Low-Cost Early Detection Device for Breast Cancer based on Skin Surface Temperature

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ABSTRACT

One of the deadly diseases that attacks many women is breast cancer. It was recorded that breast cancer cases in 2020 were 2.3 million, with deaths accounting for 29% of these cases. The BSE technique is an easy way of early identification of breast cancer that can be done independently. However, this technique often goes wrong when practiced, making it ineffective. An early breast cancer detection system is proposed to make it easier for women to carry out early identification independently. Detection is carried out based on the measured temperature of the breast surface. The temperature difference at each point is a reference for the potential for breast cancer. This system was built in a bra and tested with a mannequin as a simulator subject. The MLX90614 temperature sensor, as the primary sensor, succeeded in measuring the surface temperature of the dummy with 99% accuracy. Final testing of the proposed system can also differentiate the temperature differences in each zone.

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1. INTRODUCTION

Breast cancer is one of the most common and deadly diseases for women. Breast cancer occurs due to the growth of abnormal cells in breast tissue that multiply uncontrollably [1], [2]. This abnormal growth results in the formation of benign or malignant primary tumors [3]. According to the World Health Organization (WHO), the number of cancer cases in 2025 is estimated to be 19.3 million cases. In 2020, 2.3 million women were diagnosed with breast cancer, and 685,000 deaths occurred globally [4]. Breast cancer diagnosis is the most crucial process in treating breast cancer cases. Standard methods are physical examination, mammography, ultrasound, and biopsy [5]. This examination method has not been able to handle breast cancer cases because it is only able to detect, at an early stage, around 30% of the total number of breast cancer cases [6]. Based on research results, as many as 64.7% of patients experienced delays in treatment and diagnosis, causing high breast cancer mortality rates [7]. Early diagnosis has a vital role in improving prognosis, chances of cure, and providing treatment at an early stage of the disease, ultimately becoming a powerful weapon to minimize deaths from breast cancer [8]–[13].

Breast cancer control has been attempted through early detection of Breast Self-Examination (BSE). BSE is an easy way to detect breast cancer lumps because it is done independently. The BSE method refers to the characteristics of early-stage breast cancer, characterized by the appearance of a lump, changes in the texture of the breast skin, and reddish discharge from the breast. Dr. Jeffry Beta said that the BSE method in America is no longer recommended because the technique is often wrong, making the examination less effective [14].

Much research has been carried out for the early detection of breast cancer, which focuses on mammography, ultrasonography, and Magnetic Resonance Imaging (MRI) [8]. This detection method has high accuracy but still has shortcomings because its implementation is complicated and expensive [15]. Based on ultrasound technology, Bolarinwa produces innovative breast cancer detection products [16]. However, this technology cannot identify microcalcifications as an early sign of breast cancer and increases the problem of false positives [17].

Therefore, a system that can identify early symptoms of breast cancer is required. In this research, a system was developed that can be used to assist in the process of early detection of breast cancer. Early detection with this system is based on the difference in temperature points on the surface of the breast skin and the surrounding area. This system is packaged in clothing that is easy and comfortable to wear. This simple device design can help in the early detection of breast cancer quickly, instead of using expensive equipment that cannot be operated independently and the BSE method, which has the potential for errors in the procedure.

2. PREVIOUS RESEARCH

Early detection of breast cancer has become a global issue and a big challenge for researchers. Various systems have been developed, but each has advantages and inherent weaknesses. X-ray mammography, magnetic resonance imaging (MRI), ultrasound scanning, and Positron emission tomography (PET) are some of the clinical methods currently most widely used for breast cancer detection [18].

The mammography method is commonly used to screen for breast cancer without symptoms. However, due to the significant frequency of false negatives and false positives, the mammography method has recently been heavily criticized [19]. This will have an emotional impact on the patient. Additionally, ionizing radiation from X-rays increases the risk of developing cancer in women who undergo mammography as a screening test [20]–[22]. Another disadvantage of this imaging method is that mammography may cause physical discomfort in female patients as it requires breast compression, which may cause pain or discomfort in the patient [23], [24].

