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Implementation of Gyro Accelerometer Sensor for Measuring Respiration Based on Inhale and Exhale with Delphi Interface

Egan Graha Utama[1,2], Triwiyanto[1], Triana Rahmawati[1], Mohanad Abdulhamid[3], and Vugar Abdullayev[4]

[1] Department of Electromedical Engineering, Health Polytechnic Ministry of Health Surabaya
[2] Surabaya Health Facility Security Center
[3] Al-hikma University, Iraq
[4] Azerbaijan State Oil and Industry University, Azerbaijan

Corresponding author: Triwiyanto (e-mail: triwiyanto123@gmail.com).

ABSTRACT accelerometer sensor is widely employed in respiration studies for its ability to detect changes in position and speed. However, there is a lack of research focusing on the optimal placement of this sensor to achieve accurate respiration measurements. This study aims to investigate and analyze the ideal positioning of the gyro accelerometer sensor for precise respiration detection. To achieve this, a design is proposed that utilizes an Arduino Nano as a microcontroller to process signals and derive respiration values from three gyro accelerometer sensors. The obtained respiration signals and values are transmitted to a PC via Bluetooth and visualized through a Delphi application, enabling a comprehensive comparison of the signals from the three sensors. The main contribution of this research lies in studying the impact of gyro accelerometer sensor placement on respiration detection, ultimately identifying the most suitable sensor location. The analysis reveals that the overall error values obtained from the module are promising, with the highest error recorded at 2.06% when the sensor is positioned at the stomach and chest (sensor position 3). This result validates the feasibility of using gyro accelerometer sensors for respiration detection and provides valuable insights for future studies in this domain. However, it is important to acknowledge certain limitations in this research. During respondent movement or walking, noise is observed in the signal, which may affect the accuracy of respiration measurements. These limitations highlight the need for further investigation into refining the sensor placement and signal processing techniques to mitigate noise and enhance overall accuracy. In conclusion, this study emphasizes the significance of gyro accelerometer sensors in respiration detection and addresses the dearth of research regarding their optimal placement. By presenting the error analysis of three sensor positions, the study establishes a foundation for more precise and reliable respiration measurement techniques. Future efforts should concentrate on overcoming the limitations identified in this research, thereby advancing the potential of gyro accelerometer sensors for a wide range of respiration applications, such as monitoring respiratory health and sleep patterns.

INDEX TERMS Respiration, Gyro Accelerometer, Delphi.

I. INTRODUCTION

The gyro accelerometer sensor which is a sensor that can detect changes in position and the speed at which the position changes occur [1], the gyro accelerometer sensor has been widely studied to be used as a respiration sensor, changes in position when inhale and exhale will be a determinant as a reference To determine the respiration value[2][3], previous research has mentioned how to use the gyro accelerometer sensor, but there are still some shortcomings, including the sensitivity of the gyro accelerometer sensor that affects the respiration calculation, thus making the respiration value calculation have a large error because there are several changes in position that occur. detected by the sensor which is not actually the movement of the respiration process so that it causes an error in the calculation of the respiration rate value. This is because the gyro accelerometer sensor detects every change in position, the slightest change in position will be detected by the sensor because there are some movements that are not actually respiratory movements detected as respiratory movements[4][5]. The change in position that should be detected is a change in the position of the chest. When inflated due to the inhale process and deflates due to the exhale position, research on accelerometer aims to obtain the respiration value by monitoring changes in the inhale and exhale positions, the value detected when inhale and exhale will be the determinant as a reference for determining the respiratory rate[6]. To reduce the respiratory error value generated by the detection of inhale and exhale positions on the gyro accelerometer sensor, it can be done by filtering the gyro accelerometer output.

Accelerometer sensor is a sensor used to measure the speed of an object or object. The accelerometer can measure dynamic as well as static acceleration. Dynamic measurement is a measurement of the acceleration of a moving object, while static measurement is a measurement of the earth's gravity[7]. For example, measuring vibrations that occur in vehicles, buildings and machines. In addition, it can also be used to measure vibrations that occur within the earth, engine vibrations, dynamic distances, and speeds with or without the influence of earth's gravity[8]. The working principle of the accelerometer is the principle of acceleration (acceleration)[9][10]. Suppose a spring that has a load is released then the load moves with an acceleration until it reaches a certain condition until it stops. If there is a shock then the load will swing back[11][12]. This study aims to investigate and analyze the ideal positioning of the gyro accelerometer sensor for precise respiration detection. These measurements are also the result of chip measurements. If you want the sensor to be able to detect 3 dimensions then you need 3 pairs of plates that are installed perpendicular to each chip[13][14]. Contributions from this study are:

