

FisioLung: A System for Training and Monitoring of Respiratory Physiotherapy Sessions

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Abstract The chest vibration technique is considered a good alternative for bronchial hygiene. However, this technique is difficult to perform because it needs a chest on exact range frequency. We built a tool to analyze its execution that helped professionals to learn him. It is possible to monitor the evolution of the patient with a monitoring system based on the record of sessions and observe the application of the vibration techniques as well. This work proposed the developed system integrating hardware and software named FisioLung. The architecture has a glove with an accelerometer to capture the vibration data and a NodeMCU ESP32 board used to process them. The Flutter mobile application receives the collected data and manages the session. The system can record physiotherapy sessions by registering the patient's and the professional's data, anamnesis information, techniques used, and analysis of the manual chest vibration technique stored. On the analysis screen, it is possible to note the graphs of peak frequency versus time and the average of peak frequency versus time, as well as session information such as analysis time, anamnesis data, and applicable techniques. The researchers conducted some experiments using the system, and the initial feedback indicated that physiotherapists could adopt the system and benefit from utilizing the Vibrocompression technique.

Keywords: *Respiratory physiotherapy, Chest vibration, Medical informatics, Pulmonary rehabilitation, Low-cost technology*

1 Introduction

Respiratory physiotherapy is a large area that aims to recover the patient affected by lung diseases through physical resources in the preventive, curative, and rehabilitative treatment of thoracic-pulmonary diseases, (Azeredo, 1984). Due to the pandemic of Coronavirus Disease 2019 (COVID-19), many people infected with the new Coronavirus may face pulmonary complications. After the recovering disease, the inflammation lung can persist for weeks, compromising the organism's function. In these cases, physiotherapy becomes necessary not because it treats the disease but because it prevents and rehabilitates respiratory deficiencies and the functional limitations of daily life activities caused by it (Bispo, 2010).

During a session, numerous techniques can be applied to patients. One of the most effective techniques is thoracic vibration. The manual thoracic vibration aims to promote vibration at the bronchial level and modify mucus rheology, facilitating its displacement (Corrêa, 2012). The technique is hard to perform and often becomes tiring and harmful for the physiotherapist when applied for an extended period. Because of this, it requires powerful muscle contractions from the professional's shoulders and arms (Smidt, 2010). For the technique to be applied effectively, the physiotherapy professional must perform a movement, respecting a specific frequency. According to Liebano et al. (2009), the oscillation frequency of the professional's maneuver must be between 3

and 17 Hz. In addition, the concrete and punctual monitoring of the physiotherapy sessions would allow the follow-up of the patient's evolution in a more precise way.

Considering this scenario, the system demand to control the respiratory physiotherapy sessions was possibly verified. In addition, it was possible to develop a computational resource using sensor elements, such as an accelerometer, which makes it possible to assist the professional in performing the thoracic vibration maneuver.

In this sense, we initially developed a decision support system to monitor respiratory physiotherapy sessions. Together with this, a sensor element capable of capturing the frequency of the chest vibration technique was developed. The first version of the sensor node was developed using the Arduino prototyping platform and the accelerometer and gyroscope 3-axis MPU-6050 ¹. After some initial experiments, a new version of the sensor node was developed, considering using a glove and some architectural modifications. This proposal was called FisioLung Glove. The new architecture used an NodeMCU ESP32 ², Bluetooth communication to eliminate possible physical problems of the wiring, as well as the resulting displacement vector of the three axes of the accelerometer. Thus, after new initial experiments with physiotherapists were performed, it was possible to verify that the FisioLung Glove solution was more effective and accurate in capturing

¹Available in: <https://www.allaboutcircuits.com/electronic-components/datasheet/MPU-6050-InvenSense/>

²Available in: <https://www.espressif.com/en/products/socs/esp32>

the frequency of the chest vibration technique than the initial version. This work was organized as follows, and section two presents the fundamental concepts for understanding the work. Section three presents the modeling of the conceptual solution and software requirements. The implementation of the different proposed solutions, such as the FisioLung system 1.0 and 2.0 with the two sensor node versions, was presented in the fourth and fifth sections.

The sixth section presents the results of all the experiments and their discussions. Finally, the conclusions and references are presented in sections seven and eight.

2 Theoretical Foundation

In this section, the following concepts will be explained: medical information technology and its applications, respiratory rehabilitation: purpose and techniques, manual chest vibration, information and decision support systems, and finally, related works.

2.1 Medical Informatics

By definition, Medical Informatics is a science that studies and develops methods and systems to acquire, process, and interpret patient data through knowledge obtained through scientific research (Bemmel and Musen, 1997). The health area is one of the last areas of application of information technologies in a generalized and organized way (Jepsen, 2003).

According to Sciarra and Rondina (2018), Medical Informatics is the scientific field that deals with resources, devices, and methods to optimize the storage, retrieval, and management of biomedical information. The growth of health informatics is mainly due to advances in computing and communication technologies, the growing conviction that medical knowledge and patient information are unmanageable by traditional paper-based methods, and the certainty that the processes of access to learning and decision-making play a central role in modern medicine.

The applications of Medical Informatics allow the automation of everyday clinical processes, assisting in the demands of medical institutions. Data digitization means that searches and reports have a shorter request time, thus reducing the diagnostic time depending on the case. Integrated systems can also act in the execution of maneuvers and techniques by health professionals since they operate together and help treat patients.

2.2 Respiratory Rehabilitation

Pulmonary rehabilitation has been described by authors who address the issue as a multidisciplinary program aimed at treating patients with chronic lung disease (Vettorazi, 2006). Respiratory muscle training aims to increase these muscles' strength and endurance to improve muscle function in patients with lung, rib cage, and neuromuscular diseases, (Oliveira et al., 1999).

According to Araujo and Araujo (2013), pulmonary rehabilitation programs are defined as multidisciplinary,

evidence-based interventions. These are examples of collaborative care encompassing the physical illness and the psychological factors involved. It is aimed at patients with symptomatic chronic respiratory disease that impacts daily activities. It aims to reduce symptoms, improve functional status, increase patient participation in treatment, reduce health costs, and treat systemic manifestations of diseases (Maurer et al., 2008).

Physiotherapy participates in the rehabilitation program to promote and maximize the patient's functional independence in activities of daily living, thereby improving their quality of life and increasing exercise tolerance with a consequent reduction in the level of dyspnea, (Vettorazi, 2006).

Respiratory physiotherapy techniques are applied to contribute to patients' recovery. Bronchial hygiene maneuvers detach secretions from the lung walls and transport them proximally until they are expelled. Most of them require the help of a physiotherapist or trained adult during the learning process, or it is execution (Lopez and Morant, 2004). Bronchial hygiene therapy techniques can be divided into invasive and non-invasive techniques, which are applied depending on the conditions of each patient.

Below are described techniques that can be used during respiratory rehabilitation treatment described by the document Standard Operating Procedure: Techniques of Respiratory Physiotherapy in Adult Patients, written by the rehabilitation unit of the Hospital de Clínicas of the Federal University of Triângulo Mineiro and by the Brazilian Company of Hospital Services (EBSERH).

