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A Pioneering Study on the Design and Implementation of Bioradar Sensors for Luxurious Portable Non-Contact Respiration Monitoring

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ABSTRACT Respiratory disorders are a critical health problem. Respiration is a vital activity for the proper functioning of the body. Pandemic SARS-CoV-2 virus is a highly contagious disease and causes rapid spread of droplets. This study aims to determine the effectiveness of the bioradar sensor used in non-contact respiration monitoring by exploring the distance to find out the optimal distance for sensor readings in monitoring respiration rate per minute. The results of this study for the 3 treatments given to respondents did not affect the results of measuring respiration rate. At distances of 10 cm and 25 cm they produce 40-43 times/minute, distances of 50 cm and 75 cm produce 33-36 times/minute, distances of 100 cm produce 20-22 times/minute and distances of 125 cm and 150 cm are not detected. The highest error value is -100.00% at a distance of 125cm and 150cm and the lowest error value is 3.39% at a distance of 100 cm. based on the results of the analysis of the effectiveness of sensor readings on distance, which is quite effective at a distance of ±100 cm. It is hoped that this research can reduce the level of disease transmission during the Covid-19 pandemic. The results of the study showed that the three treatments given to respondents did not affect the results of respiratory rate measurements. At a distance of 10 cm and 25 cm, it produced 40-43 times/minute, at a distance of 50 cm and 75 cm it produced 33-36 times/minute, at a distance of 100 cm it produced 20-22 times/minute, and at a distance of 125 cm and 150 cm it was not detected. The highest error value is -100.00% at a distance of 125 cm and 150 cm, and the lowest error value is 3.39% at a distance of 100 cm. Based on the analysis of the effectiveness of the sensor reading at a distance, it was found to be quite effective at a distance of ±100 cm. The implication of this study is that this bioradar sensor is effective in monitoring breathing rate at a distance of about 100 cm. The results of this study are expected to reduce the level of disease transmission during the Cov-19 pandemic, as non-contact monitoring can help in avoiding droplet spread, which is one of the ways the virus is transmitted. This study provides important information on the use of bioradar sensors in non-contact monitoring of breathing that can be used to improve the safety and quality of healthcare, especially in the context of a pandemic.

INDEX TERMS SARS-CoV-2, bioradar, respiration, transmitter, receiver

I. INTRODUCTION

Respiratory disorders are a critical health problem. Respiration is a vital activity for the proper functioning of the body[1]. One of the respiratory diseases that is still being discussed in the world is Covid-19. Corona virus disease 2019 (Covid-19), caused by a new strain of coronavirus, known as severe acute respiratory syndrome. Coronavirus-2 (SARS-CoV-2) appeared in 2019 and is considered a pandemic in the form of a virus that causes pneumonia[2]. The World Health Organization (WHO) has officially confirmed that the spread of Covid-19 has caused a global pandemic for countries around the world. The SARS-CoV-2 virus is highly contagious and causes rapid spread of droplets. These droplets can spread through the eyes, mouth or nose within a one or two meter radius of a Covid-19 sufferer. Given the transmission rate of Covid-19 the greatest challenge of this pandemic is controlling the spread of the virus, and the best strategy to reduce the virus is to prevent direct contact and ensure social distancing. Patients with Covid-19 usually experience fever and difficulty breathing which causes coughing with fast and short breaths (tachypnoea). Therefore, one of the critical conditions that need to be monitored is the breathing pattern[3][4]. Responding to the current situation of the spread of the virus, in the conditions of the Covid-19 pandemic, respiration monitoring is generally still through patient contact. Typical systems for monitoring breathing such as nose masks and chest bands are attached to the patient's body. This action is wired and requires the user to remain stationary while the measurement is being taken. Most people are uncomfortable with the sight of a wired probe attached to them[5][6]. To limit human contact operations so as to minimize the risk of transmission, the use of non-contact equipment is quite effective in minimizing the risk of disease transmission[7].