1. This study makes a significant contribution by thoroughly investigating and analyzing the optimal placement of gyro accelerometer sensors for respiration detection. By examining the changes in position during inhalation and exhalation as reference points for determining respiration values, the research sheds light on the importance of sensor positioning in accurately capturing respiratory movements. This insight is crucial for researchers and practitioners seeking to utilize gyro accelerometer sensors effectively in respiration monitoring and related applications.
2. The study addresses a key limitation observed in previous research - the sensitivity of gyro accelerometer sensors impacting the accuracy of respiration calculations. By recognizing that the sensor's high sensitivity may detect non-respiratory movements and erroneously include them in respiration rate calculations, the research highlights the need for error reduction techniques. The findings emphasize the significance of filtering the gyro accelerometer output to minimize respiratory error values, leading to more reliable and precise respiration measurements.
3. In addition to focusing on gyro accelerometer sensors' specific application in respiration detection, this study contributes to a broader understanding of accelerometer sensors' functionalities. It provides valuable insights into how accelerometer sensors can measure both dynamic and static accelerations, making them suitable for various applications such as monitoring vibrations in vehicles, buildings, machines, and even within the Earth. Furthermore, the study outlines the working principle of accelerometers and the importance of using multiple pairs of plates to enable 3-dimensional detection, offering foundational knowledge for researchers and practitioners exploring accelerometer applications in diverse fields.

II. METHOD

This study, the test was carried out using a patient simulator (CAE, Apollo, USA) in Surabaya Ministry of Health Polytechnic nursing laboratory. This simulator patient can simulate respiration with a mechanical work system up and down the chest and abdomen. The initial test is to see changes in the shape of the signal generated by the gyro-accelerometer sensor after going through the Kalman filter process[19][20][21]. Kalman filter is a generic algorithm that is used to estimate the desired system parameters. Input can be in the form of inaccurate measurements or have noise to estimate the state of certain variables or other variables that cannot be observed with greater accuracy. Generally, the step of Kalman filter is described in the FIGURE 1.

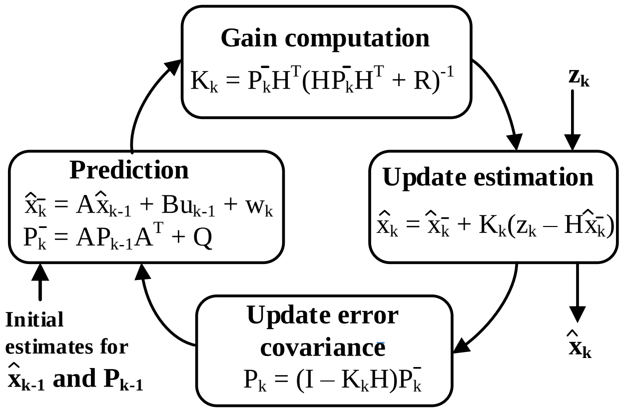

FIGURE 1. Literation of state estimation in the Kalman filter

FIGURE 2 Placement sensor on the patient simulator

FIGURE 2 shows the placement of the gyro accelerometer sensor on the abdomen. The next step is to compare the respiration values obtained after changing the constants on the Kalman filter and compare them with the parameter settings in the simulator patient. This data collection aims to see the appropriate values for the Q and R constants and have a respiratory error value between the module and the standard and the effectiveness of the Kalman filter applied to the gyro-accelerometer sensor to detect respiration. The test was carried out with 3 different respiratory rate parameter settings, namely 12, 15, and 20. Each respiration parameter setting was taken 5 times.

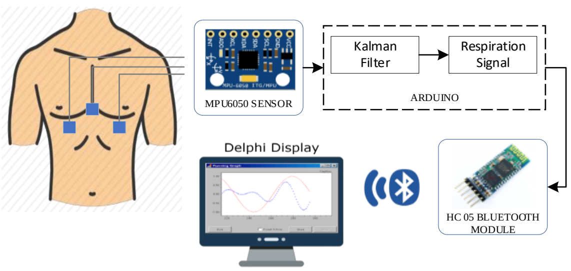

FIGURE 3. Diagram Block System

In this study using a Gyro Accelerometer Sensor (MPU6050, GY521, China) to detect respiration, Arduino Nano (Arduino, Rev3 Board, China) as a data processor obtained from the gyro accelerometer sensor and then reprocessed using a Kalman filter to obtain a respiration signal and respiration value then respiration signal and value are sent via Bluetooth (HC05, BT4, China) to the PC and displayed on the graph. The block diagram of the research module can be seen in FIGURE 3. Each measurement uses 3 gyro accelerometer sensors. The average value of the measurement is obtained by using the mean or the average by applying Eq (1) below[15].