Furthermore, this method was also challenging to distinguish tumors on dense breast mammograms because both dense breast tissue and tumors appear white on mammography images. Researchers have also discussed the issue of radiation exposure. Mammography is associated with a small amount of radiation, but the radiation risk is considered negligible compared to the benefits of early detection. Even though computer vision technology has been developed more advanced, radiologists are still tasked with interpreting screening results manually [25].

Ultrasound screening is another technique for identifying breast cancer. Sound waves are sent through a transducer, which transmits pulses to the breast and detects echoes from within the breast to produce an ultrasound image. However, ultrasound is not beneficial for breast imaging as it exhibits low resolution and cannot differentiate between malignant and benign breast tumors [26], [27]. In addition, this method is widely used as a secondary technique, usually after mammography results show a suspected mass.

Magnetic resonance imaging (MRI) is considered the best technique for post-chemotherapy imaging and has the added advantage of being sensitive to silicon breast implant imaging. MRI is highly sensitive in detecting invasive and minor abnormalities compared to mammography and ultrasonography techniques and can be used effectively for patients with dense breasts [28]. Additionally, incorrect breast positioning during MRI scanning can prevent successful detection [27]. MRI does not use radiation, making it possible to use it in pregnant patients. On the other hand, MRI is quite expensive, so it is not economically suitable as a screening and early detection method.

Positron emission tomography (PET) is an advanced medical imaging examination that provides detailed information about the function of organs or systems in the body [29]. The main advantage of PET is that it can diagnose cancer at its earliest stages and scan the entire body for recurrence. However, the resolution tends to be low [26], [30], [31]. Most imaging relies on the interaction of electromagnetic or acoustic waves with tissue and body fluids.

Different from other early breast cancer detection methods, the proposed method offers efficiency in terms of independent identification of breast cancer symptoms. The efficiency referred to is in terms of ease of use and fast measurement process. Apart from that, the system consists of components at an affordable price but can measure physical parameters well. With ease of use, the proposed system provides an experience of early detection of physical symptoms of breast cancer that does not cause trauma due to the discomfort of use.

A summary of the comparison of early detection methods for breast cancer is shown in Table 1.

Table 1. Summary of comparison of early cancer detection methods

Mammography	Ultrasonic	MRI	PET	Proposed
- Ionizing radiation - Uncomfortable: involves breast compression - Decreased sensitivity with high-density networks	- Low sensitivity - Higher cost than X-rays - Inspection requires an experienced operator	- Very expensive - Some types of breast cancer cannot be detected - Insufficient positioning may cause unsuccessful detection	- Low resolution - Combination of anatomical techniques - Using the radiopharmaceutical fluorodeoxyglucose (FDG) - Comfortable, except for people with claustrophobia	- Low cost - Easy to use - Simple Standard Operating Procedures - Does not cause discomfort

3. MATERIALS AND METHOD

Before working on this research, a study of the device's design was carried out based on suggestions from several specialists. The first suggestion is what parameters can be physically detected, the second suggestion is the design of a suitable sensor layout.

In this study, a mannequin of the upper half of the body was used as a subject model for breast cancer patients. The outer surface of the mannequin is likened to the surface of the skin that will be detected. A temperature sensor will sense the cancer point. The temperature difference at the cancer point with the rest of the skin surface is defined by the system as the cancer point [32]. On the inside of the mannequin, a small heater is modeled as a cancer point. The location of this small heater can be moved in one data collection. This ensures that the sensor can detect artificial cancer spots with random locations.

3.1. Illustrative Design

The system in this study was designed to measure the skin's surface in the breast area, so the design was made so that patients could quickly wear it. An illustration of the system to be developed is shown in Figure 1. The temperature sensor circuit, as shown in Figure 1, is arranged in an array. This temperature sensor arrangement is made as tightly as possible to suit the dimensions of the temperature sensor. The dense arrangement of temperature sensors allows the maximum area of the skin surface to be measured. A series of sensors detects the entire skin surface and compares them with each other.

