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Comprehensive characterization of the Lidar TF Mini sensor for its potential use in early breast cancer detection, employing a data-driven approach

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ABSTRACT

Breast cancer is a leading cause of death among women. Early detection helps prevent the spread of cancer to other organs, thereby reducing serious risks. This characterization aims to determine the potential of the TF Mini Lidar sensor if used as an early detection tool for breast cancer. Basically, this characterization uses a data-based approach. The method used in this study is to position the TFmini and HC-SR04 sensors in a fixed and stable position, after which the reflective object is positioned at a predetermined distance according to the distance to be used when detecting breast cancer, which is at a distance of 51-100 cm. PLX daq version 2.11 was used to facilitate data collection. The characterization of this sensor is based on the standard deviation, relative standard deviation, error and accuracy. This study concludes that the TFmini lidar sensor has a high potential to be used in breast cancer detection devices as a contour detector. This is in accordance with the measurement accuracy value of the tfmini sensor of 99.87%. However, additional sensors, such as cameras, are needed to obtain better contours and visual images.

Keywords: Breast cancer, lidar, medical physics

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INTRODUCTION

Cancer is a disease characterized by the abnormal growth of cells and their ability to spread to other cells and tissues in the body (Wulandari & Rusmini, 2020). Breast cancer is the leading cause of death among women, according to the Global Cancer Observatory (GCO)(Widyawati, 2022). Several diagnostic methods are used to confirm cancer. One of the ways to do this is through self-breast examination (SBE)(Purba & Simanjuntak, 2019).

Self-breast examination (SBE) is a simple examination that every woman can do herself. This action is important because nearly 85% of breast abnormalities are first detected by the patient through a correct self-breast examination (Olfah et al., 2019). The higher the number of breast cancer patients, the higher the mortality rate. Not all women have easy access to health facilities for examinations. The cost of examinations, especially mammography, remains a barrier for some communities. Delayed detection of breast cancer can lead to delayed diagnosis, resulting in the discovery of advanced or even terminal stages of the disease when examinations are performed. There has been research on microwave-based breast cancer detection, which detects breast cancer in the area under the skin. Meanwhile, for this study, TFmini LiDAR will be used to detect breast cancer on the surface of the skin without providing radiation like microwaves (Elsheakh et al., 2023a).

LiDAR sensors work by emitting laser beams towards the object whose distance is to be measured. The laser beam will bounce back to the sensor after hitting the object. By measuring the time it takes for the laser beam to go back and forth, the sensor can calculate the distance to the object (Holzhüter et al., 2023). The sensor measures the time required between the emission of the laser beam and the reception of the reflected signal. Then, knowing the speed of light and the travel time, the sensor can calculate the distance to the object using the formula (1)(Pratap & Rangarej, 2024).

$$\text{Distance} = \frac{\text{speed of light} \times \text{travel time}}{2} \tag{1}$$

This device can create detailed point cloud images, facilitating applications in urban planning, forestry, and environmental monitoring. LiDAR sensors can produce very detailed 3D point data, which can be used to create 3D contours of an object. Modern LiDAR sensors are capable of measuring distance at very high speeds (Li et al., 2022).

The TFmini LiDAR sensor has the potential to be used in the early detection of breast cancer. With accurate data acquisition, this sensor can help detect changes in breast tissue that may indicate the presence of a tumour. TF Mini Lidar has advantages in measuring range up to 12m, resistance to environmental interference (dust, air splash, temperature and humidity), and has a measuring speed of up to 1000Hz. When compared to other sensors, especially HC-SR04, TFmini LiDar is superior, especially in measuring speed. TFmini lidar uses light waves, while HC-SR04 is based on sound waves (Santoso & Irawan, 2022). The uniqueness of this research lies in the detection of breast contour, which generally has a change in contour when infected as an identification of cancer.

Figure 1. Sensor Lidar TFMini

This is different from previous studies that detected cancer with microwaves using frequencies to obtain detailed cross-sectional images of the breast. In this study using microwaves, detection accuracy is still very much needed to describe more informative images (Wang, 2023). This research aims to understand the performance of the TFmini sensor in detecting changes in breast tissue and develop effective algorithms to analyze data obtained from the TFmini sensor. This research aims to test the accuracy of the TFmini sensor in detecting breast cancer in a wider population.

