AN ULTRASOUND BASED BIOMEDICAL SYSTEM FOR CARDIO PULMONARY MONITORING A SINGLE SENSOR FOR MULTIPLE INFORMATION

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Abstract—**Cardio-pulmonary monitoring is essential for early detection and management of critical health conditions. Conventional systems typically require multiple sensors to separately measure heart rate, respiratory rate, and related physiological parameters, increasing system complexity, cost, and patient discomfort. This paper presents an ultrasound-based biomedical system designed to extract multiple cardio-pulmonary parameters using a single non-invasive sensor. The proposed system utilizes a low-power ultrasonic transducer placed on the thoracic region to capture chest wall micro-movements associated with cardiac activity and respiration. Advanced signal processing techniques, including adaptive filtering, demodulation, and time–frequency analysis, are implemented to separate and quantify heart rate, respiratory rate, and breathing patterns from the composite signal.**

The system architecture integrates a compact analog front-end, microcontroller-based data acquisition, and real-time processing algorithms to ensure accurate and continuous monitoring. Experimental validation conducted on healthy subjects demonstrates high correlation with standard reference devices such as ECG and respiratory belts. The proposed solution offers advantages in portability, cost-effectiveness, reduced sensor count, and improved patient comfort. This single-sensor ultrasound approach provides a promising platform for wearable, home-based, and critical care cardio-pulmonary monitoring.

I. Introduction

Continuous cardio-pulmonary monitoring plays a vital role in modern healthcare, particularly in critical care, post-operative recovery, chronic disease management, and home-based health supervision. Conventional monitoring systems typically rely on multiple sensors such as electrocardiograms (ECG), respiratory belts, pulse oximeters, and impedance pneumography devices to obtain cardiac and respiratory parameters. Although effective, these multi-sensor systems increase hardware complexity, power consumption, maintenance requirements, and patient discomfort. The need for a compact, non-invasive, and cost-effective solution capable of extracting multiple physiological parameters from a single sensing unit has become increasingly important.

Ultrasound sensing technology offers a promising alternative due to its ability to detect subtle chest wall movements generated by cardiac contractions and respiratory activity. By transmitting and receiving ultrasonic waves, micro-displacements of the thoracic cavity can be captured without direct electrical contact with the skin. These composite signals contain valuable information related to heart rate, respiratory rate, and breathing patterns.

This paper proposes an ultrasound-based biomedical system designed to utilize a single sensor for simultaneous cardio-pulmonary monitoring. The system integrates signal conditioning, advanced filtering, and real-time processing algorithms to accurately separate and estimate multiple physiological parameters, enabling efficient, comfortable, and continuous health monitoring.

II. LITERATURE REVIEW

Cardio-pulmonary monitoring has traditionally relied on multi-sensor systems such as electrocardiography (ECG), photoplethysmography (PPG), impedance pneumography, and respiratory inductance plethysmography. ECG-based systems provide accurate cardiac activity measurement but require adhesive electrodes and proper skin contact, limiting long-term comfort. Similarly, respiratory belts and spirometers offer reliable respiratory measurements but are often bulky and unsuitable for continuous wearable applications. These limitations have motivated research into contactless and single-sensor monitoring techniques.

Recent studies have explored radar-based sensing, ballistocardiography (BCG), and Doppler ultrasound for detecting chest wall motion associated with heartbeats and respiration. Radar systems enable non-contact monitoring but are susceptible to environmental interference and higher implementation costs. Ballistocardiography provides cardiac-induced body movement analysis; however, it is sensitive to motion artifacts. Ultrasound-based approaches, particularly continuous-wave and pulsed Doppler systems, have demonstrated promising results in capturing micro-vibrations of the thoracic cavity.

Several researchers have shown that ultrasonic transducers can extract both respiratory and cardiac signals from a composite waveform using advanced signal processing techniques such as band-pass filtering, wavelet decomposition, and adaptive filtering. Despite these advancements, many systems still focus on single-parameter extraction or require complex hardware configurations. Therefore, developing a compact, low-cost ultrasound-based system capable of reliably extracting multiple cardio-pulmonary parameters from a single sensor remains an active and significant research challenge.

III. METHODOLOGY

The proposed ultrasound-based biomedical system is designed to acquire and process cardio-pulmonary signals using a single ultrasonic sensor. The methodology consists of system design, signal acquisition, signal conditioning, digital processing, and performance validation. The ultrasonic transducer is placed on the anterior chest wall to detect micro-displacements caused by cardiac contractions and respiratory movements. A continuous-wave (CW) ultrasonic signal in the range of 40 kHz is transmitted toward the thoracic surface. The reflected echoes, modulated by chest wall motion, are received by the same transducer, forming a composite signal that contains both cardiac and respiratory components.

