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Multi-Beat Digital Stethoscope

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Abstract: Digital medical instruments are essential in today's world to make fast and precise diagnoses. By combining several features into a single device, healthcare can be provided more affordably and with greater patient care and medical efficiency. This project describes the development of a cost-effective digital stethoscope featuring an integrated oximeter sensor and a sound transducer. The stethoscope facilitates the simultaneous monitoring of spO2 (Saturation of Peripheral Oxygen) levels and heart activity. The sound transducer converts cardiac sounds into electrical signals, enabling the detection of anomalies in heart function. Real-time data on these vital signs is transmitted to a web-application that will be deployed on the doctors' phone, providing them with immediate access to patient information. This innovative device offers a two in one solution that is both efficient and affordable for both patients and medical practitioners.

Keywords: Stethoscope, SpO2, Heart function, Web-application, Monitoring.

Introduction

Monitoring and listening to the heart and lungs activities are crucial for identifying any abnormality or the beginning of any disease linked to both organs listed previously (American Lung Association, n.d.). In the rapidly evolving medical field, the need of multifunctional and especially low-cost devices has been increasing. The development of a digital stethoscope with integrated oximeter features is a significant advancement in this sector.

The proposed Multi-Beat digital stethoscope not only simplifies the process of monitoring the spO2 and heart activity levels but it also enhances the speed and reliability of diagnosis with a very affordable cost. Linking this device to a mobile web-application which ca be accessed on a doctor's smartphone or PC(Personal computer), will smooth any abnormality visual recognition relying on real-time graph and values with high precision in case of inconspicuous sounds heard via the stethoscope.

Objectives

The goal of this project is to create a digital stethoscope with integrated oximeter capabilities, which will improve patient monitoring and diagnosis. The project aims to simplify vital sign evaluation by integrating these essential tasks into a single, affordable gadget. This would enable healthcare practitioners to identify and treat medical issues more efficiently. The cutting-edge tool will offer real-time data that can be accessed via a mobile application, facilitating speedier and better-informed medical choices to enhance patient care.

Literature Review

The literature analysis highlights the evolution of electronic stethoscopes from traditional acoustic models to more advanced models with digital recording capabilities and improved sound amplification. The challenge with these improvements is having reliable results with the lowest cost possible which is the main purpose of this project.

Stethoscope's Evolution

The initial purpose of stethoscopes was to listen to a patient's chest sounds, assess the respiratory and cardiovascular systems, and gauge how effectively the trachea and bronchial tree were working as an airway (Sarkar et al., 2015a). During chest auscultation, medical personnel must pay close attention to the patient's interior sounds, particularly during the vesicular breath sound intervals (J. I. Gupta & Shea, 2023).

Multifunctional devices with quick processing rates have been greatly enhanced by technological developments in the healthcare industry. Wearable digital stethoscopes provide cordless, continuous, real-time auscultation for a range of illnesses (Bishop, 1980). Applications for smartphones may be coupled with these devices to provide continuous auscultation monitoring. The improvements to classic auscultation procedures in clinical and instructional contexts are intended for healthcare practitioners. Figure 1 illustrates the major milestones in the evolution of stethoscopes from analog to electronic, and ultimately digital.

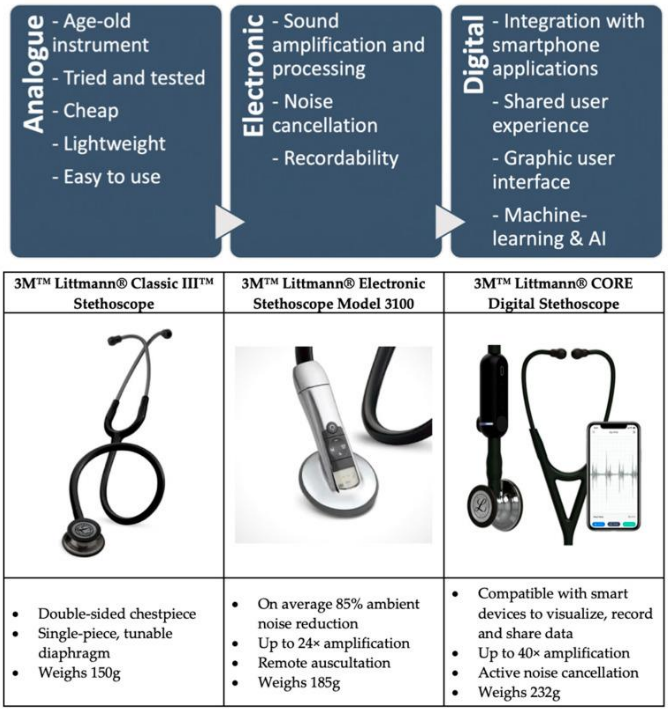

Figure 1. Evolution of stethoscopes over the year (Bishop, 1980)

Starting with the Analogue stethoscope, also known as "the traditional stethoscope", is used in order to amplify chest sounds during auscultations. It is mainly composed of a chest piece, a binaural earpiece, with the bell and diaphragm taking up lower and higher frequency (Bishop, 1980). Its ease of use and widespread availability make it a good choice for healthcare professionals.

Going to the Electronic stethoscope, which is considered an innovative method compared to the analogue one, has helped with higher clinical practice. Through it, chest sounds are amplified via electronic intervention providing audio feedback, sound level manipulation, audio data recording, and playback (Bishop, 1980). The conversion of chest sounds from analogue sound waves can be done via a microphone or a piezoelectric sensor, which will result in the amplification and processing of the sound waves' transduction into an electrical by passing through bandpass filters that are responsible of reducing unwanted noise that can corrupt the sound signal (Landge et al., 2018).

