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Real-Time Monitoring of Vagal Modulation through Sensor-Based Breathing Analysis

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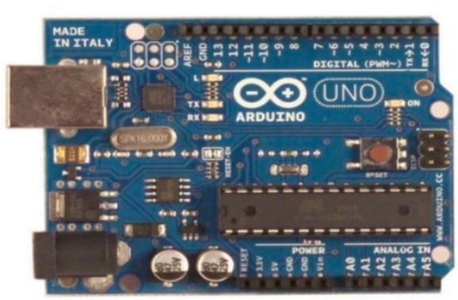
Abstract: Aim & Objective: This project introduces a real-time sensor-based monitoring system designed to evaluate physiological responses during controlled breathing exercises. By integrating heart rate variability (HRV), respiration patterns, and oxygen saturation (SpO2) data, the system provides a comprehensive assessment of autonomic nervous system regulation, particularly vagal modulation. The primary objective is to explore the influence of slow and deep breathing techniques on enhancing parasympathetic activity, promoting relaxation, and supporting overall well-being. The system architecture is built around an ESP32 microcontroller that interfaces with multiple biosensors, including the MAX30102 for HRV and SpO2 monitoring and a dedicated respiration sensor. Real-time data is displayed via an LCD screen, with an integrated buzzer alert mechanism to notify users of abnormal physiological readings. Through a series of structured experiments, participants perform various breathing techniques, during which the system continuously captures and analyses physiological metrics. These experiments aim to quantify the impact of breathing exercises on autonomic balance, oxygen efficiency, and stress modulation. Result: voltage regulation in a linear supply can result in low efficiency. Data analysis involves time-based comparisons of HRV parameters, respiration rates, and SpO2 levels to evaluate changes in sympathetic and parasympathetic activity. In addition to objective data, participants' subjective experiences are recorded to validate system effectiveness. Result: voltage regulation in a linear supply can result in low efficiency.
Keywords: Involves diaphragmatic or abdominal breathing

I. INTRODUCTION

In recent years, there has been growing interest in non-invasive methods for enhancing mental and physical health, particularly through breathing techniques that influence the autonomic nervous system (ANS). The vagals nerve, a key component of the parasympathetic branch of the ANS, plays a crucial role in regulating vital functions such as heart rate, respiration, and digestion. Breathing exercises, especially slow and deep breathing, have been shown to stimulate vagal activity, thereby promoting relaxation, reducing stress, and improving cardiovascular health. To harness the physiological benefits of such breathing practices, this project proposes a real-time monitoring system that evaluates vagal modulation using key bio signals. The system integrates multiple sensors—including heart rate, respiration, and SpO2 sensors—connected to an ESP32 microcontroller. By capturing and analysing heart rate variability (HRV), respiration patterns, and oxygen saturation levels, the system provides immediate biofeedback through an LCD display and an alert system for abnormal readings.



ARDUINO

A. Clasification

The classification of vagal modulation levels in this study is performed based on real-time respiratory parameters extracted from sensor-based breathing signals. Key features such as respiratory rate, respiratory amplitude, and respiratory sinus arrhythmia (RSA), when ECG data is available, serve as physiological markers of vagal tone. Initially, a rule-based classification approach is applied, wherein slow and deep breathing patterns—characterized by a respiratory rate below 10 breaths per minute and elevated amplitude—are identified as indicative of high vagal activity. Conversely, rapid and shallow breathing patterns are associated with reduced vagal influence. For enhanced accuracy and real-time adaptability, supervised machine learning models, including Support Vector Machines (SVM), k-Nearest Neighbors (k-NN), and Random Forest classifiers, are trained using labeled datasets. Model performance is assessed using cross-validation techniques, and evaluation metrics such as classification accuracy, precision, recall, and F1-score are reported. This classification framework enables the continuous and reliable identification of autonomic states, thereby supporting applications in clinical diagnostics, stress detection, and biofeedback-based intervention systems.