Respiratory monitoring devices that already exist today are sensors with a contact system. In research conducted by Shahid Malik et al (2018) discussing monitoring respiration rate using capacitive sensors, the advantage of this system is that it uses the MSP430 Microcontroller system for monitoring respiration in real time[8]. Vinit Kumar et al (2016) also conducted research on monitoring respiration and heart rate. A respiration rate monitor (RR) described in this study is that with a system that offers the use of a GMR sensor, the test results reveal the ability of the system to detect respiratory arrest.[9]. However, in both of these studies the data collection measures were still with the patient contact system so that there is a potential risk of disease infection[9][8]. The development of non-contact breathing sensors is carried out by utilizing the phenomenon of wave propagation. Ruthvik Kukkapali et al (2016) conducted research on wearable respiration monitors using a micro radar sensor. The advantage of this research is that the prototype is used as a pendant with a portable system that can be worn on the human chest because breathing movements can be detected very accurately. The system is also capable of penetrating walls which allows detection of breathing up to 5 meters away and also from behind walls. However, this research has not discussed the effect of distance on sensor measurements of objects because the sensor is designed in the form of a pendant so that there is no distance between the sensor and the object [5]. Sherif Abdulatif (2018) also conducted research on real time respiration monitoring using FMCW radar sensors. The results of this study are summarized based on each proposed module. The 94 GHz module shows better performance than the 120 GHz in terms of maximum aspect angle and distance over which the respiration signal can still be monitored. This is justifiable because of the higher aperture and output power in the 94 GHz module. However, the aspect of range resolution does not show much influence in the results achieved[10]. Razak Mohd (2021) also conducted the same research on monitoring respiration specifically in children using the IR-UWB radar sensor. This study presents a method for determining the respiratory status of children using a human movement detection method based on the IR-UWB radar sensor for non-contact detection of the respiratory status of children. The method applied can produce a response and distinguish the child's different respiratory states. However, in this study respiration monitoring with motion-based detection did not include the optimal distance for sensor readings used[11]. Tyas and Pramudita (2020) also conducted a similar study on the implementation of multi-frequency FMCW in detecting respiration. This research develops the drawbacks of the CW radar system, where the CW radar cannot detect the target distance. The results of this study are seen from the detection capability of the FMCW radar system in identifying target distances, it can be concluded that the radar system has the potential to be used for multi-target detection operations[12]. Panagiota Kontou (2021) conducted research on detecting heart rate and respiration using the CW radar, this continuous wave (CW) radar sensor system successfully detects a person's heart rate and respiration from a distance of 1 m. However, in this study, especially in respiratory monitoring, the calculation of the number of breaths in 1 minute had not been carried out[13]. Se Dong Min (2010) has conducted research using ultrasonic sensors which have also been used for non-contact respiration monitoring. However, ultrasound has lower penetration and is more sensitive to angular position in its implementation for non-contact measurements[14]. So that from several sensors that have been used that are more efficient, namely using a radar sensor that exploits the Doppler effect which is relatively independent of environmental conditions, such as light intensity. In addition, radar is also capable of detecting small tissue movements in the human body, such as heartbeats. Study of radar systems for medical applications, including respiratory monitoring[7].

Based on the results of a literature search and problem identification from several journal articles, the method of determining respiratory status without human contact is more efficient and tools do not need to be re-sterilized to minimize the risk of disease transmission, especially during the current Covis-19 pandemic[11][15]. On the other hand, measurements with non-contact devices will provide a better psychological aspect for patients, provide a sense of comfort and be more hygienic compared to contact sensors [15]. Several studies using radar sensors have been used, but have not carried out an analysis of the effect of optimal exploration distances on monitoring respiration, so it is important to do this. From the background above, it motivates the authors to carry out an analysis of the use of non-contact radar sensors in respiration monitoring in 1 minute, where the monitoring system will be carried out, namely by exploring the distance to the sensor to see what is the optimal distance of the object to the radar sensor readings in non-contact respiration monitoring contact. The aim of the study is to determine the effectiveness of bioradar sensors used in non-contact respiration monitoring by exploring the optimal distance for sensor readings in monitoring respiration rate per minute. The study seeks to evaluate the accuracy and reliability of bioradar sensors at different distances to identify the distance range that provides the most effective readings of respiratory rates in humans. The main contributions of this study are:

1) The study validates the effectiveness of bioradar sensors for non-contact monitoring of respiratory rates. By demonstrating the accuracy of the sensor readings at different distances, the research establishes the viability of this technology for real-time respiratory monitoring.
2) The study identifies the optimal distance of approximately ±100 cm for obtaining reliable respiration rate measurements using bioradar sensors. This finding provides essential guidance for medical device development and remote patient monitoring systems, ensuring the most effective and practical application of this technology.
3) The research highlights the implications of non-contact monitoring in mitigating disease transmission, particularly during the COVID-19 pandemic. By minimizing the risk of droplet spread through remote respiratory rate monitoring, this study offers potential solutions to improve public health safety and reduce the transmission of contagious diseases.

II. METHOD

Extensive research has been conducted on the utilization of bioradar sensors, with a specific focus in this study on harnessing the radar system's frequency to identify target distances and detect subtle movements of objects. The study's findings indicate that the radar system shows promising potential in accurately measuring small movements of the human chest, thereby enabling the determination of respirations per minute in humans. The research conducted was in the form of an experimental study, aimed at investigating the feasibility of a respiration rate measuring device (RR) incorporating a bioradar sensor equipped with a rangefinder. The primary objective was to assess the impact of varying distances on the effectiveness of the radar sensor's readings in measuring respiration rates. Detailed elaboration of the materials and methods employed in this investigation will be provided in the subsequent sections. The proposed RR device holds significant implications for advancing non-contact monitoring of respiratory rates, which could revolutionize medical device development and remote patient monitoring. By examining the interaction between bioradar sensors and human respiration at different distances, this study offers valuable insights into the optimal utilization of radar technology for healthcare applications. The research's outcomes are expected to pave the way for more accurate and efficient respiratory monitoring solutions, enhancing patient care and contributing to improved health outcomes in the future.

A. DATA COLLECTION

In this study, researchers made measurements of respiration rate. This study uses the type of bioradar sensor R24BBD1 as a sensor that functions to measure respiration and the HC-SR04 ultrasonic sensor for proximity sensors. As a microcontroller as well as data processing, ESP32 is used. Measurements are made using a radar sensor placed in front of the patient parallel to the chest or abdomen at a certain distance. Before carrying out data collection, the respondent will be conditioned in a relaxed state. When the tool is turned on and the radar sensor emits waves, the data obtained will be processed and displayed on the LCD. FIGURE 1 below shows the process of collecting data on patients.

FIGURE 1. Data collection on respondent

B. BLOCK DIAGRAMS

FIGURE 2 above shows a block diagram of this tool's system, where the system works, that is, when the power button is pressed, the power supply from PLN 220 V provides electrical voltage to the device through an adapter so that the voltage that goes to the tool is in accordance with the tool's needs. Apart from providing supply to the equipment, PLN also provides supply to the charger module through an adapter where the charger module functions as a module for charging the battery. After the tool gets an electricity supply, then the tool will turn on. Radar sensors detect respiration based on chest wall movement.

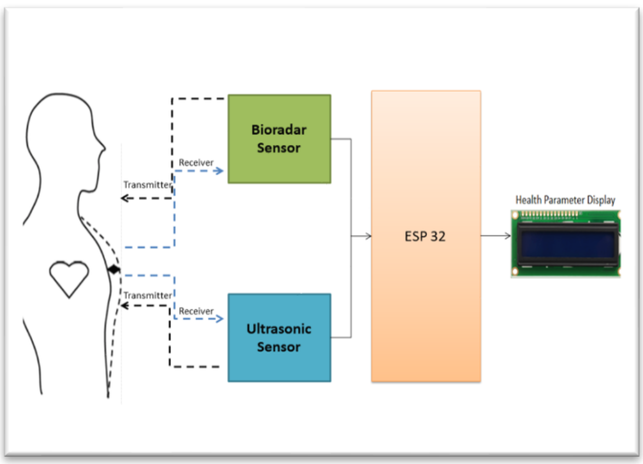

FIGURE 2. Block diagram

C. THE FLOWCHART

FIGURE 3 above shows a flow chart image on this tool. The process will begin with the initialization of the sensor and