Now, concerning the digital stethoscope, it pushes the limits of chest auscultation techniques with the use of smartphone applications and connected data processing. Designed similarly to the electronic stethoscope, it incorporates a digital filter to eliminate interference from the electrical signal and extract the desired signal from the designated frequency range. The obtained heart and breath sounds are normalized to a particular scale and segmented into cycles thereby assisting in the identification and separation of the components of the pulse and breath (Bishop, 1980).

Motivation

As listed previously, digital stethoscopes are available in the healthcare market, or, the Multi-beat digital stethoscope encloses many sophisticated and trailblazing specifications that differentiate from any other normal digital stethoscopes. With its additional oximeter allowing the doctor the real-time tracking of the SpO2 value via the mobile application, the pulse sensor allowing the continuous bpm (Beats-Per-Minute) display, the conversion of sound to waves, as well as the reasonable low cost compared to any monotask digital stethoscopes, this multitask task stethoscope has significant advantages.

Lungs and heart function continuous wireless tracking is remarkably important for the doctors as well as any patient, allowing the avoidance of the direct turn to specialized and kind of complex medical tests like ECG (Electrocardiography) for heart activity, or the Spirometry for lungs activity. So, the visual and direct results added to the stethoscope's audible effects are very useful features that would help with making the diagnosis more accurate, improve clinical decision making, along with comfort provision for the patients.

Methodology

The Multi-Beat digital stethoscope contains an embedded network of various sensors and modules working together in order to give the user a very good accuracy and facilitate abnormalities diagnosis, using the stethoscope for a basic patient's examination will surely always available even with no power on. As soon as the batteries are connected to the MCU (Microcontroller Unit) of the device, heart sounds heard by the stethoscope will be directly transformed to electrical waves by the use of the microphone transducer which is responsible of converting sound energy into an electrical one. Moreover, the pulse sensor and the oximeter will also be automatically turned on allowing the continuous monitoring of spO2 and bpm levels.

The perpetual tracking will be done using a web-application (which will be accessible on the doctor's cell phone or PC), linked wirelessly to the MCU allowing real-time data transfer helping out the doctor to not only achieve multiple tests, but also having more reliable audible and visual results. Noting that all the data displayed on the web-app will be previously saved on the main database of this apparatus which is Google Firebase allowing each user (doctor) to create his own account along with data encryption as well as specific archive folders each for one patient. This resourceful innovation has a lot of potential usage in comfort technology and healthcare.

Components

Figure 2. Stethoscope

Medically wise, a stethoscope is used in order to listen to the internal sounds generated by the heart, lungs, and intestinal tract. In this project, the aim is to connect the stethoscope's internal circuit to an external circuit that will participate in converting the heart sounds to electrical waves, helping the doctor with a better diagnostic. This medical device represented in the (Figure 2) is used for acoustic auscultation and usually consists of flexible tubing, earpieces, and a chest piece with a bell, diaphragm, or both. The bell is more suited for low-frequency noises, whereas the diaphragm excels in picking up high-frequency sounds (Grenier et al., 1998).

Heart sound, a mechanical vibration that occurs during the cardiac cycle, is caused by the contraction of the heart muscle and the shock of blood flow to the ventricular wall during diastole. It creates a mild vibration signal as it goes around the chest wall (Swarup & Makaryus, 2018). By mimicking the features of an organism's life and organizational structure, medical bionics analyzes the structure, function, and functioning principles of living things and applies these concepts to medical technology.

The MEMS (Micro-Electro-Mechanical-System) heart sound sensor, which is composed of beams and cilia, primarily imitates the structural pickup mechanism of 3D fiber bundles seen in human otic hair cells which are represented in the (Figure 3 (a)). A cilium and very accurate cantilever beams make up the novel bionic MEMS microstructure, which combines the bionic principle, piezoresistive effect, and MEMS technology (Li et al., 2021).

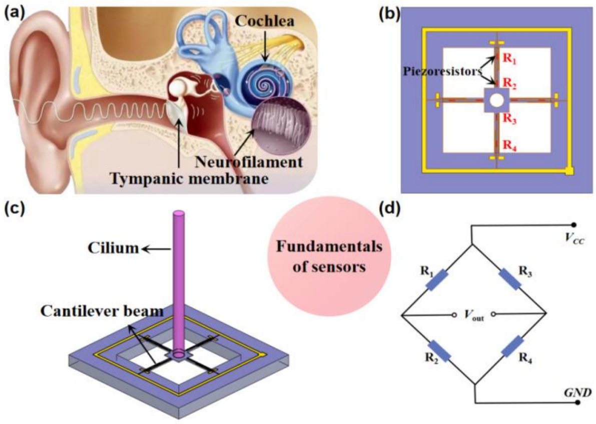

Figure 3. Principle of bionic microsensors (Yang et al., 2022)

A Wheatstone bridge is created when varistors with the same resistance are positioned underneath the greatest stress zone of cantilever beams. The bottom of the cilium is placed at the central connection of the beam members like shown in (Figure 3 (b)), (Figure 3 (c)) and (Figure 3 (d)) where V_{CC} means the input voltage of the bridge and V_{out} suggests the output voltage. When sound waves are applied to the biomimetic cilium, it oscillates and deforms the cantilever beams. Finally, the deformation of the cantilever alters the resistance of the varistor placed on its surface. The mechanical deformation is converted into electrical output via the Wheatstone bridge (Yang et al., 2022).