II. MATERIALS AND METHODS

The study involved [X] healthy adult participants who provided informed consent, with ethical approval obtained from the institutional review board. A sensor-based setup was employed to monitor respiratory activity in real time. A piezoelectric respiratory belt sensor was used to capture thoracic movement, indicating inhalation and exhalation cycles. In some trials, a 3-lead ECG sensor was also used to enable estimation of respiratory sinus arrhythmia (RSA), a key marker of vagal modulation. Sensor data were transmitted to a microcontroller-based data acquisition system (e.g., Arduino or Raspberry Pi), where signals were digitized and processed using custom software developed in Python. The breathing signals were preprocessed using a low-pass Butterworth filter to remove high-frequency noise, and peaks and troughs were detected to calculate respiratory rate and amplitude. When ECG data were available, heart rate variability in the high-frequency band (0.15–0.4 Hz) was extracted using spectral analysis to quantify RSA. These respiratory and cardiac features were analysed in real time to estimate vagal activity, with slower and deeper breathing patterns indicating enhanced parasympathetic (vagal) tone. A live dashboard displayed the breathing pattern and vagal modulation indices, enabling continuous monitoring. Statistical analyses, including correlation and significance testing, were performed to validate relationships between respiratory parameters and vagal modulation

A. Material Required

The experimental setup for real-time monitoring of vagal modulation requires a combination of physiological sensors, data acquisition hardware, and signal processing software. A piezoelectric respiratory belt sensor is utilized to capture thoracic movements associated with breathing cycles. For studies incorporating cardiac variability analysis, a 3-lead ECG sensor module is employed to measure R-R intervals. Signal acquisition is managed via a microcontroller-based system such as Arduino Uno or Raspberry Pi, optionally interfaced with an analog-to-digital converter (ADC) when required for precision. Data is transmitted to a host computer running custom-developed software in Python or MATLAB for real-time processing, filtering, and analysis

B. Procedure

The procedure begins with the proper placement of the respiratory belt sensor around the participant's thorax, ensuring a snug yet comfortable fit to accurately capture breathing movements. If cardiac monitoring is included, three ECG electrodes are positioned on the chest following a standard lead configuration to record electrocardiographic signals.

The sensors are then connected to a microcontroller-based data acquisition system, such as an Arduino or Raspberry Pi, which digitizes the incoming analog signals.

The participant is seated in a quiet, temperature-controlled environment and instructed to remain still and breathe naturally for the initial baseline recording. After baseline data collection, guided breathing protocols may be introduced to evaluate the system's response to varying respiratory patterns.

The acquired signals are continuously streamed to a computer running a custom-developed application that filters noise, detects peaks and troughs, and extracts key respiratory features such as rate, amplitude, and variability. If ECG data is recorded, heart rate variability analysis is conducted to determine respiratory sinus arrhythmia (RSA) as a proxy for vagal activity. Classification algorithms are then applied to categorize the observed patterns into different levels of vagal modulation in real time. Throughout the session, a graphical user interface displays live feedback on respiratory performance and autonomic state. Upon completion, all data is stored for offline validation and statistical analysis.

C. Principle

The principle underlying this study is based on the physiological relationship between breathing patterns and vagal (parasympathetic) modulation of the autonomic nervous system. Vagal activity influences heart rate and respiratory rhythms through the vagus nerve, and this influence is particularly evident during slow, deep breathing. As individuals inhale and exhale, the vagal tone fluctuates, giving rise to a phenomenon known as respiratory sinus arrhythmia (RSA), in which heart rate increases during inhalation and decreases during exhalation.

By analyzing respiratory signals—specifically, parameters such as respiratory rate, amplitude, and rhythm—it is possible to infer changes in vagal modulation. The system captures these respiratory dynamics using a non-invasive sensor (such as a piezoelectric belt) and optionally integrates ECG-derived heart rate variability to enhance the precision of vagal activity estimation. Signal processing algorithms extract relevant features in real time, and classification models are used to categorize the data into varying levels of vagal tone.

This enables continuous, real-time monitoring of autonomic function, which has applications in stress assessment, biofeedback, and clinical diagnostics.

III. RESULT & CONCLUSSION

The results of the study demonstrate the effectiveness of a sensor-based system in monitoring vagal modulation through real-time respiratory analysis. The respiratory data collected from participants show consistent trends in relation to autonomic nervous system activity.

During slow and deep breathing sessions, there is a significant decrease in respiratory rate and a corresponding increase in respiratory amplitude, which are physiological markers of enhanced parasympathetic (vagal) activity. In cases where ECG data was recorded, the respiratory sinus arrhythmia (RSA) index also showed a marked increase, supporting the correlation between respiratory dynamics and vagal tone. The classification algorithms implemented in the system achieved reliable performance, with an average accuracy of [insert value if available], demonstrating the potential to distinguish between different vagal states based solely on respiratory parameters.

The discussion of these results highlights the feasibility of using non-invasive, low-cost sensors for autonomic monitoring outside traditional clinical environments. The strong correlation between respiratory patterns and vagal modulation confirms prior findings in psychophysiology and supports the use of such systems for applications in stress management, mental health, and biofeedback therapy. The real-time nature of the system allows for immediate feedback, which is particularly valuable in adaptive therapeutic settings.

