

Design and Development of a Low-Cost Spirometer with Interactive Gamification

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Abstract— A digital spirometer is developed along with an application that introduces a certain level of gamification to the otherwise tedious practice of breathing exercises. The spirometer connects wirelessly with the application via Bluetooth. An illustration is displayed on the screen visualizing the patient's lung output. The immediate objective of this product is to engage the patient through gamification during their breathing exercises and consequently improve their lung strength.

Keywords—Spirometer, wireless, breathing, gamification, healthcare, psychosocial

I. INTRODUCTION

Clinical Relevance — Approximately 37 million Americans suffer from chronic lung diseases. These include mild and severe cases of COPD and Asthma [1]. However, there are only about 2000 lung transplants conducted annually [2, 3]. In order for a person to get a lung transplant, several factors are considered including but not limited to donor and recipient match, age, sex, life expectancy before and after the transplant, psychological evaluations, and distance to the hospital [4]. After conducting the required diagnostics, the patients are put on a waitlist. The order is determined by assigning scores based on the following [5]:

- 1) Life expectancy of the patient before receiving a lung transplant
- 2) Life expectancy after the transplant

Patients with a higher score are put higher on the waitlist. Generally, they are not expected to live for a long time after getting a lung transplant.

The problem to solve arises mainly post-surgery. After getting a transplant, patients are provided with a spirometer to prevent the onset of pneumonia, regain lung capacity, and strengthen the muscles [6]. The intended use of a spirometer varies on a case-by-case basis. In small sessions, patients are advised to use the spirometer 3 to 5 times daily. Currently, patients are

observed using it only once a day. The main reason noted by clinicians is the lack of motivation to carry out the repetitions.

Spirometry is a breathing test that measures the amount of air that is inhaled or exhaled from the lungs. It also measures how easily and quickly this process can be carried out [7]. A spirometry test can help diagnose COPD [8] and asthma or check lung function before surgery. It also supports a patient in improving their lung muscles post-surgery to prevent the onset of pneumonia [9]. The ability to practice spirometry is dependent on several factors. Post-surgery, the patient may experience exhaustion due to medications, chest pain while breathing, and a lack of motivation to exhaust themselves further with exercises. Since spirometry is a tedious and monotonous activity, patients often lose zeal while carrying out their prescribed repetitions. In order to motivate patients to achieve their daily repetitions, an upgrade to the traditional spirometers is proposed in this paper.

II. LITERATURE REVIEW

The objective of this literature review is to explore the various products and trends available in the market which have been studied and introduced in recent years. [10] This paper focuses on developing a prototype for a digital spirometer using a hot wire transducer. It involves the usage of an analog to digital converter which converts the signals from the hot wire sensor in order to be implemented into the LabVIEW software. The prototype works on algorithms provided by the American Thoracic Society. These algorithms help in analyzing the information received from the spirometer. The prototype uses a hot wire sensor, a single chip microprocessor (80C196KC) and an LCD Display. The paper concludes by presenting results of pulmonary functions (FVC, FEV) received from the volunteers. The major advantage is the reduced product size achievable due to MEMS technology. The disadvantages of using a hot wire anemometer are the non-thermal time constant, nonlinear resistance change against temperature, and

unidirectional measurement of airflow. The patented device [11] is an incentive spirometry device designed to assist patients with respiratory therapy. It uses an electronic air flow sensor that provides patients with feedback when they inhale or exhale at a predetermined flow rate or volume and hold their breath for a predetermined time period. The objectives are increasing transpulmonary pressure and inspiratory volumes, improving inspiratory muscle performance, and re-establishing or simulating the normal pattern of pulmonary hyperinflation. By means of a connection to a personal computer, a videogame-like therapy session could enable patients to have a more effective and enjoyable session. Some of the advantages of this device are that it is interactive and compatible with computers. The major disadvantage is incompatibility with smartphones.

This handheld digital spirometer [12] has an inbuilt LCD display and can connect to a smartphone application via Bluetooth as well. It is rechargeable and FDA-approved. It utilizes a unique pressure sensor design developed in-house by the company. The advantages of this device include a unique pressure sensor design promised to extend the product life, data collection and storage on the app for usage history, a design that allows easy maintenance. However, the drawbacks of this product are lack of a personalized training regime, simple data collection, and no motivational aspect other than data tracking. Furthermore, there is a limited product range. There is only one product offered which costs 149 USD. The NDD Easy on-PC Spirometer and the NDD EasyOne Air spirometers are the most advanced spirometry testing tools [13]. The NDD EasyOne Air Spirometer is a portable and easy-to-use device. It is equipped with ready-to-use EMR connectivity with a user-friendly interface. It has a large touch screen and can be wirelessly connected to a PC via Bluetooth. Pediatric incentive screens are available with EasyOne Connect and it is calibration-free. [14] This is a high-performance wireless spirometer with high-precision technology and a wide range of test possibilities through Bluetooth. A fully charged battery provides many hours of continuous cable-free testing. When the battery is discharged, measurements can be taken via USB. This spirometer contains all of the connectivity possibilities of a sophisticated pulmonary function testing system, such as ASCII, HI7, and networking.