- Non-Invasive Techniques: Postural drainage; Manual lung percussions; Thoracic Vibrocompression; Expiratory pressure; Cough (directed or provoked); Expiratory flow acceleration; Autogenous drainage; Forced expiration technique or Huffing; Active breathing cycle; Positive expiratory pressure; High-Frequency Oral Oscillation Therapy.

- Invasive Techniques: Tracheobronchial aspiration; Manual hyperinflation with ambu; PEEP/ZEEP maneuver.

2.3 Bronchial Hygiene

Bronchial hygiene is a set of techniques that make it possible to remove pulmonary secretions and clear the airways. Through clearing techniques, we promote the efficient removal of pulmonary secretions, preventing infections and obstructions. One of the approaches used in bronchial hygiene is manual chest vibration.

The vibration happens when a body describes an oscillatory movement concerning a referential. The graph that shows the amplitude of vibration against frequency is called the frequency spectrum (Bertoletti, 2007). According to Bertoletti (2007), vibration amplitude is quantified in several ways. For example, the relationship between the peak-to-peak levels, the maximum level, the average level, and the root mean square level of a sine wave.

Manual thoracic vibration (Figure 1) is one of the techniques used by the physiotherapist to accelerate the release and movement of secretions and mucus plugs in the conductive airways (Irwin and Tecklin, 2003).



Figure 1. Manual Chest Vibration Technique.

It generates rhythmic and delicate movements by fast isometric contractions of the upper limbs, with intensity and frequency ranging from 3 to 75 Hz sufficient to cause vibration at the bronchial level (Sarmiento, 2005). For Pavia (1990), the frequency with which the technique is performed is around 12 to 16 Hz. Irwin (2003) reported that frequencies from 12 to 20 Hz.

2.4 Decision Support Systems

Information Systems (IS) are tools that aid organizations in various processes such as organization, control, decision-making, and knowledge acquisition. Although they are not based on computer technology, they are created by streamlining the processing, generation, registration, access, and dissemination of information (Barbosa and Almeida, 2002).

IS in the area of health have the main objectives of providing, managing, and accessing relevant information on health care and promoting the quality of health services through contextualized support for medical decisions by professionals and patients themselves (Vasconcelos et al., 2004). As a fundamental premise, IS in health should improve health care quality, efficiency, and effectiveness, enabling research to be carried out, providing evidence, and helping in the teaching process, (Marin, 2010).

Decision Support Systems (DSS) are IS's computer programs that provide interactive information support to managers during the decision-making process (O'Brien, 2001). Decision-making is the ability to process information through logical and objective analysis (trusting yourself when making a decision, being prepared to take reasonable risks, and being held accountable for the results) (Batista, 2006).

According to Barbosa and Almeida (2002), the DSS intends to support decision processes that present structured problems. Experts recommend utilizing a DSS in unique environments where clear facts are absent and subjectivity is present, which requires an evolutionary process over time rather than decision-making at a given moment (Roy, 1996).

2.5 Related Work

This section will present research on Medical Informatics, Health Information Systems, and Microcontrollers to support

the proposal to create a system for monitoring respiratory sessions. The survey and study of related works are essential to evaluate the proposed solution since they allow the analysis of scenarios similar to those in the research.

Corrêa (2012) conducted a comparative study on the chest vibration technique. An accelerometer was used to measure the vibration and thus analyze the frequency of the technique performed by physiotherapists and undergraduates in physiotherapy. Finally, correlations were looked for in the variables of sex, age, time since graduation, whether he works in Respiratory Physiotherapy, and the time of this work with the results obtained at work. In the same context, an electromyographic and accelerometry analysis was carried out in the manual chest vibration physiotherapy maneuver by Saavedra (2013). This work aimed to analyze the muscle fatigue of the brachioradialis muscle through the electromyographic signal and the median frequency and to measure the oscillation frequency of the manual thoracic vibration maneuver using an accelerometer.

The prototype to support the physiotherapist's decision in elderly care developed by Pessoa (2018), despite the theme, deals with elaborating a health information system. Issues related to the system's usability by physiotherapy professionals and an overview of the use of systems in decision support in this area are addressed.

Finally, the physiotherapeutic maneuver of thoracic vibration was evaluated in the search for Bertolotti (2007). These works consisted of analyzing and measuring the oscillation frequency of the vibration technique based on experiments with several physiotherapists. The final objective was to find the dominant frequency and verify if it was close to the values found in the literature.

In this way, FisioLung contemplates the real-time analysis of the manual thoracic vibration technique to assist in the execution by physiotherapists. The vibration measurement will be automated using an accelerometer, and at the end of the session, the data will be stored in the database. In addition, a system was implemented to manage the registration of patients and physiotherapists and mainly to register physiotherapy sessions. The data available in the database are provided to analyze the progression of the patient's status and view specific sessions.

3 Session Support System

This work aims to study, propose and implement a system for monitoring respiratory physiotherapy sessions by integrating *hardware* and *software*. The proposed solution allows the physiotherapy professional to follow the patient's evolution through the system, being of great value for the treatment. For using the system, it is necessary to register users with personal data for identification, carried out by the physiotherapist who runs the session. The system has support for the recording of sessions that are associated with patients. This record contains information on anamnesis, techniques used, and analysis of manual thoracic vibration technique.

Users and session registrations were stored in a database *Structured Query Language* (SQL). Screens for each user action were created to provide a *feedback* intuitive for the pro-

fessional. The capture of vibration in the chest vibration analysis was performed by constructing a sensor node using the accelerometer sensor element, where data are collected and processed by a microcontroller and sent to the system, as illustrated in Figure 2.

In order to identify the execution standard of the Vibro-compression technique, the system collects acceleration and frequency data. The acceleration versus frequency was presented by a graph, where the three axes of the accelerometer are presented on the screen for the professional to orient himself regarding the execution of the technique. It is possible to consult the specific sessions of each user with all the information stored in the database. User reports could be generated for a more accurate analysis of the patient’s evolution over treatment.

The objective of this solution is to allow the monitoring of patients with respiratory problems, facilitating the work of physiotherapy professionals in the treatment. Digitizing the information will enable a better analysis of the patients’ periodic sessions and facilitate the daily evaluation work. The analysis of the thoracic vibration technique will provide better performance by the professional in the execution since it helps the application by assigning the frequency value and thus may result in better rates of patient evolution.

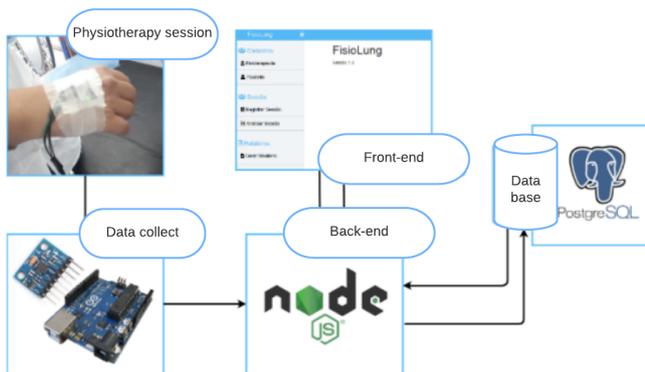


Figure 2. Conceptual Representation of Proposed Solution.