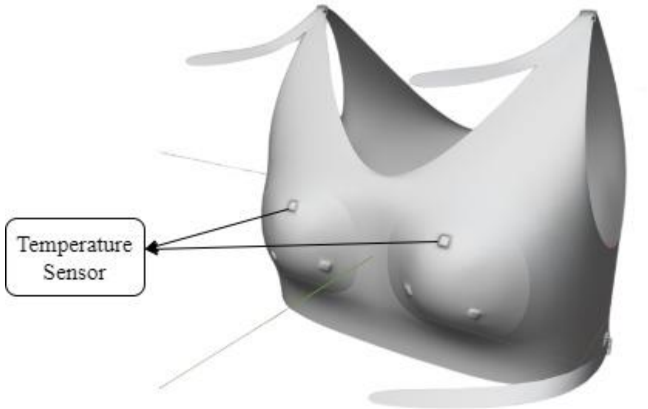


Figure 1. Illustration of a device with temperature sensors installed in an array

The design of the system considers development in more depth. Therefore, the systems currently being developed consider the system's comfort and robustness. Consideration of user comfort requires that the system be created with a minimalist effect so that the components used do not have wasted accessories. The system design is concise, with one sensor input, signal processing, and output as a simple interface application displaying reading data. Figure 2 shows a block diagram of a straightforward system.

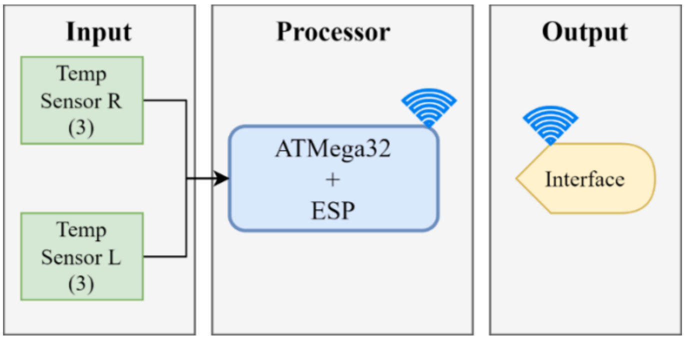
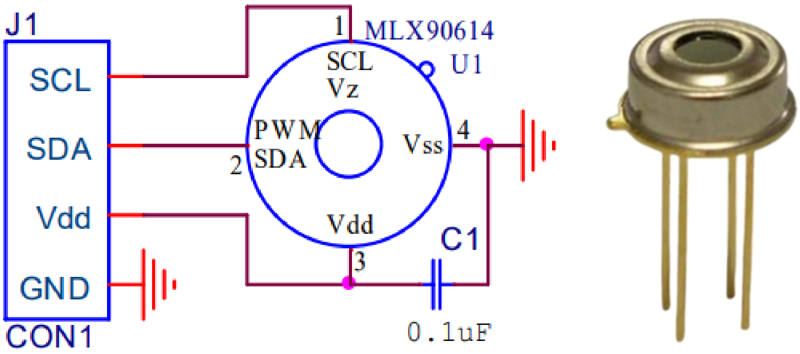


Figure 2. Block diagram of the system

There are three MLX90614 temperature sensors on each right and left side of the bra. The sensor is connected to the bra to stick to the skin's surface. The controller module used is ATMega32, which is equipped with an ESP chip that captures internet signals. The display is an interface application, so it does not require a special LCD screen placed on the device.

3.2. Temperature Sensor MLX90614

The temperature sensor used is the MLX90614 type. The functional diagram and physical form of the sensor are shown in Figure 3a and Figure 3b, respectively. This sensor is based on an InfraRed thermometer used to measure temperature non-contactly. The MLX90614 temperature sensor has four pins: SCL/Vz, SDA/PWM, VSS, and VDD. SCL/Vz is a serial clock input for two two-wire communications protocols. SDA/PWM is Digital Input/Output. This PWM pin provides the temperature of the observed object in normal mode. Open channel NMOS is automatically configured in SMBus-compliant mode. VSS is ground, and VDD is the external supply voltage.