R_1, R_2, R_3 and R_4 form a set of Wheatstone bridge as shown in (Figure 3 (d)). At this time, the output voltage of the Wheatstone bridge is shown in [1]:

$$V_{out} = \frac{(R_1 + \Delta R_1)(R_4 + \Delta R_4) - (R_2 - \Delta R_2)(R_3 - \Delta R_3)}{(R_1 + \Delta R_1 + R_2 - \Delta R_2)(R_4 + \Delta R_4 + R_3 - \Delta R_3)} V_{cc} \quad [1]$$

In formula [1], the output of the sensor's circuit is V_{out}, its input is V_{cc} and ΔR is the resistance change (Yang et al., 2022). Where R_1=R_2=R_3=R_4=R, the above formula can be simplified as shown in [2]:

$$V_{out} = \frac{\Delta R}{R} V_{cc} \quad [2]$$

The resistance change is related to the stress on the cantilever beams, which is shown in [3]:

$$\frac{\Delta R}{R} = \pi_1 \sigma_1 \quad [3]$$

In formula [3], σ_1 is the longitudinal stress component, and $\pi_1$is their longitudinal piezoresistive coefficient (Yang et al., 2022). The sensor output must be set as high as achievable in order to increase the sensor's sensitivity. Placing the varistor in the maximum linear stress region of the cantilever beams can effectively improve the sensitivity of the sensor (Yang et al., 2022).

The schematic diagram of acoustic auscultation with bionic heart sound sensor is represented in (Figure 4). The transmitted acoustic energy decreases with the increasing impedance difference when sound is input over the border between two different mediums, but the reflection coefficient rises. The stethoscope and skin have a considerable reflection when they come into contact, which causes more attenuation and less transmitted acoustic energy. Consequently, after passing through human tissues and exhibiting increasing attenuation, the heart sounds were sent to the MEMS-based bionic sensor in order to get the maximal sound signal. Furthermore, because medical silicone oil (20cst) satisfies the unique acoustic impedance criteria of human soft tissue, it was chosen as the encapsulating material (Yang et al., 2022).

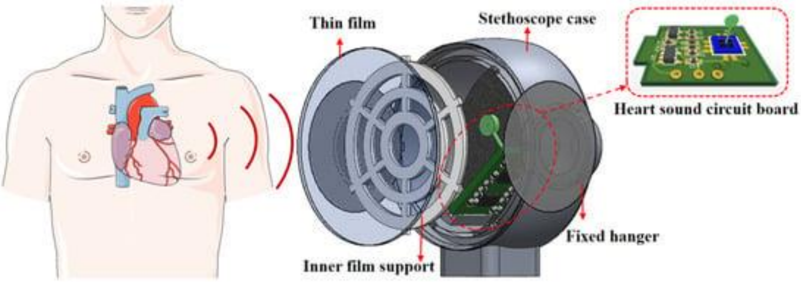

Figure 4. Diagram of auscultation with bionic heart sound sensor (Yang et al., 2022)

Moving to the next component of the Multi-Beat digital stethoscope which is the transducer which is an electrical device called a transducer is used to change the form of energy. One of the common examples is the microphone used in this project, which is a sound transducer. Thus, microphone is a transducer which converts variations of sound pressure into variations of electrical current (GeeksforGeeks, 2024). The sound detection sensor module shown in the (Figure 5) is the component that will be used in order to achieve this conversion process.

Figure 5. Microphone AMP MAX9814

Scientifically speaking, more than 2 types of microphones are available:

Carbon Microphone: Utilizes carbon granules whose resistance varies in response to differences in sound waves' pressure (Teja, 2024).

Moving Iron Microphone: This type of microphone moves an iron diaphragm in a magnetic field to produce a fluctuating electrical signal (Teja, 2024).

A moving coil microphone, also known as a dynamic microphone: uses a coil moving inside a magnetic field to convert sound waves into an electrical signal (Teja, 2024).

Ribbon Microphone: This device generates voltage by vibrating a narrow metal ribbon between two magnetic poles (Teja, 2024).

Piezoelectric Microphone: Utilizing materials that produce voltage when under mechanical stress, this device transforms sound into an electrical signal (Teja, 2024).

Capacitor Microphone: which encloses as an example, the High Sensitivity Sound Detection Sensor Module used in this project. It has two surfaces: a backplate and a conductive diaphragm. There is a fixed electric charge between the two surfaces. The diaphragm vibrates in response to the sound wave, changing the capacitance.

Given the constant charge, a voltage wave is produced by the fluctuation in capacitance. The distance between the plates determines the output. The output increases with decreasing surface spacing for a given sound level. The microphone capacitor operates under pressure. A voltage source is required in order to deliver the set charge. We refer to this voltage as polarizing voltage (Teja, 2024). Capacitor microphones offer excellent audio signals and linearity in their functioning. An electret is used to prevent polarizing voltage. An insulating substance that is permanently charged is called an electret. It is a magnet's electrostatic equivalent. A diaphragm and an electret slab make up one of the capacitor plates in electret capacitor microphones. There is no requirement for a voltage source because the electret offers a constant charge (Teja, 2024). The structure of the capacitor microphone is represented in the (Figure 6).

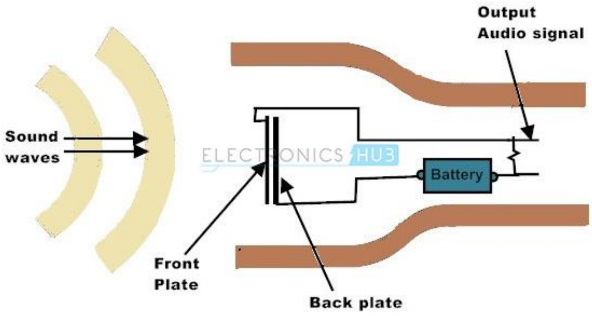

Figure 6. Capacitor microphone's structure (Teja, 2024)

In this project, the MAX9814 (Figure 5) will be used due to its low cost and high sensitivity in detecting sounds. Or, knowing that the typical frequencies of normal heart sounds fall between 20 and 150 Hz makes it hard to hear these sounds on a naked ear, and that is why auscultation tools are needed (Alanazi et al., 2020). In order to amplify these sounds before detecting it with the microphone, a 3D printed connector (stethoscope to mic) is designed in order to amplify the sounds detected by the stethoscope before the microphone receives it for more reliability, as well as isolating noises coming from the stethoscope's external environment (Figure 7).