$$\bar{X} = \frac{x1+x2...+xn}{n} \tag{1}$$

where $\bar{x}$ represents the mean (mean) for the n-measurements, *x1* represents the first measurement, x2 represents the second measurement, and xn represents the n measurements[16][17][18]. Standard deviation is a value that indicates the degree (degree) of variation in a data set or a measure of the standard deviation of the mean. The standard deviation (SD) formula can be shown in Eq (2):

$$SD = \sqrt{\frac{\sum(xi-\bar{X})^2}{(n-1)}} \tag{2}$$

where xi indicates the number of desired values, x indicates the average of the measurement results, n indicates the number of measurements[19]. Uncertainty (UA) is a doubt that appears in each measurement result. The uncertainty formula is shown in Eq (3):

$$UA = \frac{SD}{\sqrt{n}} \tag{3}$$

where UA indicates the uncertainty value of the total measurement, SD indicates the resulting standard deviation, and n indicates the number of measurements. %Error indicates a system error[4]. The lower Error value is the average difference of each data. Errors can indicate deviations between the standard and the design or model. The error formula is shown in Eq (4).

$$Error = \frac{(xn-x)}{xn} x100\% \tag{4}$$

where xn is the measured value of the machine calibrator. X is the measured value of the design.

III. RESULT

In FIGURE 4 is a picture of the entire module circuit. number 1 is the bluetooth module (HC05, BT4, China) which is used to send data from the microcontroller to Delphi. Number 2 is a multiplexer component (TCA9548A, I2C, China) that is used to get data values from 3 gyro accelerometer sensors at once. Number 3 is the arduino microcontroller (Arduino, Rev3 Board, China) which is used to process sensor data and is used for processing the

Kalman Filter. Number 4 is a Battery (18650, 2600mAh, China) that is used as a power supply for the whole circuit. FIGURE 5 is the display on the Delphi application on the Personal Computer (PC), in the upper left corner of the display there is a control panel, namely the connect button which functions to connect Delphi to the module via Bluetooth, then there is a pause button which functions to pause the monitoring process, a reset button which -function to reset the signal display on the graph, exit button which serves to close the Delphi application. There are 9 signal display charts, each of which has 2 signals, namely the white signal is a respiration signal from the gyro accelerometer sensor data before being filtered by Kalman and the colored signal is a respiration signal that has been filtered by Kalman. The respiration per minute values in bpm (breath per minute) are displayed next to the signal graph chart, respectively.