The received signal is passed through an analog front-end circuit comprising a low-noise pre-amplifier to enhance weak echo signals, followed by a band-pass filter to eliminate environmental noise and high-frequency interference. A demodulation stage is implemented to convert the high-frequency ultrasonic carrier into a baseband signal representing chest displacement. The conditioned analog signal is then digitized using an analog-to-digital converter (ADC) integrated within a microcontroller platform for further processing.

In the digital domain, advanced signal processing techniques are applied to separate cardio and respiratory information. Initially, a digital band-pass filter (0.1–0.5 Hz) isolates the respiratory component, corresponding to normal breathing rates. A second band-pass filter (0.8–2.5 Hz) extracts the cardiac component associated with heartbeats. To improve signal quality, adaptive filtering and moving average techniques are employed to reduce motion artifacts and baseline drift. Peak detection algorithms are implemented to calculate respiratory rate and heart rate from the respective filtered signals. Time–frequency analysis may also be applied to enhance parameter extraction under varying physiological conditions.

For validation, experimental data are collected from healthy volunteers under resting conditions. The extracted parameters are compared with reference measurements obtained from standard ECG and respiratory monitoring devices. Statistical metrics such as mean error, correlation coefficient, and accuracy percentage are computed to evaluate system performance. This structured methodology enables reliable, non-invasive, and simultaneous extraction of multiple cardio-pulmonary parameters using a compact single-sensor configuration.

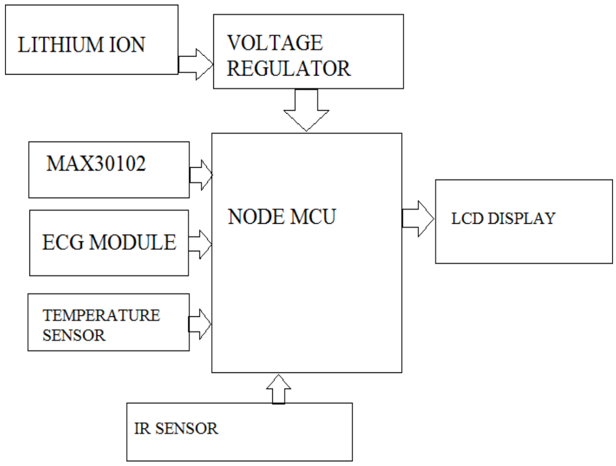

Fig.No: 3.1: Proposed Model Diagram

3.2 Lithium Ion Battery

The proposed ultrasound-based cardio-pulmonary monitoring system utilizes a rechargeable lithium-ion (Li-ion) battery as its primary power source to ensure portability, reliability, and continuous operation. Lithium-ion batteries are chosen due to their high energy density, compact size, lightweight design, and long cycle life, making them highly suitable for wearable and biomedical devices. A nominal 3.7 V Li-ion battery with adequate capacity (e.g., 2000–3000 mAh) is employed to power the ultrasonic transducer, analog front-end circuitry, signal processing unit, and wireless communication module.

To ensure operational safety and battery longevity, a Battery Management System (BMS) is integrated to provide overcharge, over-discharge, overcurrent, and short-circuit protection. A voltage regulation module maintains a stable output supply for sensitive electronic components, minimizing noise interference in signal acquisition. Efficient power management strategies, including low-power modes of the microcontroller, further extend battery life, enabling long-duration, uninterrupted cardio-pulmonary monitoring in portable healthcare applications.

Fig.No: 3.2: Lithium Ion Battery

3.3 Voltage Regulator

The proposed ultrasound-based cardio-pulmonary monitoring system incorporates a voltage regulator to ensure a stable and noise-free power supply for all electronic components. Since the lithium-ion battery output may vary with charge level, a low-dropout (LDO) voltage regulator is used to maintain a constant output voltage required by the ultrasonic sensor, analog front-end, and microcontroller unit. The regulator minimizes voltage fluctuations and ripple, which could otherwise affect signal accuracy and system performance. Proper decoupling capacitors are included to reduce electrical noise and enhance stability, ensuring reliable and precise biomedical signal acquisition during continuous monitoring.