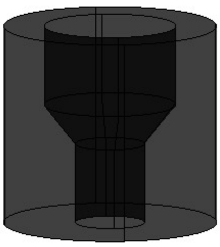

Figure 7. Customized 3D printed connector

This specific configuration of the connector placed on one end of the stethoscope's ear tube instead of the standard ear piece and on the other hand on the microphone, will allow the execution of the previously listed functions. Moreover, a pulse oximeter and heart rate monitor will be implemented in the Multi-Beat digital stethoscope in order to measure and monitor the lungs (spO2) and heart (bpm) functions. The component is shown in the Figure 8.

Figure 8. MAX30100 IC

The pulse and blood oxygen levels are measured with a pulse oximeter. Certain medical issues may cause the person to have low oxygen saturation. The reading may also be impacted by skin tones. A non-invasive test called pulse oximetry gauges the blood's oxygen saturation level and the heart's pulse, which is expressed in beats per minute. It can quickly identify even minute variations in oxygen concentrations. These values demonstrate how well blood travels to the parts of the body that are farthest from the heart, such as the limbs and legs, to provide oxygen (How2Electronics, n.d.).

This component will be connected to the Multi-Beat device through wiring independent from the circuit composed of the MEMS heart sound sensor and the transducer in order to be able to achieve a parallel monitoring of the patient's bpm and spO2 as well as a continuous, non-stop display of the waves representing the heart's function carried through the stethoscope's use. Noting that these 2 independent circuitries will be connected to the same MCU(Microcontroller Unit) in the aim of establishing real-time multi-records of more than 1 organ. This sensor will be put in a direct contact with the patient's finger or can be even used on his earlobe. Its work will be divided into 2 parts: HR (Heart Rate) measurement in bpm and pulse oximetry (measuring the oxygen level of the blood).

Internal LEDs, optical components, photodetectors, low-noise circuitry, and ambient light rejection are all included. In order to adjust LED pulses for SpO2 and HR measurements, the MAX30102 includes Red and IR LED drivers. With the correct supply voltage, the LED current may be controlled between 0 and 50 mA. The LED pulse width may be adjusted between 69µs and 411µs, enabling the algorithm to maximize power consumption, accuracy of SpO2 and HR, and other factors based on use scenarios (How2Electronics, n.d.). Moving to the working principle of the MAX30100 (noting that the module being used in this project has the MAX30102 as its photodetector), it operates by beaming both lights onto the earlobe or finger (allowing both lights to readily penetrate the tissue), and then using a photodetector to measure the quantity of light that is reflected. This method of pulse detection through light is called Photoplethysmogram (How2Electronics, n.d.). One property of arterial blood's oxygenated hemoglobin (HbO2) is its ability to absorb infrared light. Further absorption of infrared light occurs in proportion to blood redness, or hemoglobin content. Shown in the (Figure 9) is a blood vessel existing in the finger. The amount of reflected light varies as the blood is pumped through the finger with each heartbeat, causing the photodetector's output waveform to shift. A heart-beat (HR) pulse reading soon appears as you keep shining light and collecting photodetector signals (How2Electronics, n.d.).

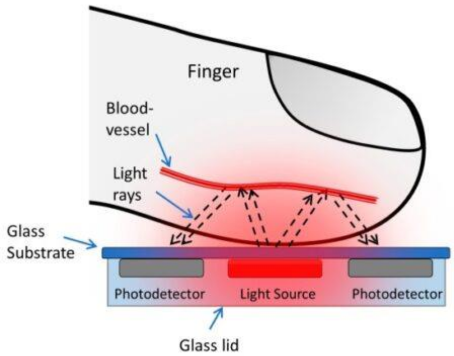

Figure 9. Working of the pulse oximeter sensor (How2Electronics, n.d.)

Concerning the pulse oximetry, it works on the theory that the quantity of oxygen in your blood affects how much RED and IR light is absorbed (How2Electronics, n.d.). The interval of Red light and infrared (IR) light shown in (Figure 10) shows the specific wavelengths that can be absorbed by the oxyhemoglobin (HbO2) in arterial blood.

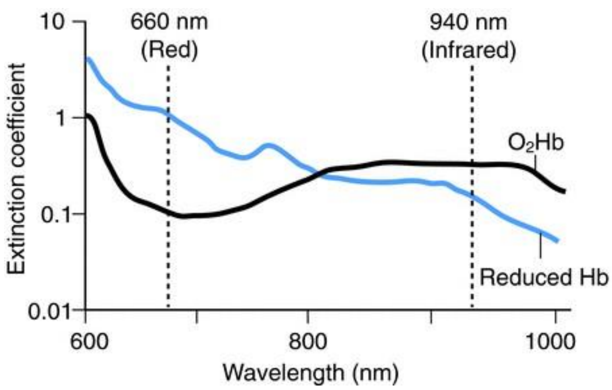

Figure 10. Pulse oximetry graph (How2Electronics, n.d.)

Moving to the main electronic component implemented in this innovation which is the Arduino UNO. It is a microcontroller-based device with 14 digital pins used for various purposes (Krelja-Kurelovic, 2023) shown in Figure 11. It can be used for almost every task. It can also be used for prototyping and developing new applications. This component is considered as the main brain of our device as well as its responsibility in monitoring and synchronizing all the components of the system.