RESEARCH METHODS

In this TFmini LiDAR characterization study, appropriate equipment, materials, and procedures were used to obtain accurate alternative breast cancer detection data. Similar studies also classify the measurement results of Microwave Imaging tools (Wang, 2023). The tools and materials used include software and hardware. The equipment used in this study includes a laptop as hardware and Arduino IDE as software for programming and data interfacing. The materials required are the TFmini LiDAR as a distance and signal strength detection sensor based on the speed of light, HC-SR04 as a distance measurement tool using ultrasonic or sound principles, ESP 8266 Lolin, jumper cables, and micro USB cable. The TF Mini Lidar sensor, with its advanced imaging capabilities, could potentially complement these traditional methods by providing high-resolution, three-dimensional imaging of breast tissue, thus enhancing the detection of abnormalities that may not be visible through conventional means (Shanker, 2023). In addition to the sensor materials, a measuring tape, a laser meter, and a reflective object or sample object were also used. These objects include a polylactic acid (PLA), a cartridge, and a silicone-based breast implant.

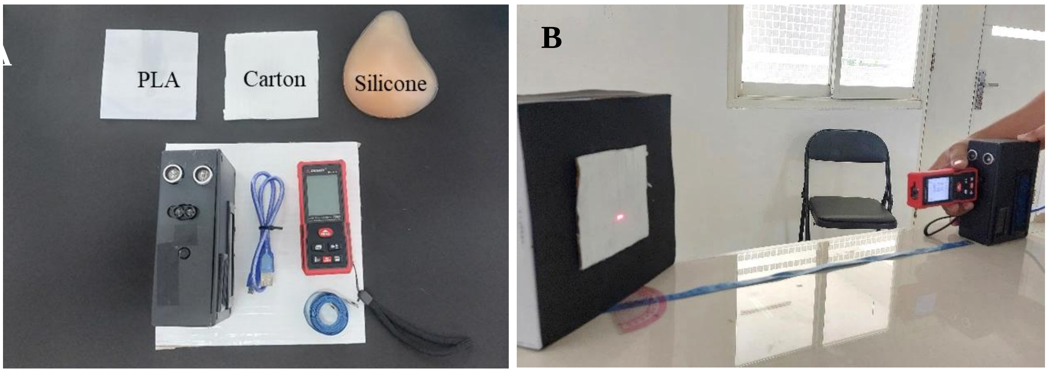

Figure 2 (a). Tools and materials; (b). Method

The steps taken in this study include preparing all tools and materials and assembling the TFmini and HC-SR04 on the ESP 8266 according to the diagram programming the Arduino IDE software using the TFmini library as a distance reader. In addition, the HC-SR04 library is also combined with the same function as a distance detection system. Creating and installing a sensor cover as protection for the TFmini LiDAR and HC-SR04 and conducting distance measurements are the core processes of the TFmini LiDAR characterization. In this process, the TFmini and HC-SR04 sensors are placed in a fixed and stable position, after which the reflective object is positioned at a predetermined distance according to the distance that will be used during breast cancer detection, which is at a distance of 51-100 cm, which aims to be additional comparative data. For data collection, PLX daq version 2.11 was used and processed with Excel software. Data processing carried out includes the average of 12 measurement data, standard deviation (SD) values, relative standard deviation (RSD), measurement error values and sensor accuracy. All data that has been calculated is made into graphs using origin software. To calculate the average, use Equation (2)

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{2}$$

Standard deviation, Equation (3)

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \tag{3}$$

Relative standard deviation, Equation (4)

$$\%RSD = \frac{100}{\bar{x}}\sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \tag{4}$$

Error, Equation (5)

$$\%Error = \frac{|Approximate - Exact|}{Exact} \tag{5}$$

Accuracy, Equation (6)

$$\%Accuracy = \frac{Correct\ Predictions}{Total\ Predictions} \tag{6}$$

Where x_i is a data value, and n is a number of summed data.

RESULTS AND DISCUSSION

In this research, several parameters were used to obtain the characteristics of the TFmini lidar sensor. Among them are obtaining the standard deviation of the accuracy value, error, sensitivity and resolution of the sensor. That way, the characteristics of the TFMini lidar sensor will be obtained, and it can be concluded whether the sensor is suitable for breast cancer detection. The measurement results of these sensors are in the form of distance data in centimeters (cm) from the tip of the sensor to the surface of the target object.