(a) (b)

Figure 3. MLX90614 temperature sensor (a) functional diagram and (b) physical form [33]

This sensor is equipped with a 17-bit ADC with a DSP unit and a low noise amplifier to increase the accuracy and high resolution of the thermometer. The MLX90614 works with an input voltage of 4.5V to 5V. The MLX90614 sensor can operate in a temperature range of -40 to 125 ˚C for ambient temperature and -70 to 382.2 ˚C for object temperature. The temperature measurement accuracy and resolution of the MLX90614 sensor are at a high level, namely 0.5 ℃ and 0.02 ℃, respectively. This can be achieved because the sensor is equipped with a low noise amplifier, a 17-bit ADC, and a powerful DSP unit. The MLX90614 temperature sensor consists of 2 chips, the MLX81101 Infrared thermopile detector, and the MLX90302 ASSP signal conditioner, to process the IR sensor output. This device meets industry standard TO-39.

4. RESULT AND DISCUSSION

4.1. Experimental Setup

Early detection of breast cancer based on differences in skin surface temperature has been implemented. The proposed device employs the MLX90614 sensor as the primary sensor to detect skin surface temperature. The system is made with a compact design to not interfere with user activities. There are a total of six MLX90614 sensors embedded in the bra for early detection of breast cancer. The MLX90614 sensor has Serial Data (SDA) and Serial Clock (SCL) pins as I2C communication protocols. Because the controller module has limited I2C pins, a TCA9548A multiplexer was added. This multiplexer has 8 I2C channels, allowing all MLX90614 sensors to be accessed using one controller module. The wiring diagram of the system is shown in Figure 4.

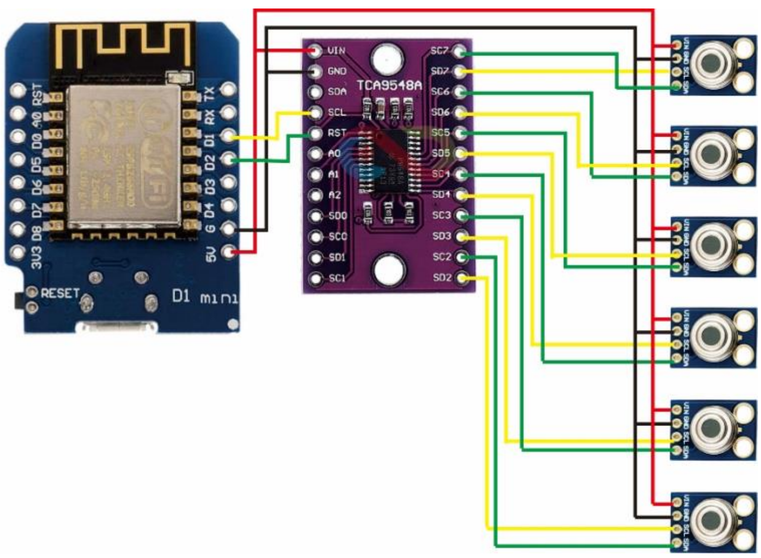


Figure 4. Wiring diagram of the device that connects the controller module, TCA9548A multiplexer, and MLX90614 temperature sensor

The small size of the MLX90614 sensor allows it to be embedded in a bra. The bra used is a sports bra, where three MLX90614 sensors are sewn on the right and left cups of the bra. The controller module is built using an ATMega32 chip and an ESP chip placed on the back side of the bra right on the user's back. Next, the tip of the MLX90614 sensor and controller module board, including the cables connecting them, are covered with cloth and sewn to the bra so that they do not come into direct contact with the user's skin. Specifically for the MLX90614 sensor, the part covered with cloth is the sensor board, while the lens at the end of the sensor is left so that it can touch the user's skin. The installation of the components on the bra is shown in Figure 5. Figure 5 shows that additional sensors are also embedded in the bra. However, these additional sensors are not discussed in this paper.