Figure 11. Arduino UNO module

A mobile web-application will be connected wirelessly to this MCU via the use of the ESP8266 12-E NodeMCU shown in (Figure 12) which is a Wi-Fi module that is used in the development of Internet of Things (IoT) devices. It is based on the ESP8266 system-on-chip which integrates a microcontroller unit and a Wi-Fi radio. Using this unit allows interfacing with external sensors, actuators, and other devices, as well as the main database of this innovation: Google Firebase, where all the real-time data of each patient will be saved securily (Hanna & Rosencrance, 2023).

Figure 12. The ESP8266 12-E NodeMCU module

Results and Discussion

Once all signals are met, real-time monitoring of the heart-function waves, bpm, and spO2 will be done via a mobile web-app. With the help of Google Firebase which is a set of cloud-based development tools that helps mobile app developers build, deploy, and scale their apps, viewing and monitoring a continuous wave graph of the patient's heartbeat will be done on the groundbreaking web-app developed by the multi-beat digital stethoscope team, as well as displaying in real-time the collected bpm and spO2 values on it

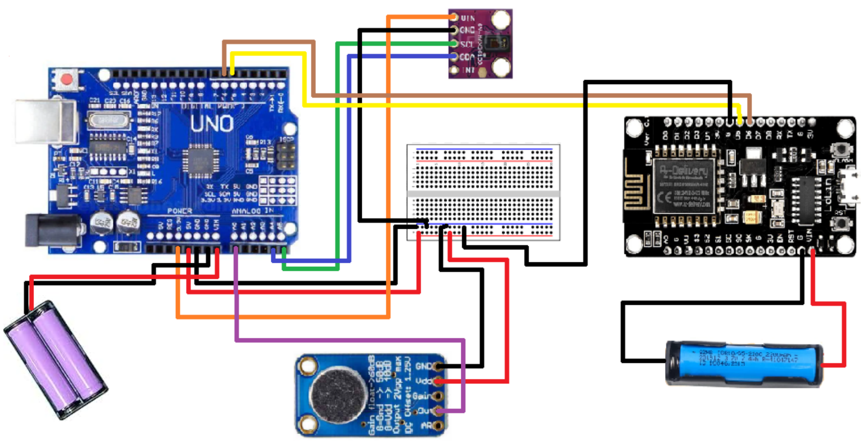

Figure 13. Design of the system

Figure 13 shows the interrelationship among these modules. The block diagram emphasizes the processes of the Multi-Beat Digital Stethoscope and is described in (Figure 14). The system's flowchart is showed in (Figure 15).

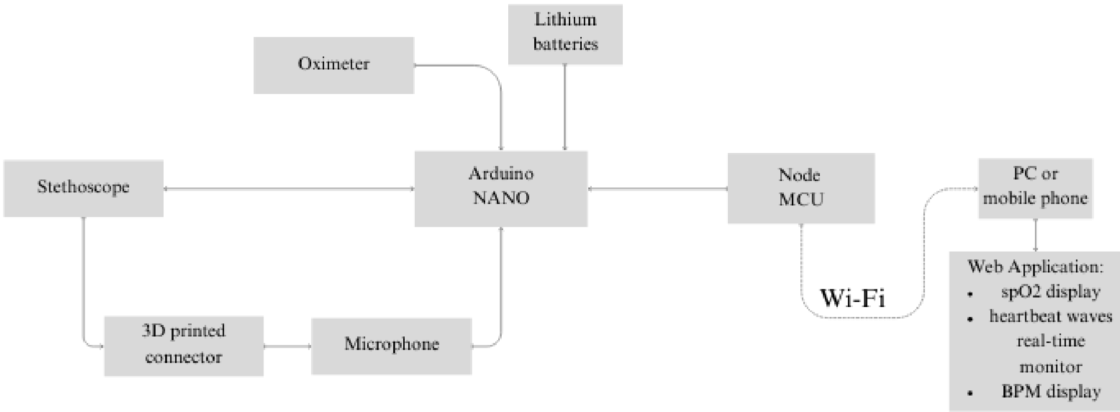

Figure 14. Block diagram of the system

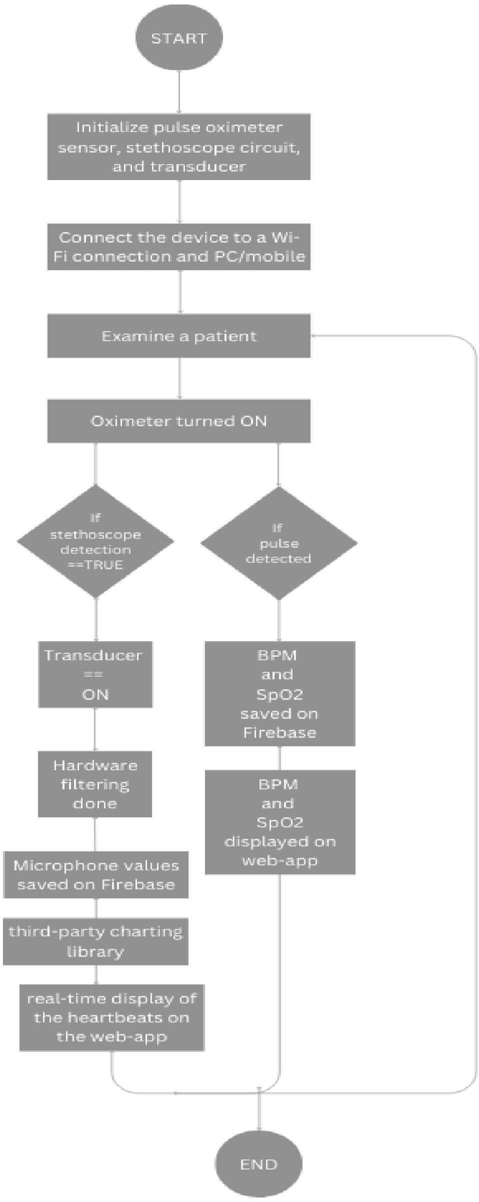

Figure 15. System's flowchart

Web Application Evaluation

After connecting all the components together, turning on the device, and start the patient's examination the stethoscope will be receiving the heartbeats' sounds that will be converted via the transducer to electronic waves. But even when using a high sensitivity sensor, incorporating filters to remove noise is mandatory. Knowing that high sensitivity detectors capture more details concerning the heart sounds, they are able to also pick up ambient noise and some unnecessary signals.