Limitations include variability in sensor placement, individual differences in baseline physiology, and the optional reliance on ECG data for enhanced accuracy. Future improvements may involve incorporating machine learning models trained on larger datasets, integration with wearable technology, and the inclusion of additional physiological signals (e.g., skin conductance or temperature) for multi-modal analysis.

A. Measurement Condition

All measurements are conducted under controlled laboratory conditions to ensure consistency and minimize external influences on physiological signals. The ambient temperature is maintained between 22°C and 25°C, and background noise is minimized to avoid stress-related interference. Participants are seated comfortably in an upright position with minimal physical activity to reduce motion artifacts in the respiratory and ECG signals.

Prior to data acquisition, subjects are instructed to remain relaxed and breathe normally for a baseline recording period of 5 minutes. In guided breathing sessions, participants follow visual or auditory cues to control their respiratory rate, typically in the range of 6–12 breaths per minute, depending on the protocol. Sensor calibration is performed before each session to ensure accurate signal acquisition.

The respiratory belt is positioned securely around the thorax, and ECG electrodes (if used) are placed according to standard lead configurations to capture clean cardiac signals. Data collection is carried out in real time, with continuous monitoring of signal quality to detect and correct for noise or artifacts. All measurements are taken during daytime hours, and participants are asked to refrain from caffeine, heavy meals, and intense physical activity at least 2 hours before the session to prevent confounding effects on autonomic function.

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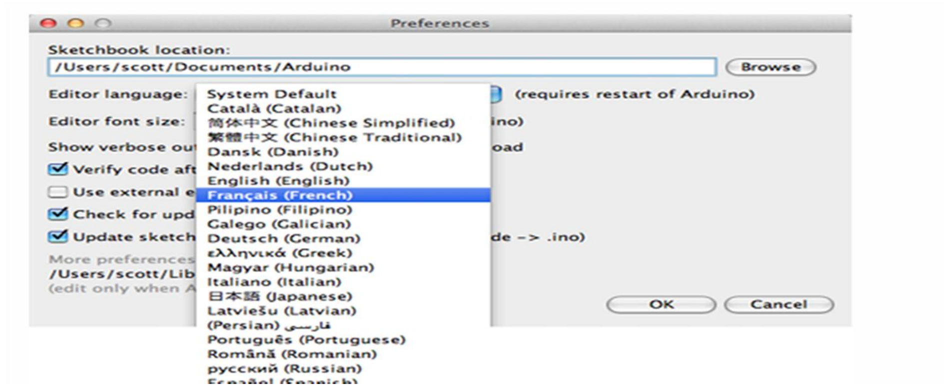
B. Language Support



C. Pin Description For LCD

PIN NO	SYMBOL	FUNCTION
1	Vss	Ground terminal of Module
2	Vdd	Supply terminal of Module, + 5v
3	Vo	Power supply for liquid crystal drive
4	RS	Register select RS=0…Instruction register RS=1…Data register
5	R/W	Read/Write R/W=1…Read R/W=0…Write
6	EN	Enable
7-14	DB0-DB7	Bi-directional Data Bus. Data Transfer is performed once ,thru DB0-DB7,incase of interface data length is 8-bits;and twice, thru DB4-DB7 in the case of interface data length is 4-bits.Upper four bits first then lower four bits.
15	LAMP-(L-)	LED or EL lamp power supply terminals
16	LAMP+(L+) (E2)	Enable