3.1 Modeling

This section presents the software modeling of the proposed solution. The treatment monitoring is performed by registering sessions that specific reports could access in the system. The system should collect data on the manual thoracic vibration maneuver sensor and provide relevant information to assist the physiotherapist in all processes. Therefore, the requirements were initially elucidated with physiotherapists of the Orthopedics Workshop of Bagé City (OW) and the Physical Rehabilitation Service of Bagé City (SRF) involved in the project, who acted as the stakeholders of the solution to analyze the system’s needs supply. The information collection was carried out in brainstorming meetings without a list of predefined questions. It was an essential requirement for the system to register patients, register physiotherapists, record sessions, and analyze sessions. It was defined as a desirable requirement for the system to issue reports about the sessions.

The sequence diagram is a behavioral diagram concerned with the temporal order in which messages are illustrated between the objects involved in a given process. A sequence diagram usually identifies the modeled process’s generating event and the actor responsible for this event. It determines how the technique should unfold and be completed by calling methods triggered by messages sent between objects, (Guedes, 2011).

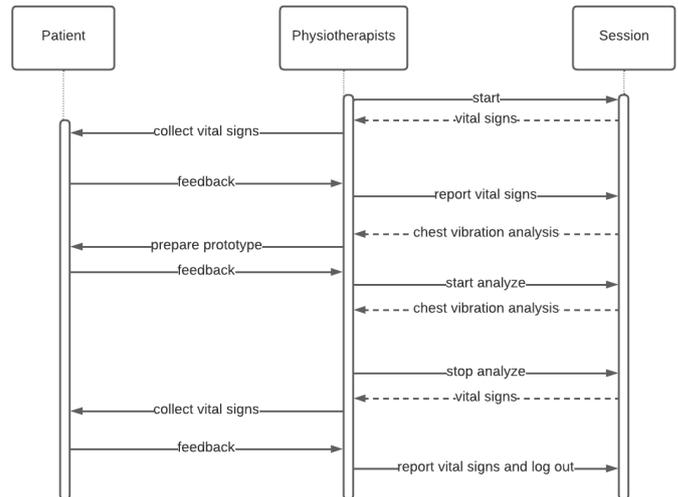


Figure 3. Sequence Diagram.

In this context, Figure 3 presents the sequence diagram of the proposed system. The diagram illustrates the temporal order in the recording of a session. The session flow starts with the physiotherapist, and soon after, the patient’s initial vital signs are collected and informed to the system. Finally, the sensor node is configured on the patient, and the chest vibration analysis is started. In the end, the physiotherapist closes the session after a particular time, when the vital signs are collected and stored, and the session is closed.

For modeling the database, the Entity Relationship Diagram was used. The Entity Relationship Diagram (ER) was designed based on the requirements. The ER diagram is illustrated in Figure 4, which represents the physical model and structure of the database after its implementation. The patient’s registration data is stored in the Patients table. The table’s fields are identifier, name, date of birth, gender, weight, pathology, individual registration, number of the unified health system, and telephone number. The physical therapists’ registration data is stored in the Physiotherapists table, which has the fields identifier, name, date of birth, gender, Individual Taxpayer Registration, Regional Council of Physiotherapy and Occupational Therapy, and telephone number. The techniques used in the sessions will be stored in the Techniques table, and the fields are identifier, name, and mode.

The Session table where patient sessions are stored, the fields which have the identifier, user identifier, physiotherapist identifier, technique identifier, sensor, initial and final respiratory rate, initial and final heart rate, oxygen saturation, initial and final blood pressure, and initial and final blood pressure.

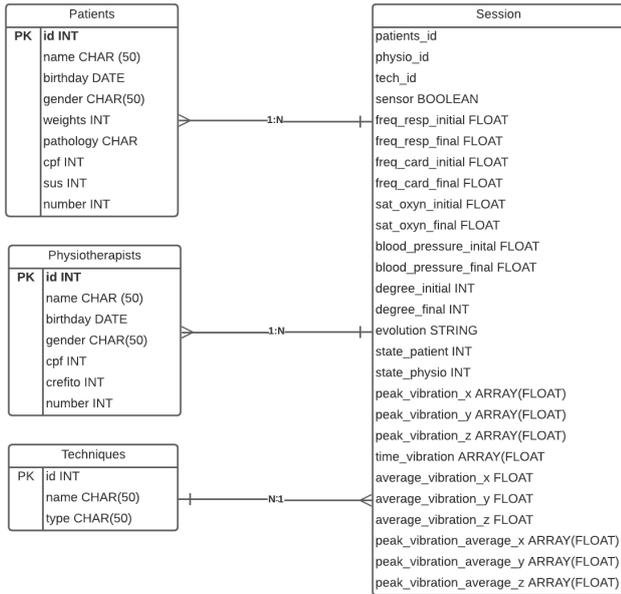


Figure 4. Entity Relationship Diagram.

In the same way, also the initial and final degree of lung impairment (that going to explain in the following subsection), patient status evaluated by him and the physiotherapist, vibration peak of the three axes, vibration analysis time, average vibration in the three axes, and the average of the vibration peaks over time.

3.2 Patient’s Degree Pulmonary Impairment

In order to record the degree of initial pulmonary impairment, a scale was developed with the physiotherapists involved in the project and adopted in the FisioLung. This scale aims to be an indicator of the degree of pulmonary impairment of the patient. It seeks to measure the state of evolution or involution of the patient. The system used this indicator to determine the patient’s general condition.

This scale uses elements based on the Likert scale, using five levels (1 to 5) referring to the patient’s condition, from the best (1) to the worst (5). For the design of the scale, a study was carried out regarding the methods already used to measure a patient’s condition. Thus, the information used to compute the scale were the following parameters: oxygen saturation, cyanotic, respiratory rate, heart rate, accessory muscles, changes in blood pressure, Borg scale, patient cooperation, patient with respiratory noises pathologies and/or cough, and classification of muscle strength. The physiotherapist must apply the scale, measure and define the input values, and inform the system of the patient’s level at the beginning and end of the session.

4 FisioLung System 1.0

The system was named FisioLung because of the terms’ physiotherapy and lung’ associated with the proposed research. The implementation of the solution is based on the integration of hardware and software. The hardware has a prototype

for the manual vibration technique using the Arduino platform and an accelerometer. The software has a back-end associated with a database that will receive requests and a front-end responsible for the information interface to the user.

4.1 The FisioLung Management System

The solution’s back-end was implemented with the Node.js framework using the Model-View-Controller (MVC) architecture to integrate the back-end with the front-end. The Bootstrap front-end framework developed the web application components with HTML, CSS, and JavaScript.