Our visits to Barrow Neurological Institute (BNI) also demonstrated the importance of gamification. Exercises were prescribed to users on traditional and digital, gamified equipment. It was noted that using the gamified devices and equipment proved to be a much more effective method and completion of the exercises was achieved in a more seamless manner as opposed to traditional equipment. The digital devices also allowed the therapists to monitor user data in real time and adjust the exercises accordingly. Digital devices also had the ability to manipulate exercises to make them more accommodating for users who were differently abled or needed specific regimes.

Evidently, only a few products have introduced gamification to tackle the psychosocial aspect of motivation. Moreover, cost-effective solutions that engage the patient are not available in the current market. Motivation also plays a crucial part in rehabilitation. The space has untapped potential and this

research aims to fill the gaps. The solution presented is an interactive spirometer that provides motivation via a gamified illustration. It also has the potential to provide feedback on how effectively a patient uses the spirometer. With a population shift towards people who are more comfortable with technology, this solution could help improve patients' rehabilitation experience.

III. SYSTEM DESIGN

The spirometry system consists of a physical prototype consisting of the electronic components housed inside a casing and the digital app which displays the gamified illustration.

The housing of the components is prototyped using additive manufacturing technology. The material used to prototype the casing is polylactic acid (PLA). The print has 0.1mm layer height with the top and bottom layers being 0.4mm in thickness. A triangular infill pattern was used to maximize structural strength at 40 percent infill. The figure shows the CAD model of the casing.

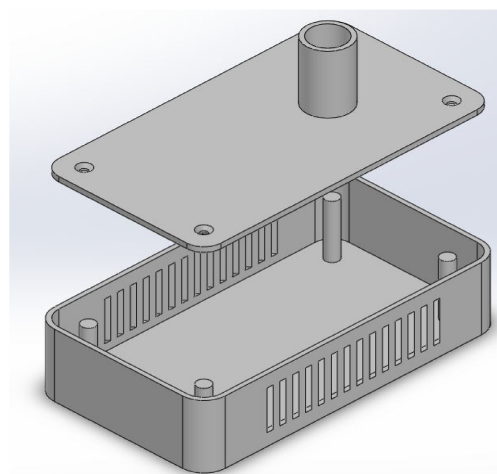


Fig. 1. CAD model of electronic housing

The following electronics are present within the housing:

- Adafruit MPRLS Pressure Sensor

The Adafruit MPRLS pressure sensor is a barometric pressure sensor [15] that is great for Sip and Puff interfaces. It allows us to measure the pressure within a vacuum or a closed chamber, making it optimum for our first prototype testing.



Fig.2. Adafruit MPRLS Pressure Sensor

The advantage of using this sensor is that it uses I2C, which makes it easy to control with any type of microcontroller. In addition to this, it has a metal port, to which one can easily attach a tube, and measure air pressure inside the closed surface. The sensor is capable of measuring absolute pressure of up to 25 PSI and works at a voltage of 3.3V.

- ESP32S Microcontroller

The ESP32S microcontroller has a robust design and is highly integrated. It has a hybrid WiFi and bluetooth module and consumes very less power [16]. Its high reliability allows it to be used in most industrial environments. It can operate within a temperature range of - 40 degree celsius to +125 degree celsius. The ultra-low power consumption makes it work perfectly with the Arduino IDE. The 38-pin development board is safe and extends to a variety of applications.



Fig.3. ESP32S Microcontroller



Fig.4. Physical Prototype of the spirometer (fully assembled)

IV. SYSTEM ARCHITECTURE

The system utilizes a MPRLS pressure sensor integrated with an ESP32S microcontroller to obtain the input data from the user and transfer it wirelessly to an asynchronous web server. This allows the device to wirelessly send the readings to the end user or therapists for real-time assessment and feedback.

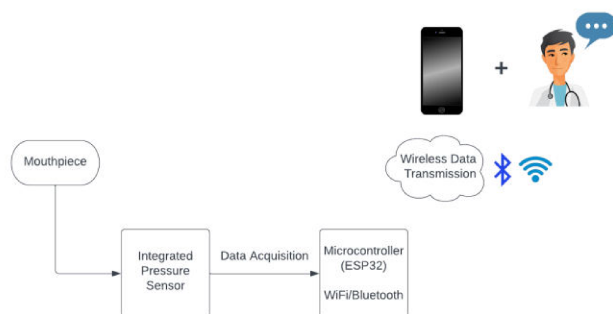


Fig.5. Spirometer process schematic

The architecture is set up so that the ESP32S checks for Wi-Fi pairing when the device is turned on. It assesses the request and connects to a nearby Wi-Fi network. It starts accepting input from the pressure sensor once the serial connection is established.