LCD programming to read the radar sensor system and ultrasonic sensors as well as the main power supply for the sensors. After the radar sensor works by emitting electromagnetic waves on the sensor transmitter towards the object, then the waves will be reflected when it hits the object which will be received by the receiver on the radar to detect the measured respiration value. Likewise the work system on the ultrasonic sensor will emit waves to the object via the transmitter and when it hits the object the waves will be reflected back and received by the receiver. The values read by the two sensors will then be processed by the ESP32 program which will then be displayed on the LCD.

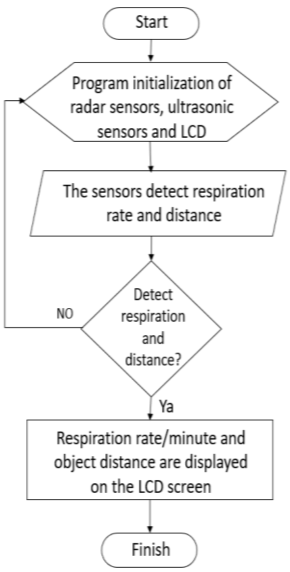

FIGURE 3. Flowchart of the whole system

D. DATA ANALYSIS

Measurement of the respiration rate parameter was carried out 3 times on 5 respondents by exploring distances of 10 cm, 25 cm, 75 cm, 100 cm, 125 cm and 150 cm. besides that, several treatments were also carried out to the respondents, namely lying, sitting and supine positions. Then the data taken is also based on the angle between the sensor and the respondent with a distance of 10 cm, 25 cm, 50 cm, 75 cm, 100 cm, 125 cm and 150 cm at angles of 10°, 20°, 30° and 40°.(1):

$$\bar{x}=\frac{x1+x2\ldots+xn}{n} \qquad (1)$$

where denotes the average value for n measurements. x1 indicates the value of the first measurement, x2 indicates the value of the second measurement and xn indicates the value of the nth measurement. The standard deviation is a value that indicates the level (degree) of variation in a group of data or a measure of the standard deviation from the mean. The standard deviation formula (SD) is shown in equation (2):$\bar{x}$

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(Xi-\bar{x})^2}{(n-1)}} \qquad (2)$$

Where xi denotes the desired number of values, indicates the average measurement results, n denotes the amount of measurement data. %error indicates a device error compared to standard tools. The %error formula is shown in equation (3):$\bar{x}$

$$\%Errors = \frac{x_{std}-x_{uut}}{x_{std}} x100\% \qquad (3)$$

Where shows the standard tool reading value (Fluke) and shows the design reading value.$x_{std}x_{uut}$

III. RESULTS

In measuring the respiration rate, patient monitors are used as a comparison tool. TABLE 1 shows the results with the most effective distance that can be used, namely at a distance of 100 cm for measuring respiration rate with a non-contact system with results that are close to the results of the comparison tool.

TABLE 1
Overall measurement results with distance exploration

Distance (cm)	Measuring instrument	RR measurement			Means	SD	Errors (%)
		1	2	3			
10	Comparison	20	19	20	19.67	0.58	116.95
	Module	43	43	42	42.67	0.58	
25	Comparison	20	20	19	19.67	0.58	115.25
	Module	42	43	42	42,33	0.58	
50	Comparison	18	19	20	19.00	1.00	82.46
	Module	33	35	36	34,67	1.53	
75	Comparison	20	19	20	19.67	0.58	79,66
	Module	35	35	36	35,33	0.58	
100	Comparison	20	19	20	19.67	0.58	3.39
	Module	20	20	21	20,33	0.58	
125	Comparison	20	19	20	19.67	0.58	- 100.00
	Module	0	0	0	0.00	0.00	
150	Comparison	20	19	20	19.67	0.58	- 100.00
	Module	0	0	0	0.00	0.00	