The Express framework was used with Node.js to create the application’s routes. The SerialPort package was used to access the data sent by the Arduino in the serial port. The Socket.IO library was applied to transmit the real-time data obtained from the serial port to the front-end. The Chart.js library was used in the front-end to plot the graphs of the three axes of the accelerometer. It was chosen because it has a simple appearance and is well-optimized for data visualization. The Handlebars package was used to facilitate the insertion of information received from the database in the HTML page. Docker was used to create a container with the PostgreSQL database. The database connection with the application is performed through Sequelize. Sequelize was used to facilitate the creation of tables, insertions, and searches in the database.

For the back-end implementation, the root route of the application was initially created, where the front-end HTML file is sent to be displayed on the screen. In constructing the analysis of the chest vibration technique, procedures were performed to establish the connection between the Arduino and the system. Data is transported from the Arduino to the system via the serial port. The connection is created using the SerialPort library, where the port where the Arduino is connected is established, with the communication rate at 38.400 Baud rates. The Socket.IO library sends data from the back-end to the system’s front-end.

The system was developed to receive data obtained from different models of accelerometers or other sensors, such as the vibration sensor. Thus, the system is adaptable to other sensor elements without strictly depending on a specific device model. Therefore, through the value of the “sensor” field in the database session table, the system is adapted to store and present data according to its category. The only condition for the sensor to be accepted is that the Arduino serial port output is in the standard used in the system parser.

In this sense, a configuration file was conceived to specify the database and make the connection. In this file, the host, port, user name, password, database name, and timezone are inserted, and these configurations are imported through environment variables. A folder is defined to create the migrations that generate the database tables. Furthermore, the models for each table are created in the model’s folder. A routes file was defined, where all the application routes are inserted, with their respective controller files, in which the functions that perform interactions in the database are inserted. Finally, a specific folder was designed in the project to store session logs. These logs are generated when a session is registered and are used for debugging and control purposes of the infor-

mation obtained from the session performed by the patient. All the handlebars files rendered through the routes are inserted in the view's folder.

The implemented front-end, the bootstrap framework, was used to help create the application screens (Figure 5). A standard layout through handlebars was defined with a side menu for navigation between the application's routes. The other application screens are inserted within the structure, thus maintaining a standard throughout the system. The registration forms are sent through the HTML action or the JavaScript fetch function.

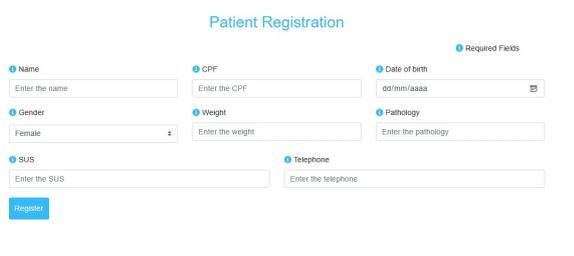


Figure 5. Application Front-end.

In the chest vibration analysis screen from the Chart.js library, three graphs are created for the data of the three axes of the accelerometer sensor obtained from the back-end by Socket.IO. On the other hand, when the sensor used is vibration, only one graph is created. Two functions were made to start and end the data transmission via the socket. The data issued by the back-end pass through a parser that executes different procedures to handle each case. These functions determine data types and suit them for storage. The data is stored in arrays for each axis and the frequency; at the end of the transmission of each data set, graphs are created with the data in the arrays, and the peaks are updated in the HTML. The average of the three axes is taken to facilitate understanding by the professional. A visual element with the colors green, yellow, and red signals the performance of the technique execution concerning the frequency values indicated in the literature. A timer is also used, triggered when the user starts the analysis, which displays the session time on the screen.

The session analysis screen selects the patient right after the specific session. The analysis is formatted in a grid, making it possible in the first part to follow the patient's initial and final vital signs through specific bar graphs for each significant character. Below is the graph of frequency versus time, the graph of average frequency versus time, and at the end, the final data of the session. In the general analysis of the patient's sessions, charts of vital signs, initial and final, are displayed throughout all sessions registered in the system. A table was generated with information on all session data, thus facilitating the comparison by the physiotherapist and showing the evolution of the patient's condition. In the reports, the user must select between general or specific analysis of the patient, select the patient and the session if necessary, and inform the desired file extension (HTML or PDF). Then the report is generated from the data in the database and with the file generation date.

4.2 The FisioLung Sensor Node

The Arduino Uno prototyping board based on the AT-Mega328P microcontroller was used to collect and process data from the accelerometer of the MPU6050 module. The choice of Arduino Uno was due to its practicality in integrating with sensor modules and the computer. The Arduino code was developed using the library for I2C communication called Wire, the Adafruit MPU6050 library to capture the data obtained from the module, and the Arduino Fast Fourier Transform (FFT) library for processing them. The MPU6050 module was selected due to its ability to use its accelerometer. The option for the Wire and Arduino FFT libraries was due to their practical implementation with the Arduino.

The logic implemented for the sensor node was developed using the Wire, Adafruit MPU6050, and Arduino FFT libraries, which were used for communication between the development board and the accelerometer, which allowed adjustments to be made to the accelerometer and applying the FFT. Initially, during the setup, the communication between the MPU6050 module and the microcontroller was started, and soon after, the use of the serial port at 38.400 Baud rates (bps) was established. The accelerometer was initialized, and the number of 64 samples was selected for the calculation of the FFT due to the internal memory limitations of the Arduino Uno development board. To perform the FFT, the number of samples must be 2^n , where n is an integer value. The higher the number, the more computational time is required for the algorithm. However, a higher resolution will be obtained for the results. Finally, according to the module's datasheet, the range was set to 8g (gravity). The sensor node architecture was illustrated in Figure 6.

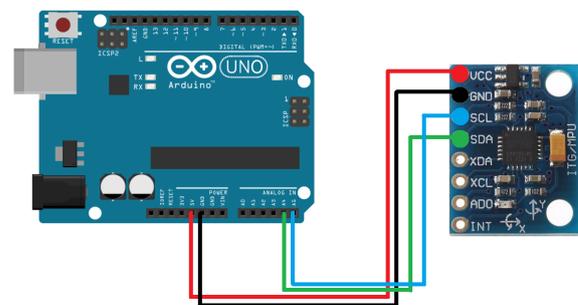


Figure 6. Sensor Node Architecture.

In the loop function, the main program, a repetition structure, executes the numbers of samples to fill the arrays of the three axes of the accelerometer. After collection, the data of the three axes are treated with the Arduino FFT library functions. They are returned already calculated, in addition to identifying the frequency peaks of the three axes. In the end, the samples are written on the serial port, and the data of the three axes with identification codes to carry out the parser in the project's back-end.

Many experiments were performed, and the results and discussions will be presented in a results chapter. However, considering the results and reports by the community, it was proposed improvements to FisioLung. This way, in this work, in the next section, these modifications will describe.