Figure 5. Installation of the MLX90614 sensor on the bra cup and the controller module board on the back of the bra

The performance of the MLX90614 temperature sensor, which is used as the primary sensor in early detection of breast cancer, will be tested first. The MLX90614 temperature sensor was tested to ensure that this system's primary sensor worked correctly to get maximum reading results. The MLX90614 sensor was tested by comparing sensor measurements with an industrial thermometer. The object measured in this test is the skin surface of the limbs. The skin surface points measured using the MLX90614 sensor and industrial thermometer were determined randomly. The test results of the MLX90614 sensor compared to the industrial thermometer are shown in Figure 6.

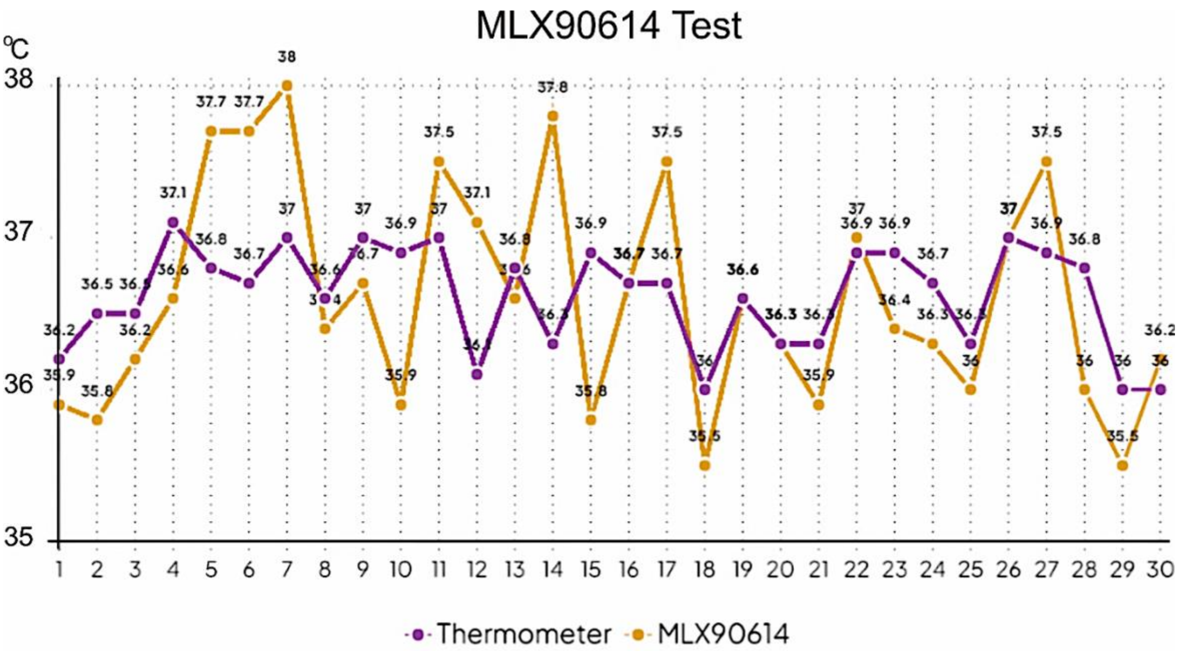


Figure 6. Testing of the MLX90614 sensor compared with an industrial thermometer

Testing was carried out by measuring 30 random points as a minimum requirement for samples obtained in a study. The test results of the MLX90614 sensor compared with the industrial thermometer show the difference in measurements between the two. Figure 6 shows that the measurement results from the MLX90614 sensor are not always the same as the industrial thermometer measurement results. Of the 30 tests at different points, the same measurement value was only produced four times at the 16th, 19th, 20th, and 26th test points. The highest measurement error value was produced at the 14th test point, 1.5 ℃.

Based on the average calculation results from 30 tests, the measurement error value obtained was 0.5 ℃. The average error value is equivalent to 1%. Referring to the MLX90614 sensor datasheet, where the maximum sensor accuracy is 0.5 ℃, the MLX90614 temperature sensor used in this research is suitable and suitable to be tested for early detection of breast cancer.

4.1. Testing Result

At this stage, testing is carried out to detect breast cancer using a system following the initial design. The upper half of the mannequin is used as a user body simulator. Figure 7 shows a device that has installed all the necessary electronic components and is installed on a mannequin with the upper half of the body.