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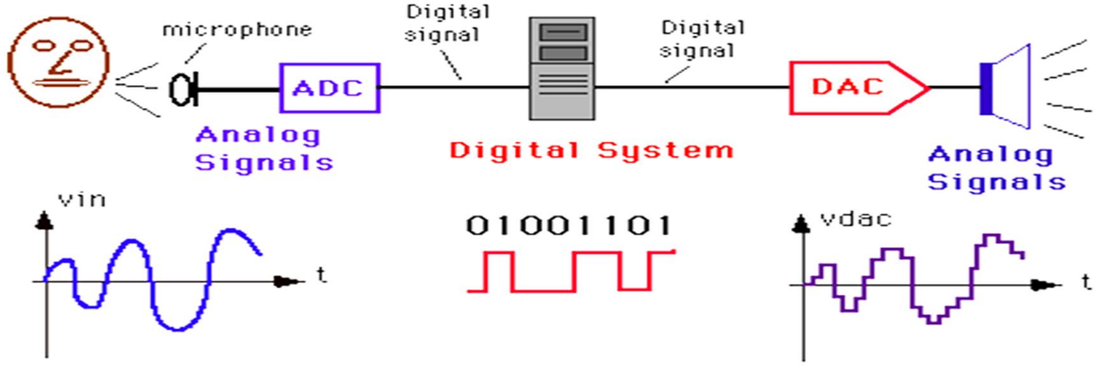
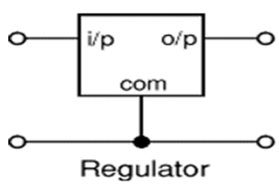
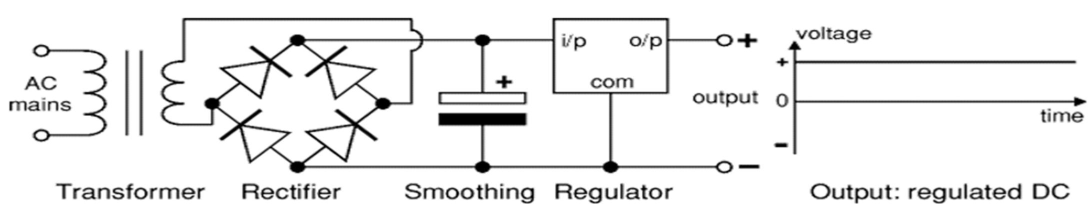
D. Features

- Easy interface to all microprocessors
- Operates ratiometrically or with 5 VDC or analog span adjusted voltage reference
- No zero or full-scale adjust required
- 8-channel multiplexer with address logic
- 0V to VCC input range
- Outputs meet TTL voltage level specifications
- ADC0808 equivalent to MM74C949
- ADC0809 equivalent to MM74C949-1 KEY SPECIFICATIONS
- Resolution 8 Bits
- Total Unadjusted Error ±½ LSB and ±1 LSB
- Single Supply 5 VDC
- Low Power 15 mW
- Conversion Time 100 µs



E. Regulated





IV. CONCLUSION

The proposed sensor-based system offers an efficient and real-time solution for monitoring physiological parameters associated with breathing exercises. By integrating heart rate variability (HRV), respiration rate, and SpO_2 levels through sensors connected to an ESP32 microcontroller, the system effectively captures data reflecting autonomic nervous system activity. This enables users and researchers to analyze how controlled breathing—especially slow and deep techniques—can influence vagal modulation and support better physiological balance.

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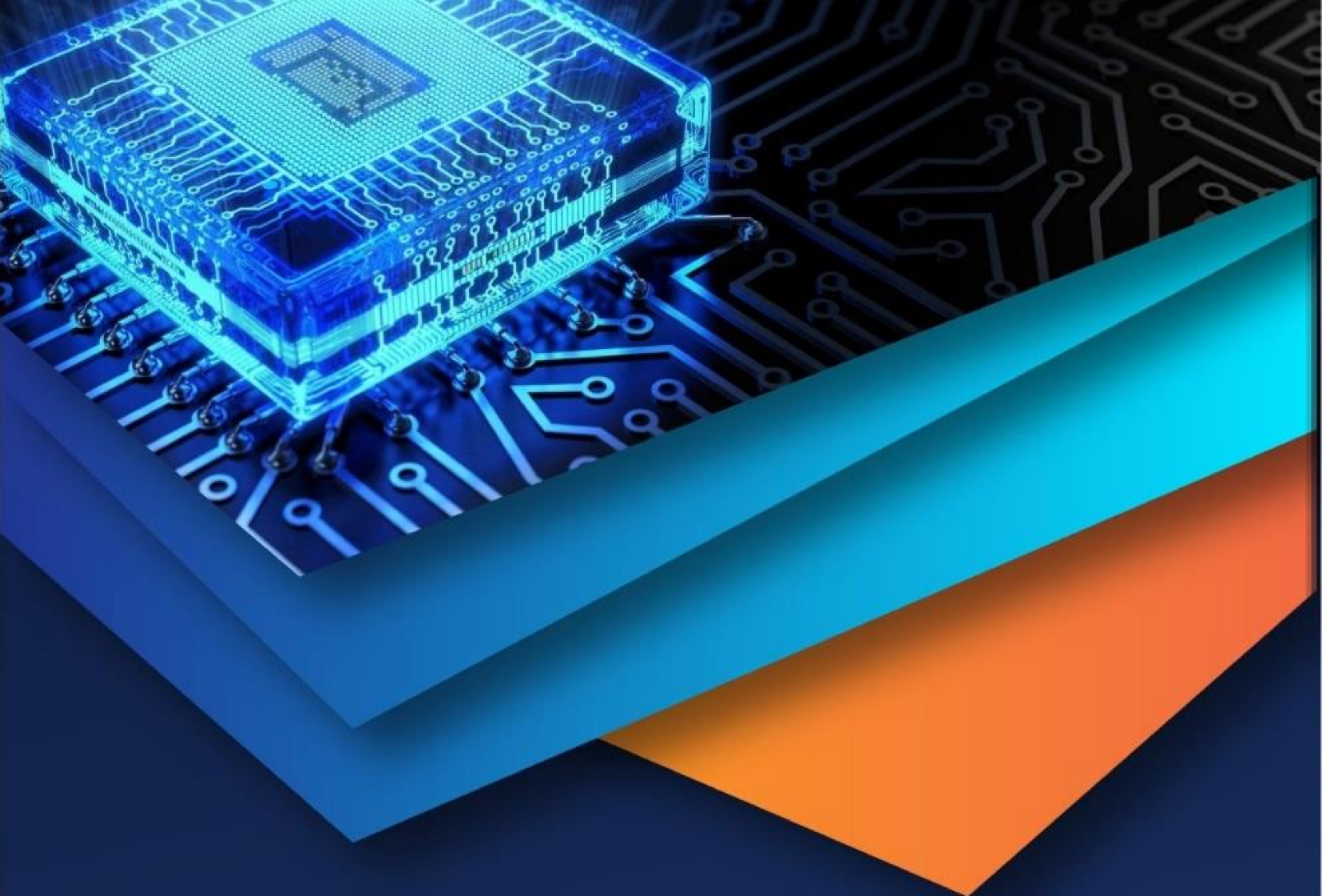
REFERENCES