5 FisioLung System 2.0

After carrying out the tests in the first version of the FisioLung project, it was found that the frequency data obtained disagreed with those obtained in the literature. In this way, we sought to use better-performance hardware to process the data from the sensor. Also, it was observed that the positioning of the sensor interfered with collecting reliable data.

FisioLung 2.0 was developed to correct the problems of the project. This version uses an ESP32 NodeMCU, which performs better than the Arduino Uno used in the first version of the project. Besides that, a power bank was used to power supply the boards and the sensor, allowing more mobility for the project. Another modification made was using a cotton glove for coupling the sensor. In addition, an application was developed in the Flutter framework for communication between the developed sensor node and the web application. The initial version web system was modified to receive the resultant of three axes of the sensor and the smartphone app. It is possible to view the technique's data on the fly on the app.

5.1 FisioLung Glove

The proposals for improvements to the FisioLung 2.0 system are present in the device's compactness, replacing the Arduino UNO platform with an ESP32 NodeMCU in the prototype architecture. This allowed a more compact solution with lower energy consumption. In addition, the NodeMCU already has built-in Wi-Fi and Bluetooth communication modules, which allows for a compact solution that is easy to integrate with other devices. For capturing the vibration by the sensor, a larger scale was set for the accelerometer, as shown in the datasheet of the MPU6050 module, which has an acceleration scale ranging from 2g to 16g, where $g = 9.8\text{m/s}^2$. The main goal was to measure the frequencies between 12 and 20 Hz using movement acceleration. It is important to note that to observe the wave produced by the movement and, in this way, explore the greater capacity of the sensor in question, a 16g scale was set. To illustrate the resultant motion wave, the resulting vector of the three axes delivered by the sensor was obtained using the formula (1), considering linear algebra to extract a resulting vector in a 3-axis plane.

$$\sqrt{x^2 + y^2 + z^2} \quad (1)$$

In order to capture the data at the exact instant of the execution, an on/off system was implemented in the architecture. Thus, by using a pressure button attached to the glove and located on the physiotherapist's index finger, it is possible to initiate the application readings when the applicator starts the vibration and finish when the applicator wants to interrupt the vibration. In this way, it is possible to produce a more satisfactory and reliable result of samples during Vibrotherapy. The changes promoted more accurate and reliable samples, as we restricted data capture only when the technique was applied. Besides that, by adding the resulting vector filter, the position of the sensor does not interfere with sampling. As a result, the movement resulting from the three axes is considered, which did not happen in the previous version of the prototype.

5.2 FisioLung APP

A mobile application prototyped in the Flutter framework was used as an intermediary for communication between the sensor node and the website developed in its first project version. This approach was selected as a more friendly solution and simple to apply Vibrotherapy sessions because it is not necessary to have an online management system. The application communicates by Bluetooth with the ESP32 NodeMCU and by HTTP with the website server, storing the data at the end of the session. The mobile solution presents the resulting frequency peaks on the fly and a band that changes color according to the vibrations performed considering the literature frequency thresholds.

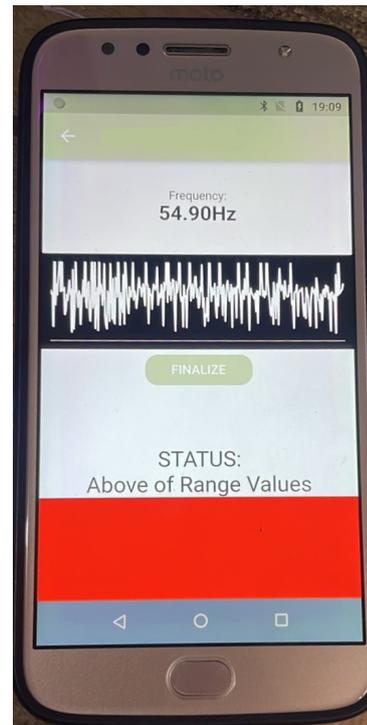


Figure 7. FisioLung APP.

The colors consider the following thresholds: red for frequencies above of-range-values, green for inside of-range-values, and yellow to below of-range-values). This approach allows the physiotherapist to analyze his performance during the session and to transform the FisioLung (glove and app) into an efficient training tool. Figure 7 illustrates the screen developed for the application. In addition, the application has a button to end the session. After being pressed, the application sends the data by HTTP to the website's back-end.

5.3 FisioLung 2.0

After modeling the mobile application and making the cotton glove which contains the MPU sensor and the ESP32 NodeMCU, we set out to integrate the system as a whole. Thus, the architecture of the new solution can be seen in Figure 8. This solution communicates with the local server via HTTP in the same way that FisioLung 1.0. However, the app, not the node sensor, transmits the data log. All data collected is sent to the system's back-end at the end of the session. In

addition, using the mobile application developed in Flutter without an internet connection is possible to visualize the Vibrocompression frequency. However, a connection is required to send the data to the back-end.

Another modification concerning version 1.0 of the project was the new approach regarding the three axes. This way, the calculation is performed considering the resulting movement of the three axes as a set. In this way, the position of the sensor does not interfere with the calculation, and it can be used in different hand positions or different hands.

After integrating the modifications, experiments with patients and professionals were performed. This experiment aims to verify whether the data obtained in this version correspond to those found in the literature. We evaluated the performance of the new architecture (FisioLung 2.0) versus FisioLung 1.0. In addition, more information about the developed system can be viewed on the project's GitLab³. The next session will present the results and reflections of the different estimates.

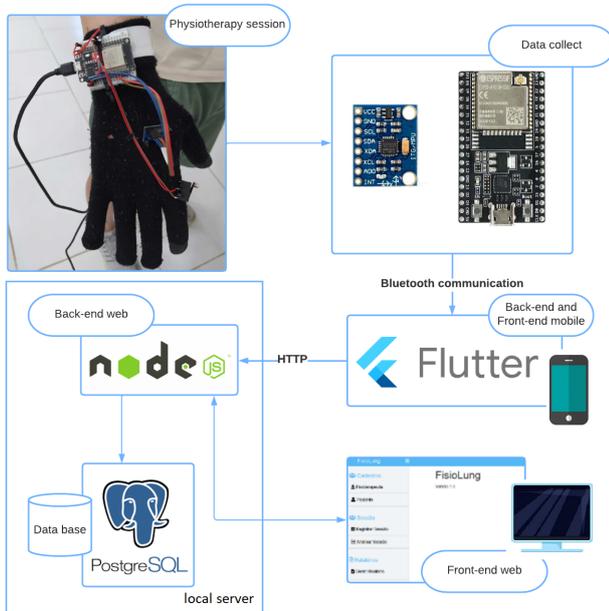


Figure 8. FisioLung 2.0 Architecture.

6 Results and Discussion

After completing implementations, both versions of the FisioLung System performed experiments for all its functionalities. This experiment aims to elucidate the performance of the system in registrations, session recording, session analysis, and reports. Patients and physiotherapists were initially registered to test the solution's operation and perform session recording tests. The results happened as expected, with the entries stored in the application's database. Notably, all tests performed involved physiotherapy professionals who helped develop the solution prototype.