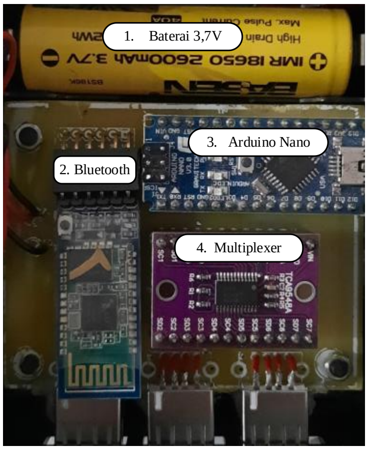

FIGURE 4. **Module Circuit Inside Box**

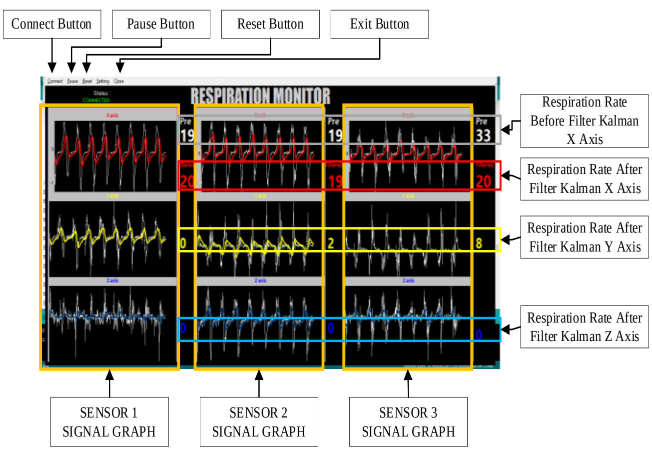

FIGURE 5. **Display on the Delphi App**

After testing the module, data collection and analysis of the results are carried out to determine the accuracy of the value of the output of the 3 gyro accelerometer sensors as sensors used to monitor the RR value in the research module. After conducting experiments on research to obtain RR values at 3 sensor positions carried out on the mannequin simulator with RR values setting 12, 20, and 25 Bpm, the results obtained on the module are as follows in the module, the results of the RR value are stable when 3 gyro sensors are placed on the mannequin simulator. The smallest error value from the module measurement is at the time of sensor position 2 with the setting value on the mannequin simulator 20 Bpm. From the measurement results, the overall error value obtained from the module can be said to be good with the highest error of 2.06% at the time of sensor position 3 with the setting value on the mannequin simulator 25 Bpm. Error data between the readings on the module and the standard can be seen in TABLE 1.

TABLE 1
Error between the module and standard readings on the respiratory rate parameter

Parameter		Setting 12 bpm		Setting 20 bpm		Setting 25 bpm	
		Mean	Error	Mean	Error	Mean	Error
SENSOR1	Module	11,6	2,6%	19,6	0,4%	24,8	2,2%
	STD	12		20		25	
SENSOR 2	Module	11,4	2,4%	19,6	0,4%	24	3%
	STD	12		20		25	
SENSOR 3	Module	11,2	2,2%	19,4	0,6%	24,4	2,06%
	STD	12		20		25	

The standard deviation value obtained from the measurement with the module is said to be good, because the result of the standard deviation value does not exceed the average value of the module measurement. This shows that the average value of the module measurements can be used as a measurement representation of the overall data.
The uncertainty value (UA) is used to see how big the deviation (accuracy) of the module is in placing the 3 sensors from the position of the mannequin simulator. TABLE 2 shows the comparison of error and standard deviation (SD Value). Relative uncertainty is closely related to measurement accuracy, which can be stated if the smaller the uncertainty, the higher the accuracy.

TABLE 2
Error table and standard deviation

Data Sensor	Error (%)	SD Value (%)
SENSOR 1	1,29	1,39
SENSOR 2	1,11	0,83
SENSOR 3	2,06	1,33

In FIGURE 6 is a flow diagram where after the module has carried out the initialization process and then reads data from the gyro-accelerometer sensor after the data is obtained, the filtering process is carried out using a Kalman filter to produce a respiration signal[22][23][24]. Then the respiration signal will go through a thresholding process with a threshold of 80% of the maximum value of the respiratory signal. Respiration value per minute is obtained from the formula 3 * 60000 divided by the period formed by 3 breaths. The processed respiration signal and respiration value are then sent to the Delphi application on a Personal Computer (PC) via Bluetooth using the Bluetooth module[25][26][27]. If Bluetooth on the PC has been activated, Delphi will get data on the value of the respiration signal and the value of respiration. Furthermore, the respiration signal is displayed on the graph and the respiration value will be displayed in real time.