Comparison of Sensor Measurements with Actual Values

The main data presented is the comparative data between the distance measurement values of the tfmini lidar sensor and the tape measure. The data is also accompanied by a second comparison, namely the HC-SR04 sensor, which can measure distance using the principle of sound waves, especially ultrasonic waves. In contrast, the tfmini lidar sensor uses a different principle, namely electromagnetic waves in the form of light (Mendo, 2022); Table 1 and Figure 3(a) present comparative data of the TFMini and HC-SR04 sensors with a tape measure.

The displayed graph will always show the entirety of the 50 measurement data from both sensors compared to the tape measure. As explained in the method, tape measure measurements are reconfirmed by a laser meter to obtain the exact reflection point on the object. So that the data obtained truly reflects the result of the target object. Because the silicone breast implant object has a surface that tends to be rounded, the use of a laser meter is very helpful in ensuring that the measured point at each distance is correct.

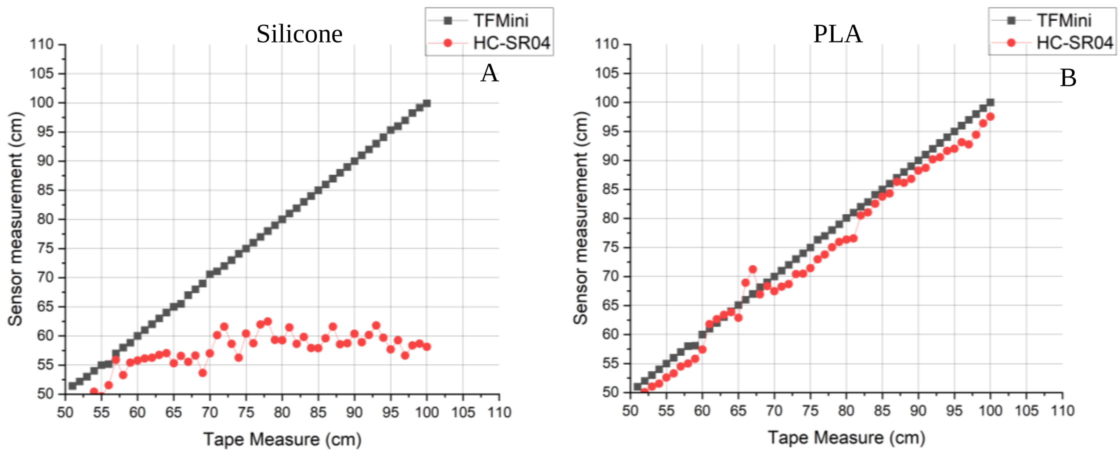

Figure 3 (a) Comparison of tfmini and HC-RS04 sensor measurements with a tape measure on silicon; (b) Comparison of tfmini and HC-RS04 sensor measurements with a tape measure on PLA

Based on the graph in Figure 3A, it can be seen that the measurement results of the tfmini lidar sensor show stable data compared to the measurement data of the HC-SR04 sensor. The measurement results of the tfmini are linear on the graph. From these data, the standard deviation (SD) value, relative standard deviation (RSD), measurement error value and sensor accuracy can be found when making measurements. Measurement results that have high accuracy above 92% are included in the high accuracy category(Huang et al., 2023). In addition, an error value below 5% can also be a benchmark for sensors that have high accuracy (Aziz & Zakarijah, 2022; Seth et al., 2023). The standard deviation in sensor characterization is usually used to determine data fluctuations (Busaeed et al., 2022). The data can be seen in Table 1.

Table 1. Comparison of tfmini and HC-RS04 sensor measurements with tape measure on silicone

Measuring Object	Average measurement (cm)		SD	RSD	Error	Accuracy
	Tape Measure	Sensor				
TFMini	67,50	67,51	0,12	0,36%	0,17%	99,83%
HC-SR04	67,50	52,22	1,95	4,58%	20,51%	79,49%

Based on Table 1, it can be observed that the TFmini lidar sensor has very good accuracy compared to the HC-SR04. In this measurement, the TFmini error data is 0.17%, which shows that the sensor error in measuring is very small. This means that the TFmini accuracy is high, namely at 99.83%. So, this sensor is good when used for measurements (Diniz et al., 2024; Cotta et al., 2024).

