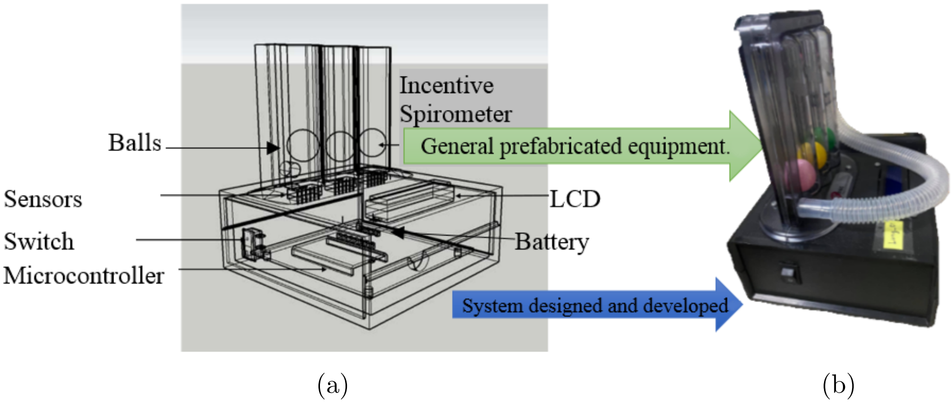


FIGURE 5. (a) Structure and components of the system; (b) complete system

After conducting a reliability assessment on the flow rate obtained from the system, the subsequent step involves testing the connection of the device by activating the switch. The device has been successfully connected to the Internet system, indicating its readiness for the patient to utilize the physiotherapy training machine. The results are displayed in Figure 6.

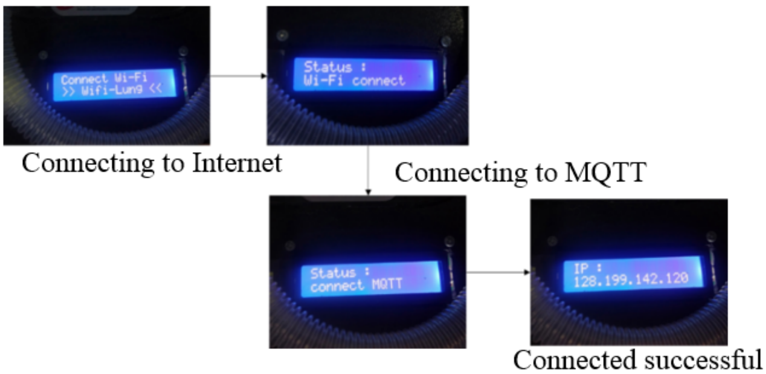


FIGURE 6. Results of connecting test

During the execution of physiotherapy exercises, the patient would inhale until the ball reached the designated mark. Simultaneously, the user would observe the outcome of this activity on the liquid crystal screen, which exhibits the flow rate as depicted in Figure 7. Subsequently, the system will transmit the outcomes to be securely stored within the cloud-based database. After the data has been saved, it will be displayed on the screen for physical activity tracking. To discontinue system usage, users can simply deactivate the system by toggling the switch to the off position.