The heart sounds, typically, fall within the frequency range of 20 Hz to 500 Hz, so filtering out the frequencies falling outside this range is crucial; this process will be done using a band-pass filter to isolate the desired frequency interval (20 Hz to 500 Hz) what will enhance and improve the clarity of the signal. Providentially, the spO2 and bpm levels will be displayed on the same web dashboard after placing the patient's finger directly on the sensor which will be placed in a specialized case for it as well as placing the stethoscope's chest piece on the patient's chest. (Figure 16), (Figure 17), (Figure 18) and (Figure 19) show respectively the display and monitoring results on each of the Arduino and NodeMCU serial monitors, as well as each of Firebase and the web-app dashboards.

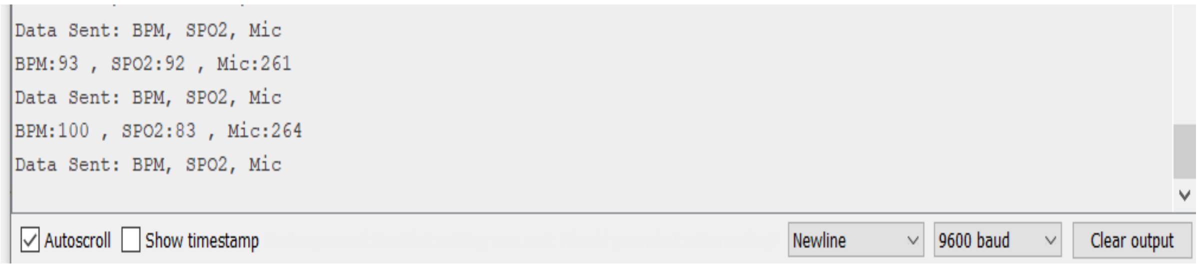

Figure 16. Arduino UNO serial monitor

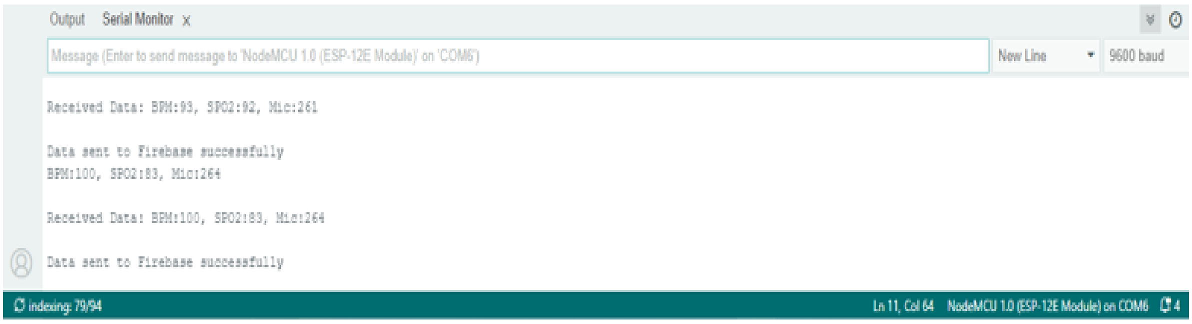

Figure 17. NodeMCU serial monitor

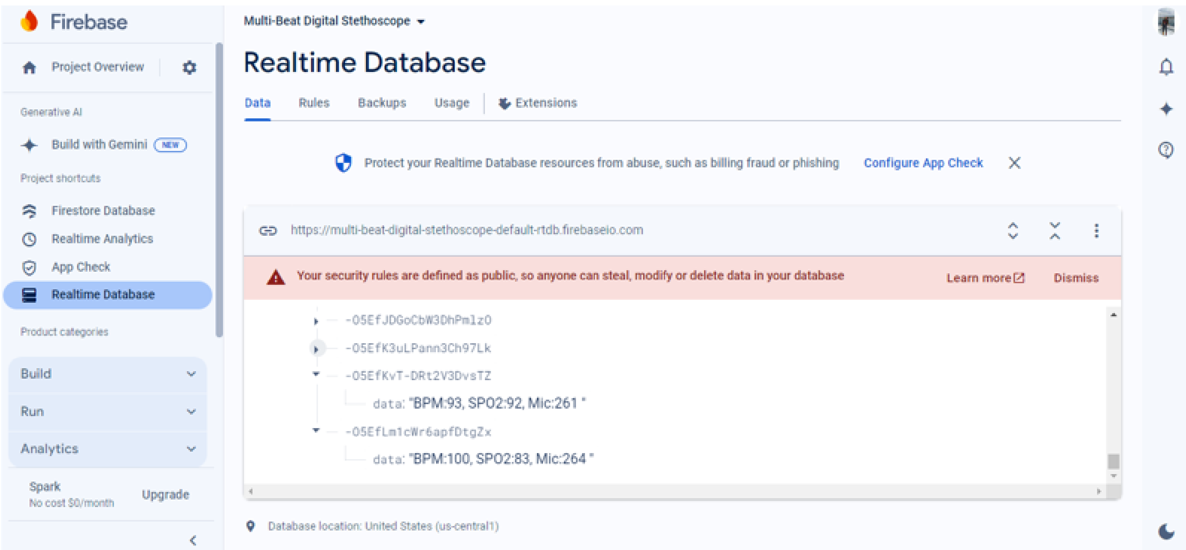

Figure 18. Firebase dashboard

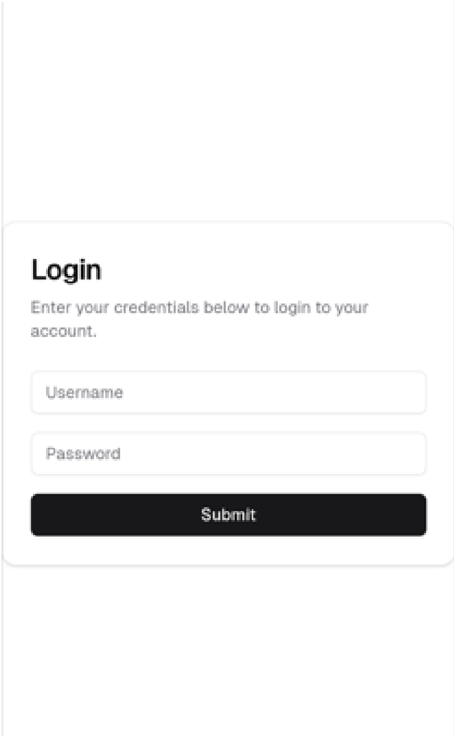

Figure 19. web-app first page

Figure 20. Web-app dashboard

Results Assessment

In order to discuss the results shown in the previous figures, the development of this innovation will be broken down extensively. First and foremost, the components are connected to the main brain of this machine as seen in the (Figure 13). Afterwards, the connection of this MCU to the NodeMCU is done. This microcontroller is responsible for transferring all the sensors' data collected in real-time from the Arduino to the Google Firebase via Wi-Fi. An analysis was done for the data received by the Arduino from the GY-MAX30100 and is shown in (Figure 21).

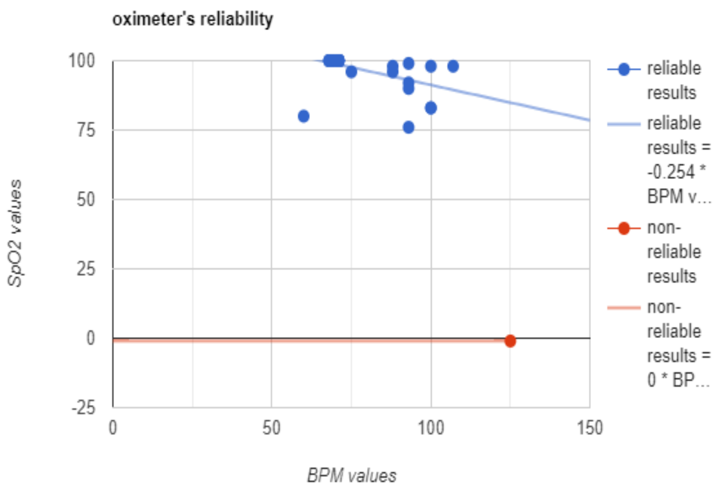

Figure 21. Scatter plot for Oximeter accuracy analysis

The scatter plot shown in (Figure 21) represents the variation of the sensor's reliability by focusing and analyzing the relationship between the BPM and SpO2 values.

$$Reliability = \frac{a-1}{a} \times 100 \qquad [4]$$

Referring to these 31 values received continuously from the GY-MAX30100 oximeter sensor, where the ranges of the BPM and SpO2 values are varying respectively from 60 to 107 and from 76 to 100, the reliability calculation can be done using formula [4] where 'a' represents the number of values which is 11 in this case. And since referring to the scatter plot out of 31 values only 1 of them is in the non-reliable range, the '-1' is used in the formula. In these circumstances, Reliability = 96.77 % which falls in the range of "high-reliability" sensors.