³Documents available in: https://gitlab.com/gimm_unipampa/fisiolung2.0

The experiments going to be reported as follows performed on two moments. The first experiment was performed to evaluate the FisioLung System for the 1.0 version. The second was performed to evaluate improvements in the FisioLung System 2.0, especially for this work.

6.1 FisioLung 1.0 Experiments

Concerning version 1.0 of the application, with the sensor node already connected to the computer and the accelerometer, the user is directed to the vibration analysis screen. In the control part of the application, there are the session command buttons, where it is possible to start and end the analysis of the chest vibration technique. The results for this step happened as expected. The software received the necessary information from the sensor node, and thus, the data were presented accurately and without delays. The peak rate data and the average of the peak rates over time are shown at each collection. A state control section can be colored green, yellow, or red. This section corresponds to the performance of the technique applied to the patient, corresponding to good, satisfactory, and unsatisfactory levels, depending on the information in the literature. When the close session button is clicked on the website, the corresponding data is stored in the database (Figure 9), as expected.



Figure 9. Thoracic Vibration Analysis Record.

Selecting the patient and a specific session to be analyzed is necessary. After loading the page, the graphs of the initial and final vital signs are displayed to illustrate to the physiotherapist the difference that may have occurred during the session. In Figure 10, the graph of the frequency peak of the collections concerning time is presented, and the illustrated graph presents the frequency peaks over time of the vibration analysis. This graph is responsible for elucidating the points of greater frequency and more significant physical effort by the physiotherapist in the application during the session. Thus, it is possible to identify when the Vibrocompression technique applications took place and verify whether the performance is within the range stipulated in the literature.

In the general session analysis, it is also necessary to select the patient, and then the analysis page is generated with data from all sessions of the selected individual. Initially, the patient's data are displayed, then, as shown in Figure 11, a table is shown with the data of the vital signs of the patients in each session, in addition to the date, session's time, the

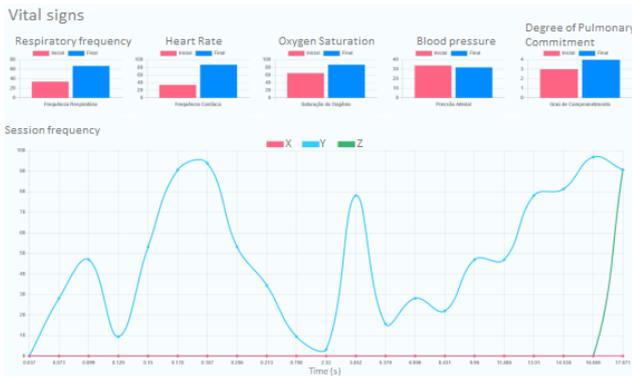


Figure 10. Session's Data.

physiotherapist who applied the session, and an access link to each specific session.

ID	Fisio	FR Inicial	FR Final	FC Inicial	FC Final	SO Inicial	SO Final	PA Inicial	PA Final	GCP Inicial	GCP Final	Tempo (s)	
9	João	64	71	87	21	43	21	56	45	3	3	22.433	28/7/2021 Access
10	João	76	65	45	45	63	45	34	56	3	2	16.4	28/7/2021 Access
11	João	70	70	70	70	70	70	70	70	2	2	17.26	28/7/2021 Access
12	João	73	75	73	73	73	73	79	2	1	17.872	28/7/2021 Access	

FR: Respiratory Frequency FC: Heart Rate SO: Oxygen Saturation PA: Blood Pressure GCP: Degree of Pulmonary Commitment

Figure 11. Table with Session's Data

Finally, line graphs show the patient's evolution throughout the sessions. Each vital sign and the scale of the degree of pulmonary impairment are illustrated at this stage. FisioLung also provides the resource for generating reports to be accessed. The specific or general session report option must be chosen. In the specific one, the patient, session, and format must be selected, and in the general one, the patient must be selected and the format. Formats can be PDF or HTML, and the desired report with the current date is generated.

The session data used in the first evaluation was strict to test the performance and demonstrate the functionalities of the FisioLung system. On the other hand, in the second moment, experiments were carried out with a group of physiotherapy students and the teacher in charge. The activity was carried out at the URCAMP University's Hospital Doutor Mário Araújo, where each physiotherapist performed a session with five repetitions of the vibration technique. The technique was applied to a seated volunteer, as shown in Figure 12.

The physiotherapist students' experiments session was organized to validate the system. The session included the registration of fictitious patients, the performance of the manual chest vibration technique, and the demonstration of the operation of the FisioLung software. The main goal was to collect their opinion about the system. Ten students aged between 21 and 39 years old, supervised by a physiotherapist teacher, participated in the activity.

Regarding the protocol for using the sensor, during the experiments, specific care was taken depending on the position of this equipment in order to obtain information more reliably. Thus, two accelerometer sensor positions were analyzed to collect vibration data above the hand and at the thumb. The accelerometer was attached to the skin in both



Figure 12. Physiotherapist's Students Session

cases utilizing adhesive tape. We used the accelerometer on top of the hand due to the practicality and sensitivity of the sensor.

In Figure 13, the vibration frequency graph is illustrated by applying the Vibrocompression technique. The average frequencies reached from the five movements of execution of the manual vibration technique were 1.25 Hz, 51.27 Hz, and 53.56 Hz in the axes *x* (pointing to the thumb), *y* (pointing to the index finger) and *z* (pointing to the plane outside the hand) respectively. Values that are in the stipulated frequency range for performing the technique, that is, between 3 and 75 Hz, according to Sarmento, except for the *x* axis. In the graphs, the purple lines indicate this expected frequency range. It is possible to notice that the behavior of the chart has highs and lows due to the application of the technique by the physiotherapist.

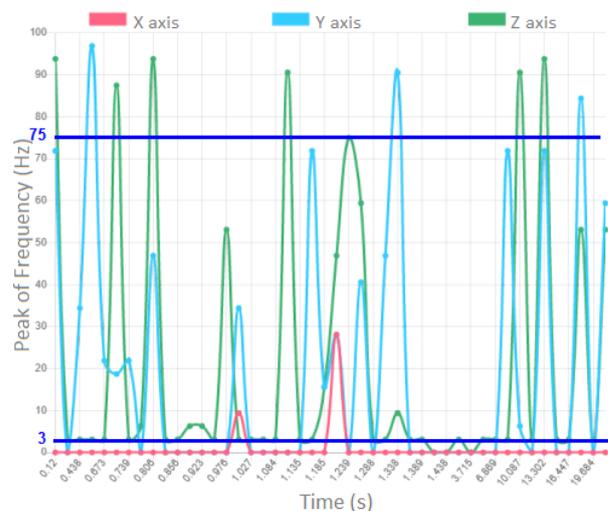


Figure 13. Graphics Generated

The average frequency levels obtained from the vibration applied by the volunteers for bronchial clearance are 4.5 Hz on the *x* axis, 66.61 Hz on the *y* axis, and 68.11 Hz on the *z*

axis. Generally, the frequencies obtained follow Sarmento's reference values, where the frequency range that causes vibration at the bronchial level is between 3 and 75 Hz, numbers that are found in the mean values of the y axes and z .