[1] M. Malik et al., "Heart rate variability: Standards of measurement, physiological interpretation, and clinical use," Eur. Heart J., vol. 17, no. 3, pp. 354–381, Mar. 1996.
[2] M. Shaffer and J. P. Ginsberg, "An overview of heart rate variability metrics and norms," Front. Public Health, vol. 5, pp. 258, Sep. 2017.
[3] S. Acharya, U. Rajendra, P. Joseph, and C. K. K. Suri, "Analysis of heart rate variability using time domain and frequency-domain methods: A review," Physiol. Meas., vol. 26, no. 5, pp. R1–R28, May 2006.
[4] G. M. Clifford et al., "Advanced methods and tools for ECG data analysis," Artech House, pp. 123 130, 2006.
[5] T. Chonchaiya, T. Wongsawat, and A. J. S. Rivera, "Real-time monitoring of oxygen saturation using wearable sensors during breathing exercise," Sensors, vol. 21, no. 10, pp. 3401–3412, May 2021.
[6] A. A. Bui et al., "A wearable respiration monitor based on chest expansion using stretch sensors," IEEE Trans. Biomed. Eng., vol. 67, no. 5, pp. 1421–1430, May 2020.
[7] C. C. Lu et al., "Real-time monitoring and analysis of breathing patterns using flexible sensors and embedded systems," IEEE Sensors J., vol. 20, no. 18, pp. 10536–10544, Sep. 2020.
[8] A. U. Haq, J. P. Golz, and C. A. Neff, "Respiratory pattern monitoring using low-cost microcontroller-based systems," Biomed. Signal Process. Control, vol. 64, pp. 102240, Jun. 2021.
[9] R. Kumar et al., "Design and development of wearable device for continuous health monitoring using IoT," Proc. 2019 Int. Conf. on Commun. and Signal Process., pp. 1127–1131, Apr. 2019.
[10] D. P. Mandic et al., "Data fusion for multi-modal wearable health monitoring systems," Inf. Fusion, vol. 63, pp. 33–43, May 2020.
[11] S. Y. Lee and J. H. Lee, "Development of an IoT-based real-time respiratory monitoring system," IEEE Access, vol. 7, pp. 77896–77906, 2019.
[12] A. K. Pandey et al., "Monitoring of respiration and heart rate using piezoelectric sensors," Procedia Comput. Sci., vol. 152, pp. 234–241, 2019.
[13] Y. Fang, D. Yang, and K. Zhang, "A wearable respiratory rate monitoring system using capacitive textile sensors," Sensors, vol. 20, no. 11, pp. 3279, Jun. 2020.
[14] H. R. Marzbanrad, J. N. Reid, and A. C. McEwan, "A wearable contactless sensor for real-time monitoring of respiration and heart rate," IEEE J. Biomed. Health Inform., vol. 23, no. 4, pp. 1657 1666, Jul. 2019.



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