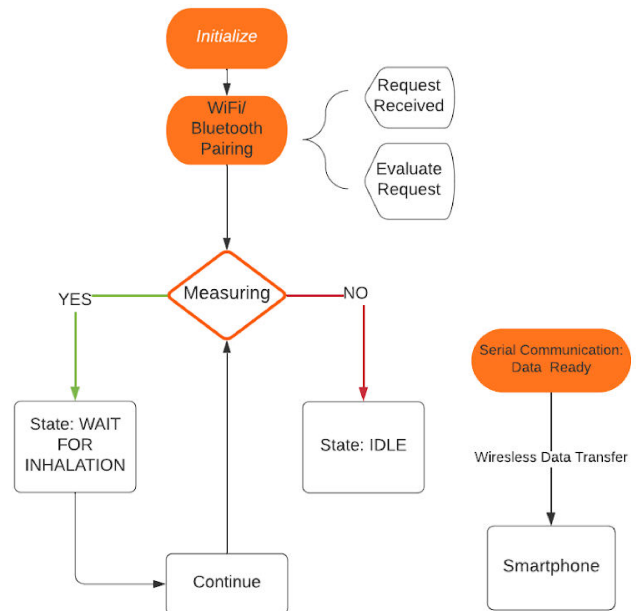


Fig. 6. System architecture

The sensor values decrease when the user inhales from the spirometer. These Serial values are processed and sent to an asynchronous web server, which is then integrated into the project's gamification section.

V. GAMIFICATION

The gamification part of the project plays a crucial role in engaging users. A 2D Rocket Launcher test game has been developed for the initial prototyping phase of this product. The game interface was designed using the Unity Real-Time Development platform [17].

The game features a rigid body that moves between two points on the vertical axis. The distance moved and the direction of movement is dependent on the inputs received from the sensor. In this case, the direction of the vertical movement of a Rocket character is being used to differentiate between inhaling and exhaling. For the purpose of this prototype, the serial port was used to communicate between the ESP and Unity at a baud rate of 115200. This was also required to initialize the serial port in C#. Once the connection is established, an initial value is taken to determine the base pressure and threshold. If the pressure decreases or increases, the rocket moves upward or downward, respectively. To achieve this, the RigidBody 2D and the Box Collider [18] functions from Unity were utilized. Multiple layers of background are added to provide a better sense of movement and progress.

Since this is a prototype, it exclusively demonstrates upward and downward motion. Future developments of the game will include features like high scores and multiple levels of difficulty set by the medical practitioner to provide a better sense of progress. Visual and sound cues will also be added to guide the user through the exercises.

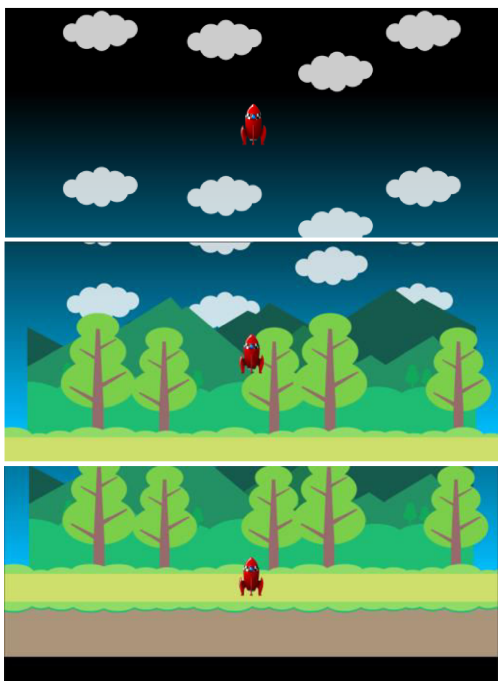


Fig.7. User Interface of the application

VI. CONCLUSION

A spirometry system was designed and developed consisting of a physical prototype and gamified application. The gamification helps create a feeling of motivation amongst users who find it difficult to complete the required repetitions. While functioning efficiently, ESP32S and MPRLS are not the most ideal sensor and microcontroller for this device. With the use of more advanced microcontrollers and sensors, more accurate and precise data can be obtained. This project has achieved the successful implementation of gamification to solve the psychosocial element of motivation.

VII. DISCUSSION

Future research and development include optimizing the design of the spirometer. Using better microcontrollers and sensors, along with rechargeable batteries, there is potential to make a more portable and compact design. More games need to be developed in order to appeal to the needs of a larger user base. Further gamification elements such as high scores, ghost players, and feedback animations need to be introduced to engage users with the games. Cloud connectivity needs to be introduced to allow therapists and physicians access to patient data in order to track improvement and patient health. This needs to be secured and encrypted to ensure privacy.

Another possible approach to this solution is using a pneumotachometer and a differential pressure sensor instead of the MPRLS barometric pressure sensor. This would measure the gaseous flow and transform the input signal from the user to obtain accurate readings.

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