An artificial heater was inserted into the mannequin to test the device’s performance distinguishing between potentially cancerous and non-cancerous spots. The mannequin is made of heat-insulating material, so it needs a particular way to channel the heat so that it can be read by the MLX90614 sensor correctly. The breast part of the mannequin is hollowed out with a diameter of around 2mm right in the measurement area of the MLX90614 temperature sensor. The hole in this mannequin aims to channel heat directly to the MLX90614 temperature sensor and not spread it to the inner surface of the mannequin.

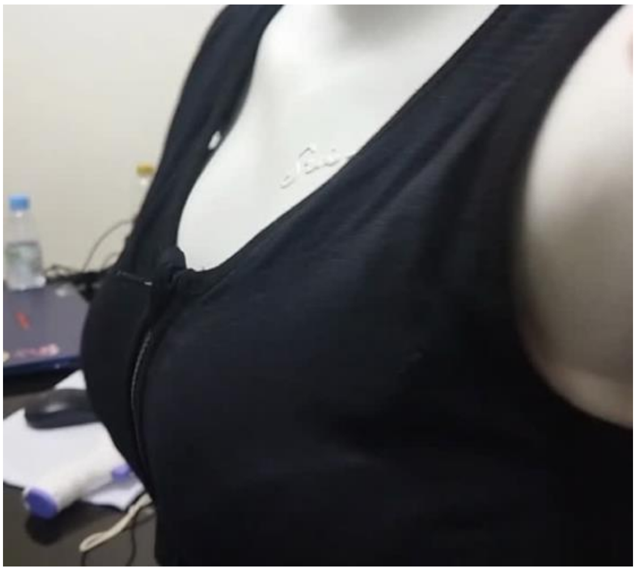


Figure 7. Early breast cancer detection installed on a mannequin for the upper half of the body

The test was carried out on a device installed on the mannequin by turning on an artificial heater inside the mannequin’s body. Heat testing was carried out randomly to obtain 30 iterations. Figure 8 shows the results of heat testing on one side of the bra cup, while detailed data is shown in Table 2. Addressing the MLX90614 temperature sensor on each bra cup is carried out so that the system can decide and determine the difference in the measured points. The MLX90614 temperature sensor addresses on each side of the cup are named Zone 1 (blue), Zone 2 (green), and Zone 3 (purple).