TABLE 1 above shows the measurement results based on distance exploration. The smallest % error calculation value is at a distance of 100 cm at 3.39% and the highest % error value is at a distance of 125 cm and 150 cm at -100.00%. TABLE 2 shows the overall measurement results based on exploration of the patient's angle to the sensor which shows the maximum angle that can be measured, namely at an angle of 30° with a distance of 100 cm which is the most effective.

IV. DISCUSSION

The overall working system of this research is that there are several circuits consisting of a series of bioradar sensor modules R24BBD1 as a sensor that functions as a respiration meter, an HC-SR04 ultrasonic sensor as a sensor that functions as a measure of the distance of objects to sensors, and there is a series of battery charger modules for portable system tools. Overall, the performance of the bioradar sensor can be used to measure respiration in humans, it's just that the measurement process is not effective enough at certain distances, the most effective distance used to detect respiration is ±100 cm. As for the performance of the ultrasonic sensor itself, it has been very effective in using it to read the distance between the sensor and an object. In the overall working system of this tool there is the main coding listing to run the tool system, namely the radar sensor program listing which functions to send data from sensor readings to detect chest movements so that the number of breaths per minute can be known. And the Ultrasound sensor program listing functions to send sensor reading data to detect the distance between the sensor and an object.

Based on the results of data analysis and discussion of several tables, it is shown that there are deficiencies, namelyThere is still a delay in sensor readings if there is a change in distance, they are still very sensitive to external movements and there is still a difference in readings with the comparison device. For the advantages, namely monitoring with a non-contact system so as to prevent disease transmission and the module is equipped with a portable system so that it is more flexible to use.

In the previous research that was carried out by Sherif Abdulatif (2018) also conducted research on real time respiration monitoring using FMCW radar sensors. The results of this study are summarized based on each proposed module. The 94 GHz module shows better performance than the 120 GHz in terms of maximum aspect angle and distance over which the respiration signal can still be monitored[10]. Panagiota Kontou (2021) also conducted research on detecting heart rate and respiration using the CW radar, a continuous wave (CW) radar sensor system that successfully detects a person's heart rate and respiration from a distance of 1 m. However, in this study, especially in respiratory monitoring, the calculation of the number of breaths in 1 minute had not been carried out[13]. The thing that distinguishes this research from this research is the type of sensor used later in previous studies did not analyze the effect of changes in distance to sensor readings. Then the sensor frequency specification used in this research is 24 GHz.

TABLE 2
Overall measurement results with angle exploration

Measuring instrument	Distance	Corner	RR measurement		
			1	2	3
Module	10 cm	10°	43	43	42
		20°	Not Reading	Not Reading	Not Reading
		30°	Not Reading	Not Reading	Not Reading
		40°	Not Reading	Not Reading	Not Reading
Module	25 cm	10°	43	43	42
		20°	Not Reading	Not Reading	Not Reading
		30°	Not Reading	Not Reading	Not Reading
		40°	Not Reading	Not Reading	Not Reading
Module	50 cm	10°	33	35	33
		20°	35	35	35
		30°	Not Reading	Not Reading	Not Reading
		40°	Not Reading	Not Reading	Not Reading
Module	75 cm	10°	33	33	33
		20°	35	35	34
		30°	Not Reading	Not Reading	Not Reading
		40°	Not Reading	Not Reading	Not Reading
Module	100 cm	10°	22	22	22
		20°	22	21	21
		30°	22	20	20
		40°	Not Reading	Not Reading	Not Reading
Module	125 cm	10°	Not Reading	Not Reading	Not Reading
		20°	Not Reading	Not Reading	Not Reading
		30°	Not Reading	Not Reading	Not Reading
		40°	Not Reading	Not Reading	Not Reading
Module	150 cm	10°	Not Reading	Not Reading	Not Reading
		20°	Not Reading	Not Reading	Not Reading
		30°	Not Reading	Not Reading	Not Reading
		40°	Not Reading	Not Reading	Not Reading

From some of the things that have been discussed above, the implications or positive impacts of this research are that in the future it can become an additional comparative literature from previous research, both from the use of the type of sensor or the method used so that future research can develop the shortcomings of this research.