Subsequent to receiving the data from the sensors, the communication between the Arduino UNO and the ESP8266 is established via the serial communication where the pins used in the Arduino to achieve it are the pins 5 and 6 in addition to the NodeMCU pins used: D5 and D6. Eventually, the ESP8266 operates like a modem for Wi-Fi communication so, using the AT command set which is a set of instructions allowing the Arduino UNO to send and receive data from servers or even help with the connection of the NodeMCU to a Wi-Fi connection. In the Multi-beat digital stethoscope project case, AT commands are not needed since Arduino IDE is equipped with libraries such as "FirebaseESP8266" and "WiFiClientSecure" employed in this project abstract away the need of using this command set and applying it manually (Mobizt, n.d.). Accordingly, sensors' continuous data is sent to the NodeMCU where it is displayed on the serial monitor as shown in (Figure 17) to make sure that the serial connection is working successfully.

Afterwards, the ESP8266 starts a communication with Firebase, which occurs over HTTP requests sent from the NodeMCU to Firebase surely after the connection of the ESP8266 to the Wi-Fi connection via "WiFi.h" library. These requests are the REST API calls (Representational State Transfer Application Programming Interface), which allows the communication between different systems on the internet, like the sensors' values sending by using POST and PUT methods used respectively to create new resources on the server and update an existing resource on this server which is in this project the Firebase (L. Gupta, 2023), where a database will be created to saved GY-MAX30100 and MAX9814 values and then continuously updated each time ESP8266 receives new values since Firebase is known to offer real-time synchronization. Noting that these values are saved as JSON objects in order to allow structured storage. Providentially, the use of ESP8266 is shown to be advantageous in this case, not only because of its low cost or the previously listed working process, but also because of the authentication feature available in the data sending to the server where it securely sends data to Firebase by including authentication token in the HTTP headers which is an API (Application Programming Interface) key to validate the identity and ensure authorized access to the service. Therefore, the data will be saved in a real-time database and displayed on Firebase's dashboard of the specific account linked to the ESP8266, as shown in (Figure 18), noting that only in the testing procedure, the security rules of the account were declared as public.