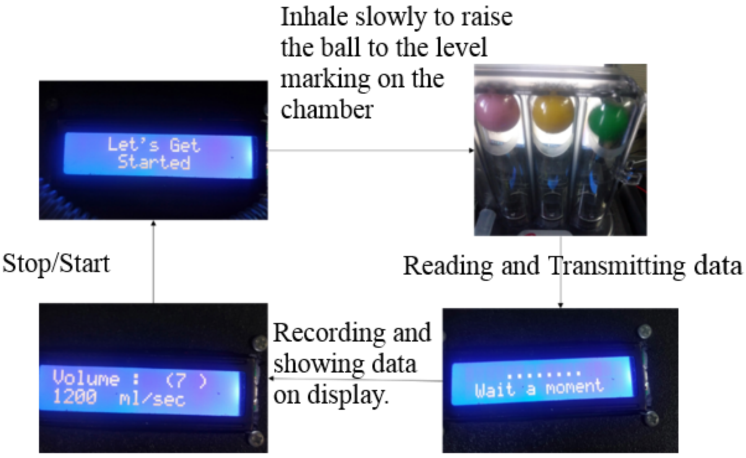
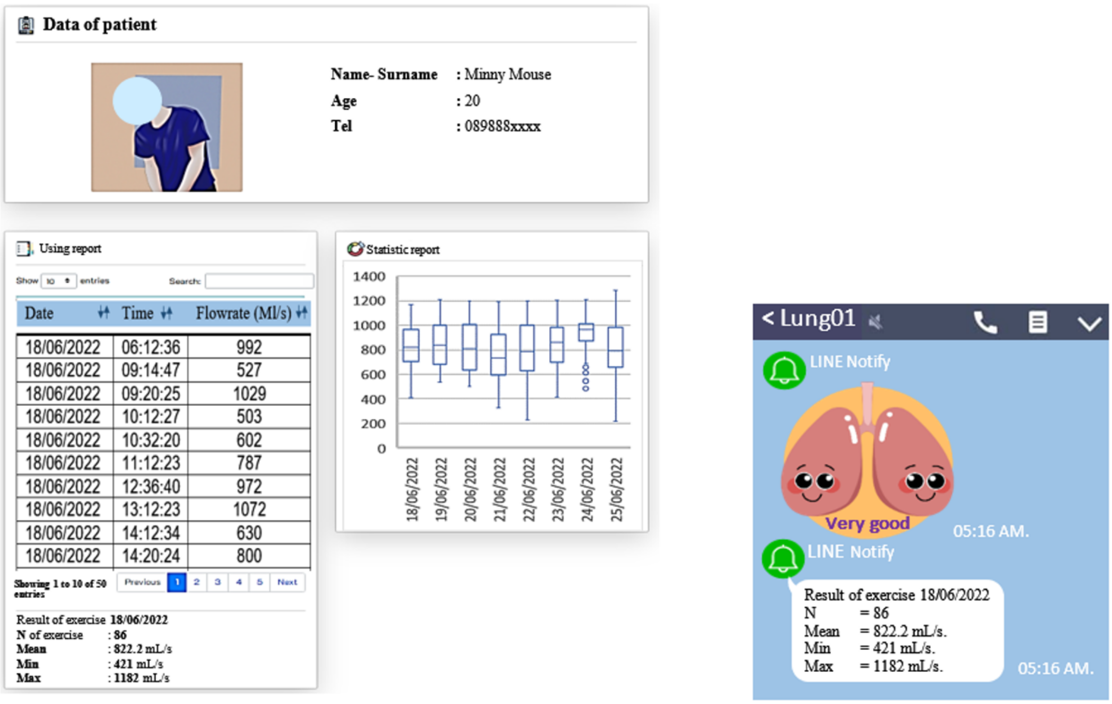


FIGURE 7. The results of breathing activities and transmission of data for storing in the database

Upon recording the information in the database, patients and physicians have the ability to track and view the physiotherapy activity report. This can be done by accessing the report through the homepage, as shown in Figure 8(a). In order to ensure the security



(a) (b)

FIGURE 8. Results of lung exercise follow-up reports: (a) The web application, (b) the notification from Line application

of healthcare information, users are required to complete a registration process to obtain permission. Once registered, users can then proceed to log in to the system. After a successful login, the system presented the user with two primary menus: physician and patient. Physicians possess the capability to perform various actions, such as adding, deleting, editing, and viewing patient information, including the physiotherapy report. Patients are granted the capability to independently modify and access their own personal information and the report pertaining to their physical therapy. The system provides users with a daily report and delivers a notification to them via the Line application. There exist three distinct categories of sticker lines, namely excellent, very good, and good. The key information for each type is transmitted to motivate the users, as depicted in Figure 8(b).

The final test involved users assuming the role of a hypothetical patient and engaging in lung exercises using the developed tools. During the execution of the assigned exercise, users were instructed to maintain handwritten notes in the format specified, a total of 690 times. After the exercise was finished, the participants were given instructions to access the system in order to view the outcomes of the physiotherapy report. Upon conducting a thorough comparison, it was determined that the recorded results in the system were identical to the handwritten reports.

4. **Discussion.** The IoT system of the incentive spirometer allows for the measurement and reporting of airflow rates. The range of airflow rates that can be measured is from 0 to 1200 mL/s. The results are in accordance with the specifications outlined in [17] for breathing exercise apparatuses. As illustrated in Figure 8, the system has the capability to automatically store data instead of relying on manual recording. It can also transmit this information to physicians, caregivers, and patients for the purpose of accurately verifying and monitoring the patient's lung exercise history. To improve accessibility, it is beneficial to employ a web-based application that is compatible with widely used computers and mobile devices. The effectiveness of patients' physical rehabilitation has improved. In contrast, the practice of traditional lung exercise requires the involvement of a joint assistant who offers motivation, guidance, and documentation of progress [2]. Without the support of such an assistant, patients often fail to adhere to this routine. As a result, there is no retrospective recording or monitoring of the results.

5. **Conclusion.** The development and implementation of an IoT system for incentive spirometers has resulted in the ability to measure air flow levels within the range of 0 to 1200 mL/s. This is achieved by detecting the vertical distance of the ball movement, which can range from 0 to 80 mm. During the comparative testing of 690 instances, the outcome yielded a 100% accuracy rate for history tracking. The primary focus of this research is to enhance convenience for patients, caregivers, relatives, and physicians during the development of the system. The system has been designed to ensure ease of follow-up, and timely retrieval of reports is crucial to improve the efficiency of verifying patient activities. The implementation process considers both cost and availability factors. The research study opted for the affordable equipment that is readily accessible within the country. Furthermore, the design also incorporates security measures. User authentication is a process that is employed to gain access to the system. Ultimately, it is anticipated that the receipt of a daily message, including an encouragement sticker, from the Line application will serve as a reminder for users to consistently review the statistical data and engage in the prescribed physiotherapy activities. There are future plans to develop a mobile application specifically designed for gaming on smartphones or tablets. The primary goal is to encourage pediatric patients to participate in respiratory exercise through the use of an incentive spirometer.