Regarding the x axis, it presents low values in most applications due to the movement. The position established for carrying out the sessions in the seated volunteer captured vibration values in the y axis, indicated for the index finger, and in the axis z , pointing out of the plane of the hand, while on the x axis, indicated for the thumb, the values are low including zeros. This fact was also reported in Corrêa's work.

The standard deviation on the x axis reached values between 2.79 and 2.81. The values presented for the y axis were between 14.59 and 9.86; on the z axis, the values were in the range of 16.54 to 7.58. The higher values for the standard deviation found on the x , y , and z axes occurred because the collected data were spread over a wide range of values. It happened because the vibration applied by the volunteer in the execution of the technique varied in each movement. Thus, low values were collected during low vibration captured in the accelerometer sensor, and high-frequency values were obtained during moments of more significant vibration in the execution of the technique.

The values presented are the results of the performance in applying the technique by the physiotherapists during the experiment. The performance at the time of application influenced the results of each individual, who obtained higher or lower values due to the vibration performed. The lowest average frequency value was 51.27 Hz on the y axis, performed by physiotherapist 1, while physiotherapist 2 obtained the average frequency at 71.81 Hz. The lowest mean frequency value on the z axis was 53.56 Hz, performed by physiotherapist 1, while the highest mean frequency value was 79.38 Hz, applied by physiotherapist 2. On the x , an axis average for physiotherapist 1 was 1.25 Hz, while for physiotherapist 2, it was 1.26 Hz.

In general, the tests carried out using the prototype were satisfactory. Considering that the proposed solution is low-cost, a low-sensitivity sensor is necessary. Based on the observations made and within the limitations, the prototype met the proposed objectives, showing the variations of each physiotherapist in applying the technique, thus helping to homogenize the execution of the movement in the ideal frequency range for the effectiveness of the technique.

6.2 FisioLung 2.0 Experiments

After modifying the architecture of FisioLung and creating FisioLung 2.0, some initial experimental procedures were performed, considering evaluating the modifications in functional aspects. A physiotherapy session was held at the Orthopedics Workshop of Bagé City that a local project partner with the Physical Rehabilitation Service of Bagé City (SRF). This partnership makes available technical support on physiotherapy subjects by her professionals. This way, three physiotherapists collected their opinion on the improvements. These were chosen to help the Medical Informatics and Microelectronics Group with professionals trained to perform the Vibrocompression technique. The session demonstrated how FisioLung 2.0 works and applied the thoracic

vibration technique. The technique was applied in two ways: one with the patient standing and the other with the patient lying down, as illustrated in Figure 14. Twelve sessions were performed with three physiotherapists and two patients. In each session, five Vibrocompressions techniques were applied. The Bluetooth communication is performed between the sensor node and the mobile device to start the tests. After, the professional places the glove on the hand and fires the on/off trigger to start the session. At the end of the session, the professional selects the closing command button, where all data collected is sent to the web system database. As in version 1.0 of the system, the right hand of the technique applicator was always used. However, in the future, we will do studies to determine whether there is a hand for better results.



Figure 14. Experimental Procedure in Patient.

The results in this step were satisfactory; the mobile software can communicate with the sensor node and send the information collected at the end of the session to the database. In the same way, as in the 1.0 system experiment, graphs are displayed at the end of each session to show the frequency peaks and the average frequency.

In Figure 15, the vibration frequency graph is illustrated during the application of a chest Vibrocompression technique performed by a physiotherapist with a standing patient. The average frequency from the five movements of execution of the manual vibration technique was 19.09 Hz for the three axes. That is, the value found is in the stipulated frequency range for the execution of the technique. The outliers of the graph were created between the movements, and it was possible to verify that despite the switch on/off approach being better than the previous solution, it still needs improvements.

Table 1 shows all Vibrocompression sessions performed by physiotherapists on patients, where at certain times they were standing or lying down, to verify whether or not the positioning of the sensor interfered with the collection of reliable data.

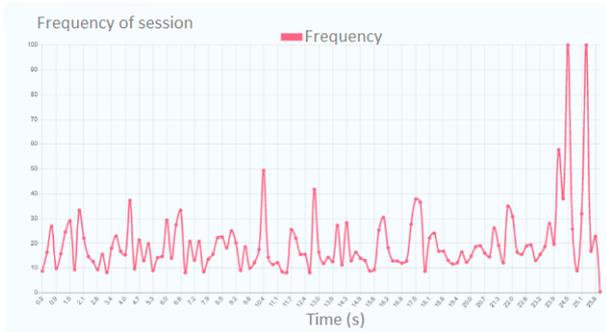


Figure 15. Frequency During Experimental Procedure in Patient.

Table 1. Frequency during Experimental procedure.

Professional	Position	Frequency
1	standing	19.09 Hz
1	standing	18.59 Hz
1	lying down	17.90 Hz
1	lying down	20.31 Hz
2	standing	21.25 Hz
2	standing	19.47 Hz
2	lying down	15.92 Hz
2	lying down	19.42 Hz
3	standing	14.35 Hz
3	standing	24.90 Hz
3	lying down	19.47 Hz
3	lying down	18.92 Hz

In this way, the improvements created allow more accurate and reliable samples. How we restrict data, capture only when the application is started, and by adding the resulting vector filter, the position of the sensor does not interfere with the sampling. This since the result takes into account the movement of the three axes as a set, which did not happen in the previous version of the prototype.

The experiments presented more realistic data with more minor variances. This way, the system behaved more stable with the new architecture with Bluetooth communication, ESP32 NodeMCU, and the development of the cotton Glove. According to the physiotherapists, the results are very close to reality and what would be expected. The following steps will be laboratory tests to check the calibration, in addition to carrying out a robust experiment, again with a group of students. Besides that, some modifications like configurable range frequency on the app and improvements on the switch on/off in the Glove. In short, after a new series of experiments, the system will have become more reliable and effective in aiding the application of Vibrotherapy, providing a low-cost training tool for professionals, and monitoring the evolution of patients in respiratory physiotherapy.

6.2.1 Evaluation FisioLung 2.0 by physiotherapists

In order to initially evaluate the usability, importance, and relevance of the FisioLung System 2.0 system, a research instrument was created available to the experiment participants in the form of a questionnaire. In order to collect feedback regarding the system’s use and elucidate whether it can be used in respiratory physiotherapy sessions, for this evaluation model, the Technology Acceptance Model was used.

Thus, the questionnaire answered by the physiotherapists contained thirteen objective questions, twelve with quantitative answers based on a 5-point Likert scale, and one with a descriptive answer. In questions with a Likert scale, scores from 1 to 5 were defined, referring to the following values: “completely disagree”, “disagree”, “no opinion”, “agree”, and “completely agree”. Table 2 shows the questions included in the questionnaire.