For the live display of MIC values in the application, a combination of modern web technologies is utilized. Firebase Realtime Database is used along with backend services to create a responsive and real-time monitoring system. The key frameworks and technologies used include React.js, Recharts, Firebase Realtime Database, shadcn for UI components, and a Node.js backend with TypeScript for user authentication and data storage in MongoDB. Regarding the Fronted Framework (Shadcn, n.d.), React.js is used as the core front-end framework. React's component-based architecture allows to efficiently manage the UI state and handle real-time updates. Moving on with the MIC's live Data Visualization which is done using Recharts, a React-based charting library that integrates smoothly with the component architecture (Salimi-My, n.d.). The LineChart component is utilized to represent MIC data over time, with time on the X-axis and MIC values on the Y-axis. The chart is configured to update every 200 milliseconds, displaying the last 10 seconds of MIC data. For performance reasons, chart animations have been disabled to ensure smooth transitions during live data updates.

Providentially, We are using Firebase Realtime Database to fetch and sync live MIC, BPM, and SPO2 data. As mentioned earlier, Firebase is a cloud-hosted NoSQL database that provides real-time synchronization, making it ideal for this specific application (Hanna & Rosencrance, 2023). Using Firebase's JavaScript SDK (Software Development Kit), we establish listeners to monitor changes in the database for the MIC, BPM, and SPO2 values. Thus, Firebase SDK allows to set up a connection between the front-end and Firebase Realtime Database (SDKs and Client Libraries | Firestore | Firebase, n.d.). Using the onValue method, subscription to data changes is done. Each time a new MIC, BPM, or SPO2 value is pushed to Firebase, the listener is triggered, and the front-end is automatically updated with the new data. Over and above that, real-time data fetching is done where the new data is stored in React's state and triggers a re-render of the chart and cards displaying the live MIC, BPM, and SPO2 values. As new data is fetched, the state updates in real time, ensuring that the user always sees the latest data for all three metrics. Now, for the Backend Services, a Node.js application with TypeScript is employed. The backend is responsible for user authentication and securely managing the user's data. Also, the Node.js backend handles authentication, using JWT (JSON Web Tokens) to securely authenticate users.

The tokens are used to ensure that only authorized users can access the application and interact with the live data. User data, including authentication details and historical MIC data, is securely stored in a MongoDB database. MongoDB is a document-oriented NoSQL database that scales well with real-time applications like this (*W3Schools.com*, n.d.). The Node.js backend ensures secure storage, retrieval, and management of the data in the MongoDB database, ensuring data consistency and security. Furthermore, the UI (User Interface) is styled and structured using shadcn, a UI component library for React. shadcn provides reusable and customizable UI components that adhere to modern design principles. This allows in building a clean and consistent UI with minimal effort while ensuring that the UI remains highly responsive and visually appealing across all device sizes. Regarding the data flow, it will be divided to 4 subtitles for ease of understanding:

Backend Authentication: The user logs in to the system via the Node.js backend, which authenticates the user using TypeScript and stores user details in MongoDB.

Firebase Realtime Database: Once authenticated, the application subscribes to the Firebase Realtime Database, fetching live MIC, BPM, and SPO2 values. Firebase's real-time synchronization allows the app to receive updated data continuously as shown in (Figure 20).

Real-time Data Rendering: The fetched data is displayed using Recharts in a LineChart component for MIC and dynamically updated UI cards for BPM and SPO2 values (Figure 20). The chart and cards are updated every 200 milliseconds to show the latest data in real time. This data will be displayed on the web's dashboard after the user assign his login credentials on the login page that appears right after opening the web-app as shown in (Figure 19).

UI Components: The live data and additional metrics (such as BPM and SPO2 values) are displayed within UI cards built using shadcn components.

Last but not least, the domain name of this web-app is a free domain provided by vercel. So, in other words, the website is deployed on vercel. Eventually, during the process of the innovation's development, advantages and limitations were discovered. This apparatus is defined as very low-cost compared to other comparable devices, high accuracy referring to the calculated reliability as well as user friendly whether it is for the doctor or the patient due to its ease of use. Fortunately, few limitations were shown where this system lacks a two-factor authentication security.

Conclusion

To sum up, the Multi-Beat digital stethoscope, which incorporates integrated oximeter capabilities, represents a noteworthy progression in the medical domain. It remains lower costs than the closely resembling products in the medical market while improving diagnostic speed and reliability by simplifying the monitoring of cardiac activity and SpO2. Real-time data visualization is made possible by the device's link to a web-application that may be accessed on a doctor's PC or smartphone. This facilitates the early identification of anomalies even in the case of faint or subtle noises.

The Multi-Beat digital stethoscope serves as an example of how technology may improve conventional medical procedures by lowering the cost and increasing the accessibility of sophisticated diagnostic equipment. This gadget meets the demands of the healthcare sector today and establishes a benchmark for upcoming developments that prioritize affordability and usefulness. Essentially, it increases diagnostic precision, simplifies patient monitoring, and promotes the effectiveness of healthcare delivery, all of which lead to improved patient outcomes and a more robust healthcare system.

As a future work, the first thing that is being worked on is developing a two-factor authentication system allowing a high security website. Moreover, the ability to choose between a user-oriented system or admin-oriented one will be available as well as the capacity for each medical health staff especially doctors to create their own account enclosing all patients archive. At long last, collaborations with medical companies will be carried out in order to implement the whole circuit in a specialized traditional stethoscope.

Scientific Ethics Declaration

The authors, Rebecca Dib, Daniel Al Boutros and Lama Bou Farah, declare that they bear the scientific, ethical, and legal responsibility for this article published in the EPSTEM journal.

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