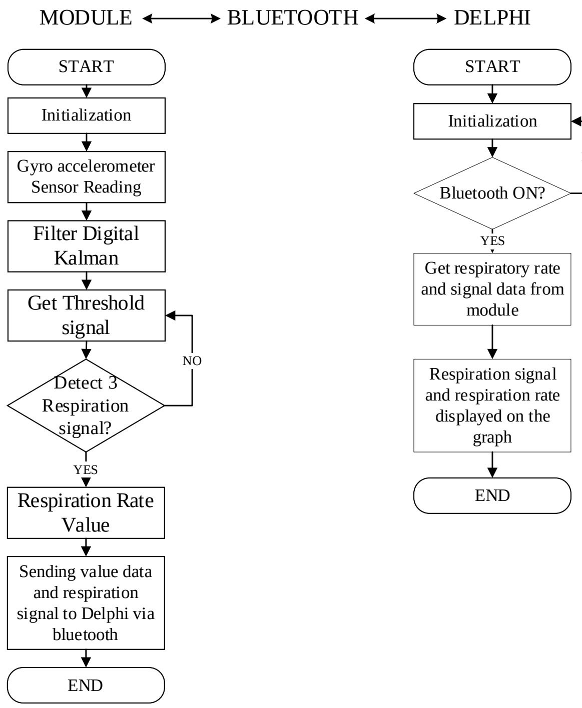

FIGURE 6. **The Flowchart of the system**

IV. DISCUSSION

After conducting data collection and analyzing the results, the developed Delphi-based system for regulating respiration based on inhalation and exhalation (Sensor Position Parameters) has been successfully implemented and utilized with the Gyro Accelerometer Sensor. This tool enables the measurement of respiration during inhalation and exhalation, and it demonstrates variations in respiration values depending on the placement of Sensor 1, Sensor 2, and Sensor 3 [28][29]. The RR signal captured by the gyro accelerometer sensor is then read by the microcontroller from sensors 1, 2, and 3. Subsequently, the RR signal is transmitted to a PC via Bluetooth, and the collected data from one respondent during six sleep sessions is stored in CSV format. During the data analysis, certain factors affecting the accuracy of respiration values before implementing the Kalman filter were identified. These factors include high levels of noise in the signal and signal instability, which contributed to fluctuations in the RR values per minute. However, after applying the Kalman filter, the RR signal exhibited a more stable shape, leading to improved accuracy in the respiration measurements. Additionally, measures were taken to optimize the data processing in the microcontroller to prevent any unnecessary additions that could impact the accuracy of the results. Furthermore, using batteries as a power supply helped reduce noise present in the signal, further enhancing the reliability of the measurements.

As for the system's hardware, there is room for improvement in terms of display and data storage. Implementing more user-friendly applications or interfaces for the hardware could offer clearer visualization of the respiration values, making it easier for users to interpret and analyze the data. Additionally, providing options for data storage within the module itself would enhance its usability and convenience for long-term data collection and analysis.

Despite the promising results achieved in this study, several limitations should be acknowledged to provide a comprehensive understanding of its scope and potential implications. Firstly, the data collection was carried out using only one respondent, which may limit the generalizability of the findings. To validate the system's effectiveness and accuracy further, future studies should involve a larger and more diverse pool of participants, covering different age groups, health conditions, and sleep patterns. Furthermore, the study primarily focused on respiration measurements during sleep. While this is undoubtedly a critical application, the system's performance in other scenarios, such as monitoring respiration during physical activities or while awake, remains unexplored. Expanding the study's scope to encompass various contexts and conditions would provide valuable insights into the system's versatility and potential real-world applications.

This research opens up various avenues for further exploration and improvement in respiration monitoring using gyro accelerometer sensors. By successfully demonstrating the feasibility of this tool, it encourages the integration of gyro accelerometer sensors into broader health monitoring and medical applications. For instance, the system's accuracy and portability make it a promising candidate for assisting in the diagnosis and management of respiratory disorders, such as sleep apnea and asthma. Moreover, its non-invasive nature makes it well-suited for continuous monitoring of patients' respiration, enabling healthcare providers to gain valuable real-time insights into their respiratory health. To enhance the system's robustness and accuracy, future studies could focus on refining the Kalman filtering technique and exploring other advanced signal processing methods. Moreover, incorporating additional sensors or leveraging machine learning algorithms could help account for individual variations in respiration patterns, leading to more personalized and precise measurements. In conclusion, this study's successful implementation of the Delphi-based system for respiration monitoring using gyro accelerometer sensors marks a significant step towards advancing the field of health monitoring and medical diagnostics. While recognizing its limitations, the findings of this research provide valuable groundwork for further research and development in respiration monitoring technologies. As these technologies continue to evolve, they have the potential to revolutionize the way respiratory conditions are diagnosed, managed, and ultimately improve the overall quality of life for individuals with respiratory health concerns.

IV. CONCLUSION

Overall, this research can be concluded that the application of the Gyro Accelerometer Sensor to Regulate Respiration Based on Delphi Based Inhales and Exhales (Sensor Position Parameters) has been successfully created and can be used properly. This means that the tool can apply the use of the Gyro Accelerometer Sensor to measure respiration at the time of inhale, exhale and there is a difference in the value of respiration at the placement of Sensor 1, Sensor 2 and Sensor 3[30][13][31]. The placement of 3 different sensors in this study has an error value that tends to be low because it has a difference. value is not far off. When the respondent is sitting and sleeping, the lowest error value is in Sensor 2. When the respondent is sitting, the respiration rate end to be higher than during the sleeping position, because when the sleep condition occurs when the respondent in a relaxed state. So, the number of inhales and exhales tends to be low per minute. For further research, it is necessary to add an analysis for the placement of the gyro accelerometer sensor on respondents standing and walking.

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