The first variable of the TAM model, which seeks to assess the degree of technology adoption, was measured through six questions, which are displayed in the Table as [FUP1], [FUP2], [FUP3], [FUP4], [FUP5] and [FUP6].

Table 2. Quiz Questions.

Number	Question
[FUP1]	Is the tool easy to use?
[FUP2]	Is the tool self-explanatory in terms of navigability? Is it possible to understand and navigate your menus without problems/difficulties?
[FUP3]	Is the tool clear to be understood?
[FUP4]	Is it easy to find the information, I want in the app?
[FUP5]	Is the tool intuitive so that before clicking on a button, I know what it will do?
[FUP6]	Is using the tool pleasant?
[UP1]	Does the tool provide viewing of reports at the end of the session?
[UP2]	Does the tool provide the visualization of graphs in the data output?
[UP3]	Does the tool produce the results I expect?
[IC1]	Do I recommend using the tool?
[IC2]	Am I motivated to use the tool?
[IC3]	Did using the tool meet my expectations?
[IC4]	Is the tool appropriate for performing chest vibration?

Figure 16 illustrated that the maximum response was obtained for both questions. According to the evaluations received, it is possible to affirm that the FisioLung System 2.0 has an easy navigation system. That is, it is possible to navigate the application quickly, in a practical way, and to improve the professional’s performance in the performance of Vibrocompression technique. In this way, the system is efficient in terms of usability and navigability in conducting and analyzing sessions.

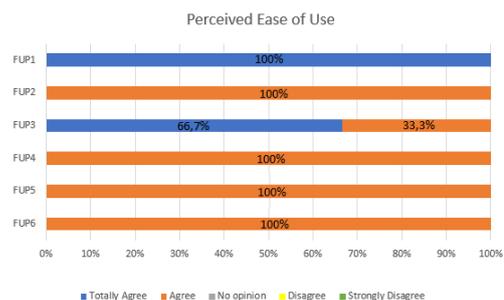


Figure 16. Assessment by physiotherapists.

The second variable of the TAM model, which is defined as the degree to which professionals agree that the system will increase their performance in Vibrocompression, was measured through three questions, which are shown in Table [UP1], [UP2] and [UP3] as illustrated in Figure 17. For both questions, the maximum response was obtained. According to the evaluations received, it is possible to state that the FisioLung System 2.0 meets the performance requirements to meet the needs of physiotherapists to assist in Vibrocompression through graphics generated in real-time during the session.

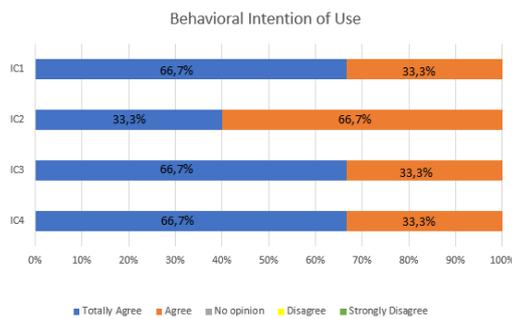


Figure 17. Assessment by physiotherapists.

The third variable used, which is defined as the degree of intention to use the system, was measured through four questions, which are shown in Table as [IC1], [IC2], [IC3], and [IC4]. Figure 18, illustrated that the maximum response was obtained for all questions. As measured through the responses obtained, it is possible to state that the evaluators would use the FisioLung System 2.0 system in their daily lives to perform the Vibrocompression technique due to its practicality and functionality, mainly because the system is capable of storing the data captured during the session to obtain feedback on the evolution of patients.

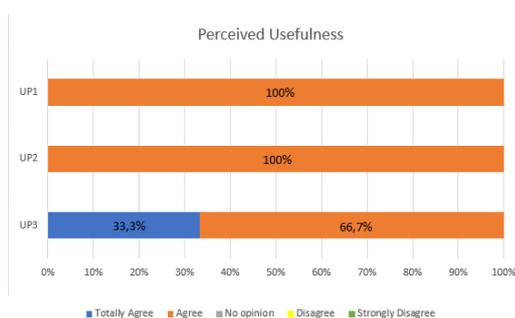


Figure 18. Assessment by physiotherapists.

Finally, a last question was asked to determine whether the system evaluators had any suggestions for improvement for the application. Thus, the evaluators explained that adding a button to pause data collection would be essential to take a break between some maneuver applications.

In the last, evaluating the results obtained through the validation and analysis of the research instruments, it can be verified that the built system can be used to help professionals apply the chest Vibrocompression technique. With the high

scores, verifying that the system meets the proposed requirements and that its development was carried out satisfactorily is possible.

7 Conclusion

Based on the proposed research, we can conclude that the developed system met the expected results. The study on state-of-the-art respiratory rehabilitation and physiotherapy sessions was carried out to build a proposal for a sensor node and an application to aid in applying respiratory physiotherapy techniques. In this way, the system implementation technologies were defined according to the identified needs.

With the development of the FisioLung system and its improvement to the version of the FisioLung System 2.0, patients suffering from lung diseases will benefit from these resources throughout the treatment and recover more quickly. The system’s development included analyzing the thoracic vibration technique, storing session data, and generating analyses related to execution and patient and physiotherapist registration. A general analysis of the patient’s sessions was developed, which provides detailed monitoring of the patient’s status during treatment and generates reports to display the collected data.

For version 1.0 of the project, tests were carried out with two students from the physiotherapy course to validate the implemented solution and evaluate the system’s performance, usability, and viability. A questionnaire was applied to obtain feedback from the physiotherapists, where the questions obtained averaged close to the maximum value (five).

As for version 2.0 of the project, tests were carried out with three physiotherapy professionals to validate the update developed, including adding a glove to which the MPU sensor and the ESP32 NodeMCU were attached. Also, a power bank was used to make a mobility solution on the glove. In the same way, to evaluate the usability and viability of the system, a questionnaire was applied following the Technology Acceptance Model to obtain the opinion of the physiotherapists, where the questions obtained maximum answers.

The obtained results were presented and discussed regarding the application of the Vibrocompression technique. The expected results were achieved. Thus, it is possible to analyze the frequency values of the execution by the physiotherapist and verify if they are following the values presented in the literature. The system obtained approval close to the maximum in evaluating the physiotherapists who tested the system, thus being able to be used in the sessions of patients affected by pulmonary diseases. As future research activities, a project will be carried out to include automatic lung auscultation in the system, integrating hardware and software, and an analysis of the user experience and usability of the system, helping to improve interfaces through design patterns. Another modification is the addition of the definition and implementation of a battery to improve the mobility of the solution.

Finally, it is essential to highlight that the project developed was approved by the Research Ethics Committee of the Federal University of Pampa (UNIPAMPA) and registered at Plataforma Brasil under CAAE number 51777521.5.0000.5323.

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