The weaknesses identified from this research are as follows, first of all, the determination of the measurement space is not effective at a certain distance. This indicates that the sensor may not provide accurate and reliable readings beyond a certain distance, which may limit its practicality in some situations. Next is the matter of sensitivity to external movement: it turns out that the bioradar sensor seems to be very sensitive to external movement, which could interfere with the accuracy of respiration measurements. External factors such as vibration or environmental movement may affect the sensor readings. Next regarding the difference in readings compared to the comparison device: there was a difference in readings between the bioradar sensor and the comparison device. This suggests that the sensor measurements may not be fully aligned with the readings obtained from the standard device, potentially affecting the accuracy of the respiration rate calculation. The strength or advantage of this study is in terms of non-contact monitoring. The bioradar sensor used provides a non-contact system for respiration monitoring, which is beneficial in preventing disease transmission. This feature is very important, especially in the context of a pandemic like COVID-19. Next up is Portable System: This tool is equipped with a portable system, making it more flexible and convenient to use in various places, both in medical facilities and in remote locations.

Comparison with previous research highlights the novelty and uniqueness of this research in terms of the type of sensors used and the analysis of the effect of changes in distance on sensor readings. While previous studies focused on different sensors and aspects of respiration monitoring, this study provides valuable insights into the performance of bioradar sensors at various distances. Implications and positive impacts of this study include: comparative literature can serve as additional comparative literature for future research. Researchers can use the findings from this study to compare and improve existing methods and sensor technologies used in respiration monitoring. In addition, the advantages of this study are in terms of identifying areas for improvement. By recognising the weaknesses of the bioradar sensor system, this research opens the door for further advancements and developments in non-contact respiration monitoring technology. Future research can focus on addressing the identified limitations to improve sensor performance. Contributing to the advancement of research is that this research contributes to the broader field of respiration monitoring and sensor technology. The knowledge gained from this study can be used as a springboard for further research in medical device development and remote patient monitoring. Whilst it can be concluded that this research highlights certain weaknesses in bioradar sensor systems, it also gives attention to their positive aspects, including non-contact monitoring and portability. The findings from this study may pave the way for future advancements in respiration monitoring technology and contribute to ongoing progress in healthcare research and innovation.

V. CONCLUSION

In conclusion, this research demonstrates the feasibility of utilizing bioradar sensors for reading the number of respirations per minute in humans, with the condition that an optimal distance of approximately ±100 cm is maintained. Within this range, the results obtained closely align with normal respiratory values in humans. Additionally, the study reveals that the maximum angle for accurate respiration measurements extends up to 30°. These findings hold significant implications for future advancements in medical device development and remote patient monitoring. The use of effective distances, as identified in this research, can pave the way for non-invasive and convenient methods of monitoring respiratory rates in real-time. Integrating bioradar sensors into medical devices could lead to enhanced patient care, earlier detection of respiratory irregularities, and improved overall health outcomes. Moving forward, further investigations should focus on refining the technology to achieve even greater accuracy and reliability. Additionally, clinical trials involving a diverse population would be beneficial to validate the efficacy of bioradar sensors in various healthcare settings. Moreover, exploring the potential integration of bioradar sensors into wearable devices would extend the benefits of continuous respiratory monitoring, facilitating early intervention and personalized healthcare solutions. In conclusion, this study opens up new avenues for the application of bioradar technology in the medical field and offers promising prospects for enhancing patient care through remote respiratory monitoring. By continuing to build upon these findings, we can drive medical device innovation and ultimately contribute to improved healthcare outcomes for individuals worldwide.

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