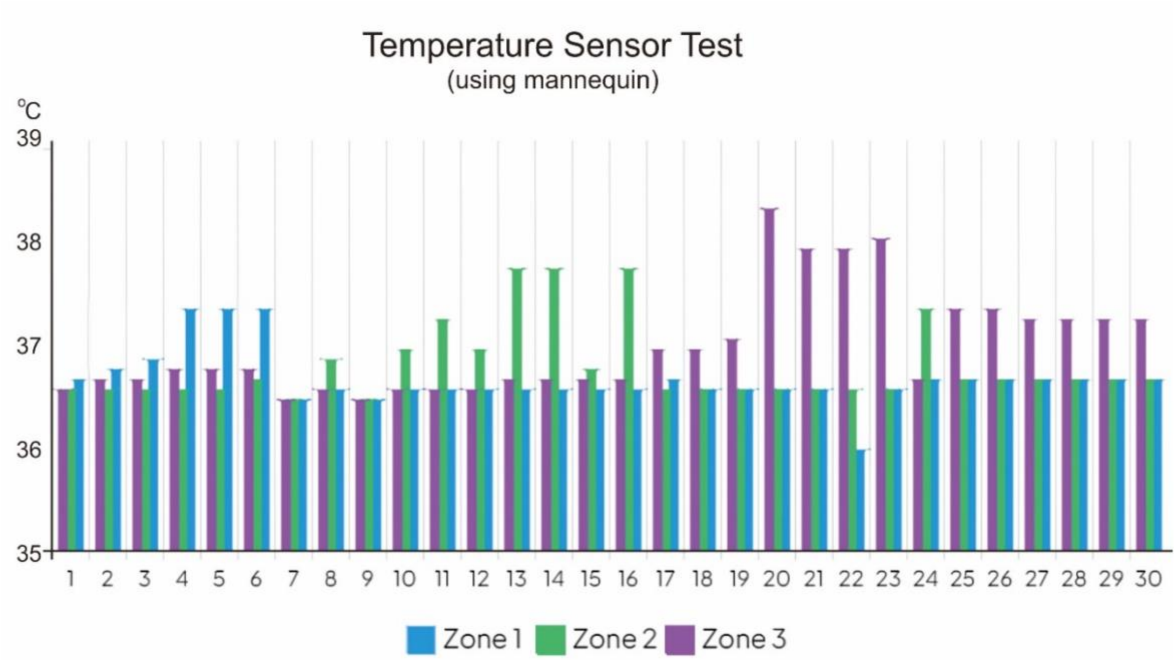


Figure 8. Diagram of heat test results on one side of the bra cup

Table 2. Details of heat test results

Itr	Zone	Temp (°C)	Itr	Zone	Temp (°C)	Itr	Zone	Temp (°C)	Itr	Zone	Temp (°C)	Itr	Zone	Temp (°C)
	1	36.7		1	36.5		1	36.6		1	36.6		1	36.7
1	2	36.6	7	2	36.5	13	2	37.8	19	2	36.6	25	2	36.7
	3	36.6		3	36.5		3	36.7		3	37.1		3	37.4
	1	36.8		1	36.6		1	36.6		1	36.6		1	36.7
2	2	36.6	8	2	36.9	14	2	37.8	20	2	36.6	26	2	36.7
	3	36.7		3	36.6		3	36.7		3	38.4		3	37.4
	1	36.9		1	36.5		1	36.6		1	36.6		1	36.7
3	2	36.6	9	2	36.5	15	2	36.8	21	2	36.6	27	2	36.7
	3	36.7		3	36.5		3	36.7		3	38.0		3	37.3
	1	37.4		1	36.6		1	36.6		1	36.6		1	36.7
4	2	36.6	10	2	37.0	16	2	37.8	22	2	36.6	28	2	36.7
	3	36.8		3	36.6		3	36.7		3	38.0		3	37.3
	1	37.4		1	36.6		1	36.7		1	36.6		1	36.7
5	2	36.6	11	2	37.3	17	2	36.6	23	2	36.6	29	2	36.7
	3	36.8		3	36.6		3	37.0		3	38.1		3	37.3
	1	37.4		1	36.6		1	36.6		1	36.7		1	36.7
6	2	36.7	12	2	37.0	18	2	36.6	24	2	37.4	30	2	36.7
	3	36.8		3	36.6		3	37.0		3	36.7		3	37.3

Figure 8 and Table 2 show that the test results of the temperature sensor applied to the mannequin show temperature differences in each zone. The high temperature in one of the zones is caused by artificial heat being activated. If the sensor reads a uniform temperature, it is identified that there are no cancer spots. On the other hand, if the sensor reads one or more hot spots that are different from other surfaces, it is identified that there are cancer spots in the area detected by the sensor.

A striking temperature difference in one of the zones was shown in tests 4, 5, 6, 13, 14, 16, 20, 21, 22, and 23. Tests in iterations 4, 5, and 6 showed that in Zone 1, the measured temperature value was higher than in Zone 2 and Zone 3. Tests on the 13th, 14th, and 16th iterations showed that Zone 2 measured a higher temperature value than Zone 1 and Zone 3. Meanwhile, the 20th, 21st, 22nd, and 23rd iterations showed that in Zone 3, the measured temperature value was higher than in Zone 1 and Zone 2. However, in other iterations, there is also a temperature difference between the zone given artificial heat and the zone not.

Testing iterations 20, 21, 22, and 23 best exemplify the purpose of this system. Zone 1 and Zone 2 measured a temperature of 36.6 ℃, representing average body temperature, while Zone 3 measured a temperature of 38 – 38.1 ℃, representing a fever temperature. The temperature difference in each zone can be measured well by the MLX90614 temperature sensor so that the right decision can be made to distinguish points that can potentially contain breast cancer. Thus, the early breast cancer detection system created based on skin surface temperature can function well because it can distinguish different heats at each point.