REFERENCES

[1] D. Vervoort, M. S. Babar, M. E. Sabatino, M. M. A. Riaz, M. T. Hey, M. P. H. Prakash, S. E. Mathri and J. Kpodonu, Global access to cardiac surgery centers: Distribution, disparities, and targets, *World Journal of Surgery*, vol.47, no.11, pp.2909-2916, 2023.

[2] K. Rattanakanlaya, Coaching on breathing exercise by applying incentive spirometer in post-operative patients, *Journal of Faculty of Nursing, KKU*, vol.19, no.3, pp.1-9, 2018 (in Thai).

[3] T. J. Overend, C. M. Anderson, S. D. Lucy, C. Bhatia, B. I. Jonsson and C. Timmermans, The effect of incentive spirometer on postoperative pulmonary complications, *A Systematic Review Chest*, vol.120, no.3, pp.974-978, 2001.

[4] W. Liu, Y.-L. Pan, C.-X. Gao, Z. Shang, L.-J. Ning and X. Liu, Breathing exercises improve post-operative pulmonary function and quality of life in patients with lung cancer: A meta-analysis, *Experimental and Therapeutic Medicine*, vol.5, no.4, pp.1194-1200, 2013.

[5] J. M. Cairo, *Mosby's Respiratory Care Equipment*, 11th Edition, Elsevier, St. Louis Missouri, 2013.

[6] M. V. Dole and V. V. Yerigeri, ESP8266 based health monitoring system using Arduino, *International Research Journal of Engineering and Technology*, vol.7, no.7, pp.4071-4079, 2020.

[7] N. Z. Nadzri, Y. Yusof and A. F. Ahmad, Ibox: Smart medicine box with IoT application, *European Journal of Molecular & Clinical Medicine*, vol.7, no.8, pp.3741-3757, 2020.

[8] N. Sangprasert and K. Inthavisas, Mobile x-ray tracking and monitoring system using the Internet of Things (IoT) technology, *Kasem Bundit Engineering Journal*, vol.10, no.1, pp.149-163, 2020.

[9] W. Hao, H. Ye and F. Huang, Data collection algorithm for Internet of Things based on age of information and sample extrusion awareness, *International Journal of Innovative Computing, Information and Control*, vol.18, no.2, pp.497-509, DOI: 10.24507/ijicic.18.02.497, 2022.

[10] A. Keerathana, A. Loganayagi, M. Swetha and R. Radhiga, IoT based electronic incentive spirometer, *International Journal of Engineering Research and Applications*, vol.11, no.7, pp.59-63, 2021.

[11] P. Jantaraprim and T. Sangkaew, Tri-ball incentive spirometer using distance sensors and digital flow meter, *Proc. of the 15th Conference of Electrical Engineering Network*, Nakhonphanom, Thailand, pp.850-853, 2023 (in Thai).

[12] A. S. Kumar, G. K. Alaparthi, A. J. Augustine, Z. C. Pazhyaottayil, A. Ramakrishna and S. K. Krishnakumar, Comparison of flow and volume incentive spirometry on pulmonary function and exercise tolerance in open abdominal surgery: A randomized clinical trial, *Journal of Clinical and Diagnostic Research*, vol.10, no.1, pp.1-6, 2016.

[13] A. Opaspasu, P. Trisarawat, U. Kongamnoiysak and S. Buranapuntalug, The immediate effects of costal breathing exercise with sustained maximal inspiration technique and flow incentive spirometer on chest expansion in sedentary young adults, *Thammasat Medical Journal*, vol.11, no.2, pp.220-229, 2016 (in Thai).

[14] Pololu 2490, *VL53L0X Datasheet*, https://www.pololu.com/file/0j1187/vl53l0x.pdf, Accessed on 19 October, 2022.

[15] M. Swiecki, J. Szymelewicz, J. Matusiewicz and R. Gradzki, Test of useful field of view of laser sensors used in autonomous nano sumo robots, *International Journal of Machinical Engineering and Robotics Research*, vol.10, no.8, pp.414-421, 2021.

[16] *ESP8266EX Datasheet*, https://www.espressif.com/sites/default/files/documentation/0a-esp8266ex_datasheet_en.pdf, Accessed on 19 October, 2022.

[17] M. R. Miller, J. Hankinson, V. Brusasco, F. Burgos, R. Casaburi, A. Coates, R. Crapo, P. Enright, C. P. M. van der Grinten, P. Gustafsson, R. Jensen, D. C. Johnson, N. MacIntyre, R. McKay, D. Navajas, O. F. Pedersen, R. Pellegrino, G. Viegi and J. Wanger, Standardisation of spirometry, *European Respiratory Journal*, vol.26, no.2, pp.319-338, 2005.