If you look at the graph in Figure 3B, the data produced by the tfmini sensor still shows stable and accurate values. In addition, significant changes occur in the HC-SR04 measurement data, where the data becomes more linear compared to the measurement data of the same sensor on the breast implant object. To get details of the error and accuracy of both sensors, see Table 2.

Table 2. Comparison of tfmini and HC-RS04 sensor measurements with tape measure on PLA

Measuring Object	Average measurement (cm)		SD	RSD	Error	Accuracy
	Tape Measure	Sensor				
TFMini	67,50	67,49	0,04	0,06%	0,05%	99,95%
HC-SR04	67,50	65,77	1,21	2,01%	3,21%	96,79%

The accuracy value of 99.95% on the tfmini and 96.79% on the HC-SR04 in measuring objects made of PLA shows good results, both for the tfmini and HC-SR04. This value needs to be reconfirmed with the third sensor measurement object, namely the carton. Figure 4 shows the comparative data of sensor measurements with the actual value of the carton object.

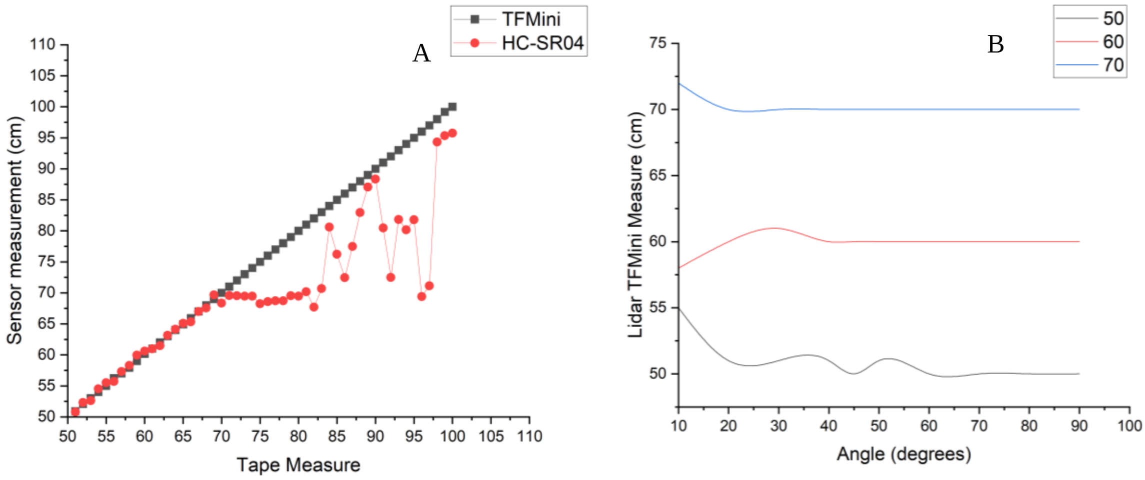

Figure 4 (a) Comparison of TF mini and HC-SR04 sensor measurements with a tape measure on a carton; (b) Effect of sensor shooting angle on a flat surface

It is clearly seen in Figure 4 that the measurement results of the carton object by the tfmini sensor show data that is also stable, like the previous data. However, in HC-SR04, there is data fluctuation again at a distance of 70 cm and above. Details of the accuracy and error calculation results are in Table 3.

Table 3. Comparison of tfmini and HC-RS04 sensor measurements with tape measure on carton

Measuring Object	Average measurement (cm)		SD	RSD	Error	Accuracy
	Tape Measure	Sensor				
TFMini	67,50	67,49	0,09	0,43	0,22	99,78
HC-SR04	67,50	62,91	2,00	3,16	6,28	93,72

In sensor measurements with cardboard objects, the results obtained are not very different from those of PLA objects. In this cardboard measurement, tfmini still has good data accuracy of 99.78%, and HC-SR04 has an accuracy of 93.72%.

Based on the three comparisons above, an interesting phenomenon can be discussed. The phenomenon is the stability of data from the TFMini lidar sensor and data fluctuations that occur in the HC-SR04 sensor. The measurement conditions in this study were carried out in a closed laboratory room. There is air conditioning and additional light from the lamp. The table used is directly under the air conditioning. So there are conditions where the wind is directed directly at the table, and there are conditions where the table is not affected by the wind. In the phenomenon of the HC-SR04 sensor, which has measurement results with fluctuating values, there are physical factors in the form of changes in temperature and air movement. This can happen because the HC-SR04 sensor uses the working principle of sound waves (Abdulkhaleq et al., 2020; Gabriel & Kuria, 2020). These sound waves can be physically affected by temperature and air movement (Huggins, 2000; Pain, 2005). Air movement can be affected because air is the medium for the propagation of sound waves in this case (Braik et al., 2024; Costa et al., 2024).