Finally, the temperature measurements that have been taken are displayed on the local host website. Figure 9 shows the display on the website of the sensor readings. All sensor data in the form of temperature levels in centigrade from each zone of the right side and left side of the bra cup are displayed. The display on this website makes it easier for all stakeholders involved to observe and further evaluate the results of early detection of breast cancer in patients. However, this website display requires further development and is not discussed further in this paper.

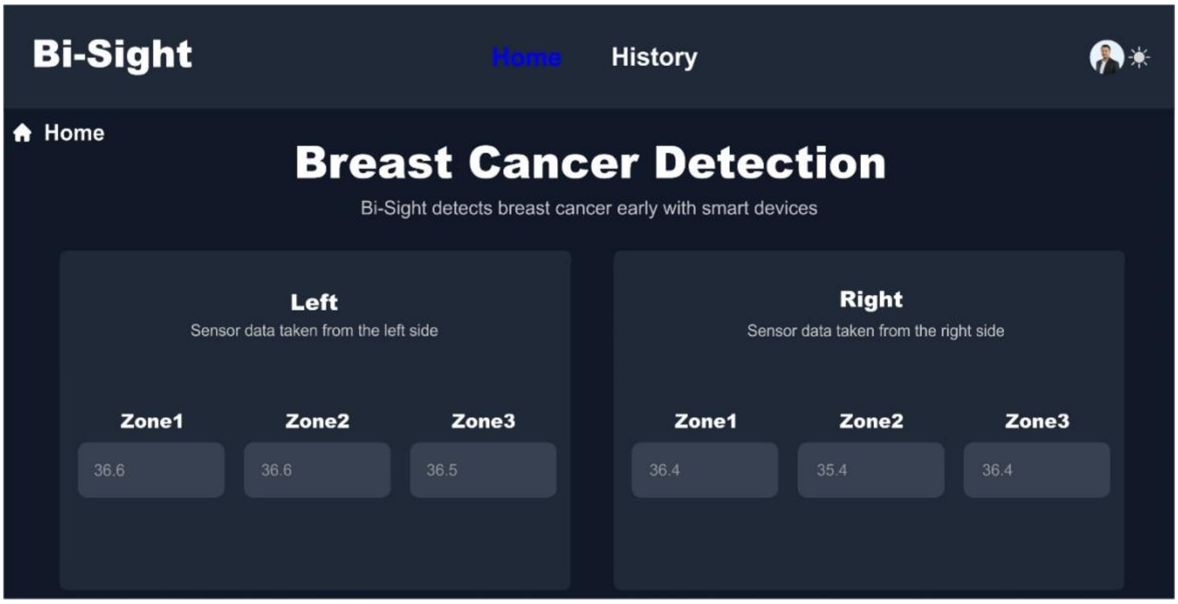


Figure 9. Display on the website of the temperature measurement results with the sensor

5. CONCLUSION

Breast cancer is deadly and threatens millions of women if it is not treated early. Early examination is an important step that must be taken. Unfortunately, there are still many errors in early examination using the BSE method. The system developed aims to make it easier for women to carry out early examinations independently. The system developed is based on the physical differences that occur on the surface of the breast. The MLX90614 temperature sensor plays a vital role in measuring these physical differences. Several MLX90614 temperature sensors are placed on the inner layer of the bra cup. The bra embedded with the MLX90614 temperature sensor is attached to the upper part of the mannequin as a subject simulator. The test was carried out by providing artificial heat from inside the mannequin. The test results show that the MLX90614 sensor can measure temperature well. The average calculation results from 30 tests were recorded, and the measurement error value obtained was 0.5 ℃, equivalent to 1%. Furthermore, the system developed can detect temperature differences in each predetermined measurement zone. As a result, this system can distinguish different heats at each point, namely average body temperature and fever heat, representing the potential for breast cancer.

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