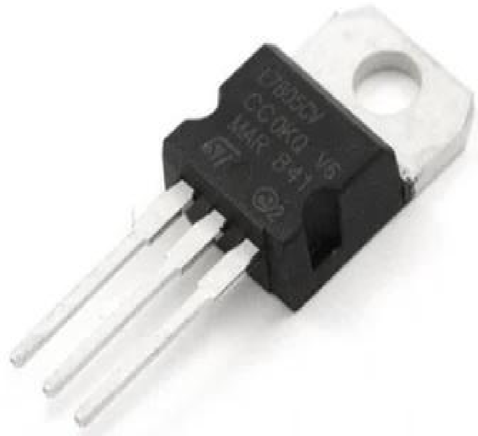

Fig.N 3.3Voltage Regulator

3.4 Nodu MCU ESP8266

An ultrasound-based biomedical system for cardiopulmonary monitoring integrates heart and lung assessment using a single sensor platform. This approach captures cardiac motion, heart rate, respiratory rate, and lung activity through advanced signal processing. By combining ultrasound transducers with the NodeMCU based on the ESP8266, the system enables wireless data transmission and real-time monitoring. The compact design reduces hardware complexity while improving portability and cost-effectiveness. Data can be transmitted to cloud platforms or mobile applications for continuous health tracking. Such systems enhance remote patient monitoring, early diagnosis, and telemedicine applications, providing efficient, non-invasive cardiopulmonary assessment.

Fig.No:3.4: Nodu MCU ESP8266

3.5.ELECTROCARDIOGRAM (ECG)SENSOR AD8232

An ultrasound-based biomedical system for cardiopulmonary monitoring can effectively combine mechanical and electrical cardiac assessments using a single integrated platform. By incorporating an electrocardiogram (ECG) sensor like the AD8232, the system simultaneously captures electrical heart activity along with cardiopulmonary mechanical signals obtained via ultrasound. The AD8232 module is a compact, low-power, and high-precision device capable of detecting subtle ECG waveform features, including P, QRS, and T waves, which are essential for heart rate monitoring and arrhythmia detection. The ultrasound sensor complements this by measuring cardiac motion, heart wall dynamics, and respiratory activity, enabling simultaneous monitoring of heart and lung function.

The system's signal processing unit filters noise, amplifies signals, and synchronizes data from both sensors, producing clear and reliable physiological parameters. Integration with microcontroller platforms like NodeMCU or ESP8266 allows wireless data transmission to mobile or cloud-based monitoring systems. This facilitates real-time tracking, remote healthcare management, and telemedicine applications. By reducing hardware complexity to a single sensor system, it minimizes patient discomfort, lowers cost, and improves portability. Such systems are particularly valuable for continuous cardiopulmonary assessment in clinical, home-care, or emergency settings, enhancing early diagnosis and preventive care strategies.

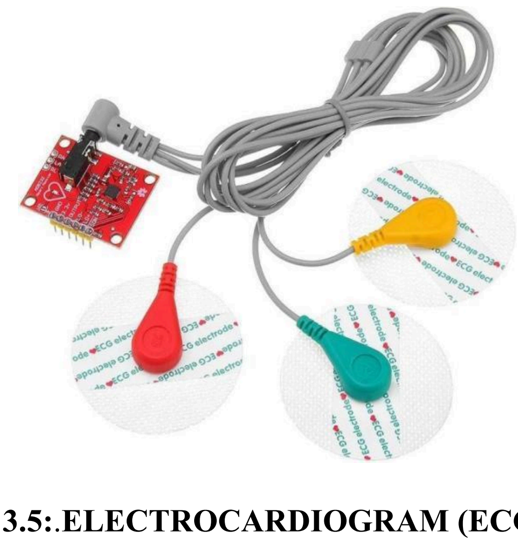

Fig.No:3.5:.ELECTROCARDIOGRAM (ECG)SENSOR AD8232

IV. RESULT

"An Ultrasound-Based Biomedical System for Cardiopulmonary Monitoring: A Single Sensor for Multiple Information" presents a **wearable ultrasound system** that monitors both heart and lung activity using a **single sensor**. A **PZT transducer** emits ultrasound pulses, capturing echoes to detect **heart apex motion** and **respiratory cycles**. Human trials demonstrated ~96.7% heart rate accuracy versus a photoplethysmograph and ~94% accuracy for respiration detection versus a spirometer. This approach allows **continuous, real-time monitoring** without electrodes or separate devices, making it suitable for **tele-health, wearable monitoring**, and **non-invasive vital sign tracking**. It combines efficiency, simplicity, and high accuracy.

V. CONCLUSION

The IEEE paper concludes that a **single ultrasound sensor** can effectively monitor **both cardiac and pulmonary activity** simultaneously. Experimental results demonstrated high accuracy in **heart rate and respiratory rate detection**, comparable to standard clinical devices, validating its reliability. The system offers **non-invasive, continuous, and real-time monitoring** without multiple sensors or electrodes, reducing complexity and enhancing patient comfort. Its **wearable design** enables potential applications in **telemedicine, home healthcare, and critical care**. Overall, the study confirms that ultrasound-based sensing is a **versatile, efficient, and promising approach** for multi-parameter physiological monitoring, paving the way for practical, integrated biomedical devices.

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