The physical phenomena that occur in the tfmini sensor can also be explained scientifically. The tfmini lidar sensor uses the working principle of electromagnetic waves, which in this case is light (Castiblanco et al., 2024). By using the principle of electromagnetic wave propagation, the waves do not require a propagation medium (Pedrotti et al., 2017). So, there are no significant obstacles to the measurement using the tfmini lidar sensor.

Comparison of Sensor Measurements with Target Object Variations

In this comparison of the target measurement objects, some data needs to be known. The accuracy value of the TFmini sensor is very stable and high. While the HC-SR04 shows fluctuations, to make it easier to compare, see Table 4 and Table 5.

Table 4 Comparison results of TFmini lidar sensor measurements based on the measured object

Measuring Object	Average measurement (cm)		SD	RSD	Error	Accuracy
	Tape Measure	TFMini				
Silicone Breast Implants	67,50	67,51	0,12	0,36%	0,17%	99,83%
PLA	67,50	67,51	0,12	0,36%	0,17%	99,83%
Carton	67,50	67,49	0,04	0,06%	0,05%	99,95%
Average Overall	67,50	67,50	0,10	0,26%	0,13%	99,87%

Table 4 and Table 5 show the accuracy values of each sensor when used to measure different objects. The TFmini sensor has an average accuracy of 99.87%. And the HC-SR04 sensor has an accuracy value of 90% when averaged from the three materials. This shows that the TFmini sensor can measure all object samples accurately. Thus, this sensor remains stable and accurate when used to detect breast implants made of silicone. This will facilitate breast cancer detection research using lidar as a skin contour plotting sensor. From the research conducted, it was found that TFMini can still detect various materials with different densities. So that differences in breast density can still be detected using this sensor.

Table 5. Comparison results of HC-SR04 sensor measurements based on the measured object

Measuring Object	Average measurement (cm)		SD	RSD	Error	Accuracy
	Tape Measure	HC-SR04				
Silicone Breast Implants	67,50	52,22	1,95	4,58%	20,51%	79,49%
PLA	67,50	65,77	1,21	2,01%	3,21%	96,79%
Carton	67,50	62,91	2,00	3,16%	6,28%	93,72%
Average Overall	67,50	60,30	1,72	3,25%	10,00%	90,00%

This is evident from the good relative standard deviation value of less than 5% (Prihatini et al., 2024). The low error in each measurement is also a parameter for this sensor to be used for breast cancer detection (Hamza, Islam et al., 2024; Hamza, Koziel, et al., 2024). Meanwhile, the HC-SR04 sensor is less effective when used for contour plotting. This is because the HC-SR04 sensor is unstable and has a very high error. In addition, the working principle of this sensor based on sound waves is not suitable for detecting areas that have uneven surfaces (Hamza, Islam et al., 2024), and ineffectiveness occurs because of the reflective media (Aldhaeebi et al., 2020). Moreover, objects that have a silicon base material with a rounded shape and a texture that is not dense can cause the sound not to reflect perfectly (Subrata et al., 2024; Elsheakh et al., 2024).

Comparison of Sensor Shooting Angles on Flat Objects

Comparison of the sensor shooting angle on a flat reflective object aims to determine the effect of changes in angle when measuring with the sensor. The object used in this measurement is a carton. The effect of the shooting angle on the TFmini sensor can be seen in Figure 4(b).

The data obtained from the distance measurement by the TFMini lidar sensor, as seen in Figure 4B, shows an interesting phenomenon. When measuring a distance of 50 cm, it shows very stable data. This can be seen from the graph of changes in data starting from a low angle of 20 degrees. Meanwhile, at a distance of 60 cm, data fluctuations occur at a distance of 40 degrees. At a distance of 70 cm, fluctuations occur at a slope of 65 degrees. To better understand the characteristics of the tfmini based on changes in the shooting angle, you can see Table 6.

It is very clear that almost all angles in Table 6 show that the accuracy value of the tfmini sensor is above 95%. There is only 1 angle that has a value of 94.7% accuracy, namely at an angle of 10 degrees. In other words, this sensor will not have problems when used on sloping surfaces (Mittapally & Bollam, 2024). This TFMini sensor can also measure accurate distances and can be plotted as contours on the data mapping it obtains (Nur Aziz, F., & Zakarijah, M., 2022). From the research conducted, it was found that the difference in sensor angles has sufficient accuracy so that breast cancer with variations in size that cause varying detection angles can still be detected with TFMini.

Table 6. Accuracy values on the tfmini sensor based on the shooting angle

Dist.	Angle	90°	80°	70°	60°	50°	40°	30°	20°	10°
70 cm	TFMini Meas. (cm)	70,0	70,3	70,0	70,0	70,0	70,0	70,0	69,6	72,0
	Error (%)	0,0	0,4	0,0	0,0	0,0	0,0	0,0	0,6	2,9
	Accuracy (%)	100,0	99,6	100,0	100,0	100,0	100,0	100,0	99,4	97,1
60 cm	TFMini Meas. (cm)	60,0	61,1	61,3	61,8	61,3	61,0	60,6	60,0	58,0
	Error (%)	0,0	1,8	2,2	3,1	2,1	1,7	1,0	0,0	3,3
	Accuracy (%)	100,0	98,2	97,8	96,9	97,9	98,3	99,0	100,0	96,7
50 cm	TFMini Meas. (cm)	50,0	50,0	50,6	50,1	51,0	50,7	51,0	51,1	54,8
	Error (%)	0,0	0,0	1,2	0,2	2,0	1,3	2,0	2,2	9,7
	Accuracy (%)	100,0	100,0	98,8	99,8	98,0	98,7	98,0	97,8	90,3
Error Average (%)		0,0	0,7	1,1	1,1	1,4	1,0	1,0	0,9	5,3
Acuracy Average (%)		100,0	99,3	98,9	98,9	98,6	99,0	99,0	99,1	94,7

All the comparisons made show that the TFmini sensor has very good accuracy and can be used to measure distances on various materials. In addition, this sensor is also quite good even though it detects areas with a high slope of 20 degrees. The TFmini lidar sensor has a high potential to be used in area plotting tools or plotting the surface contour of an object by detecting distance. However, measurements with the TFmini lidar sensor in this study have a sampling rate that is not too fast. For breast cancer detection, using TFMini requires an object speed that is not too fast. This causes the need to adjust the object speed so that detection is more accurate to create the skin contour of the breast. So, further development and research are needed. Additional sensors, such as cameras, are needed to obtain better contours and visual images. When compared to laser meters that can measure distances with lower resolution, this TFmini should also be able to (Junior & Lima, 2024). The advantage of using TFMini compared to other modalities for breast cancer detection is that it does not require radiation in the detection process. Thus reducing the risk of exposure to more radiation. In addition, medical imaging modalities for cancer detection require coming to a medical facility and cannot be used every day. Early detection of breast cancer requires us to know the slightest difference in breast condition. So, TFMini can be used every day to detect changes experienced by the breast. Of course, further research is still needed regarding other aspects related to early detection of breast cancer.

Based on research conducted by Eleakh (2023) explains that breast cancer can be detected using a textile antenna sensor. The results of this study showed that this antenna sensor has a low specific absorption rate (Elsheakh et al., 2023b). So, the study conducted using LIDAR has the characteristics of a wider range detector and can be done portably.

Research conducted by Fakhri (2020) explains the prototype of detecting object coordinates using LIDAR and HCSRO4. The results of the study show that this prototype can detect object coordinates with an average error for the x-axis of 1.178 cm and the y-axis of 1.2875 cm. This result means that this prototype is quite good at detecting object coordinates (Fakhri et al., 2020). So, in the current research, LIDAR and HCSRO4 were found to be quite good at detecting 360-degree objects and skin contours. So it can be used to detect early breast cancer prototypes.

CONCLUSION

This study concludes that the TFmini lidar sensor has a high potential to be used in breast cancer detection devices as a contour detector. This is in accordance with the measurement accuracy value of the tfmini sensor of 99.87%. However, additional sensors, such as cameras, are needed to obtain better contours and visual images. The disadvantage of this sensor is that it has a sampling rate that is not too fast, especially in this study. In further research, an evaluation of the software or hardware system is needed.

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