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Thermal Imaging-Based Body Temperature and Respiratory Frequency Measurement System for Security Robot

***Abstract**. Measurement of body temperature and respiration rate is the most basic screening in knowing a person's health. For security reasons and to prevent the spread of transmission, in the Covid-19 pandemic conditions, measurements can be made by security robots. Measurement of body temperature and respiration rate was done non-contact based on thermal imaging. Temperature measurement is based on the temperature in the face area, while the respiration rate is based on changes in temperature in the nose area. The ability to measure temperature gives an accuracy of 98.21% with a standard deviation of 0.536. And the best respiration rate is the fast Fourier transform method which gives an accuracy of 79.8% with a standard deviation of 3.291.*

***Streszczenie.** Pomiar temperatury ciała i częstości oddechów jest najbardziej podstawowym badaniem pozwalającym poznać stan zdrowia człowieka. Ze względów bezpieczeństwa oraz aby zapobiec rozprzestrzenianiu się transmisji, w warunkach pandemii Covid-19 pomiary mogą być wykonywane przez roboty zabezpieczające. Pomiaru temperatury ciała i częstości oddechów dokonano bezkontaktowo w oparciu o obrazowanie termiczne. Pomiar temperatury opiera się na temperaturze okolicy twarzy, a częstość oddechów na zmianach temperatury w okolicy nosa i ust. Możliwość pomiaru temperatury daje dokładność 98,21% przy odchyleniu standardowym 0,536. A najlepszą częstością oddychania jest szybka metoda transformacji Fouriera, która daje dokładność 79,8% przy odchyleniu standardowym 3,291. (**System pomiaru temperatury ciała i częstotliwości oddechowej oparty na obrazowaniu termicznym dla robota zabezpieczającego**)*

Keywords: Temperature measurement, respiration rate measurement, thermal imaging, security robot.
Słowa kluczowe: Pomiar temperatury, pomiar częstości oddechów, termowizja, robot zabezpieczający.

Introduction

Security officers generally carry out the task of securing and supervising an area. As technology develops, this task can be replaced by a robot. Robot Security is a robot that has the task of securing an area, building, office, and others like humans. This robot works automatically or is controlled wirelessly from a distance.

With the issue of covid-19, the robot application is very important to use. Several studies are currently trying to analyse the use of robots in handling COVID-19, one of which is Chen et al [1] and Javaid et al [2]. One of the applications of robots that can be done is regarding monitoring a person's health condition. Health conditions that need to be observed are body temperature, heart rate, and respiratory rate. Common symptoms shown by COVID-19 sufferers are body temperature above 38 °C [3], heart rate above 100 times per minute [4], [5] and breathing above 30 times per minute [6].

During the Covid-19 pandemic, security officers have a new task to select visitors to a public facility. Selection is made based on the body temperature measurements of visitors. If the temperature exceeds 38 C, then the visitor is prohibited from entering. The body temperature limit follows the symptoms of COVID-19 proposed by the World Health Organization (WHO) [7]. Based on these problems, the security robot can be upgraded to perform the task of measuring temperature.

The use of security robots to detect human body temperature conditions has become a very important requirement. This condition is due to the susceptibility to the transmission of the Covid-19 outbreak when using humans to carry out these activities [8], [9]. Therefore, the use of robots can replace the activity of monitoring the condition of symptoms in humans. The use of artificial intelligence algorithm applications in the process also increases accuracy in decision-making. Research related to robots equipped with artificial intelligence has been developed in a rescue robot [10].

In addition to symptoms of body temperature that exceeds 38 C, other vital signs such as respiratory rate is also important to note. According to Negishi et al., the respiratory frequency of COVID-19 sufferers can reach 30 times per minute, faster than normal conditions, which range from 15-25 times per minute [11]. So to improve its capabilities, the security robot is equipped with a body temperature and respiratory rate measuring system. This measurement system is carried out non-contact to avoid physical contact and the use of contact measuring instruments interchangeably.

Non-contact measurement of respiratory frequency can be done by using a digital camera. According to Fielder et al., The forehead is the most suitable part because it has a relatively thin layer of skin so that when the signal is extracted, it has a higher level than the finger [12]. The video image obtained on the device is then extracted to obtain a Photoplethysmography (PPG) signal. The signal will be pre-processed to get the respiratory rate divided into certain time intervals and provided a digital filter. The final respiratory rate estimation results were used Fast Fourier Transform (FFT) to obtain the dominant frequency.

In addition to using a digital camera, reading the respiratory frequency can also use a camera with an infrared sensor. According to Abdulkadir et al., Respiratory frequency readings are obtained by changing the infrared radiation found at the tip of the nose [13]. The infrared radiation emitted by the object depends on the surface temperature and emissivity. The emissivity will be compared with the average human skin with a temperature of 32 C and an emissivity of 0.98. These measurements are carried out in real-time.

In principle, measurement of temperature and respiratory rate are two variables that cannot separate in detecting physiological symptoms in humans. In its application, the two variables can be obtained using video images from infrared cameras. Jakkaew et al. used thermal imaging from an infrared camera to detect changes in temperature due to respiration [14]. The use of thermal cameras or infrared cameras has been very fast in monitoring symptoms of the human condition.

In this study, an update of the capability upgrade of the security robot will be carried out. In addition to patrolling and monitoring the area, this robot has the ability to measure heart rate and respiratory frequency non-contact to humans in real time. This is useful if there is a violation of the health protocol, then the robot can directly screen the health of the subject.

Method

In this section, the mechanical and electrical design of the robot will be explained. Furthermore, the algorithm for measuring body temperature and respiratory frequency non-contact based on thermal imaging is also explained.

Mechanical and Electrical Design

In this study, the security robot has 500 mm in length, 400 mm in width, and 1600 mm in height. The robot is made with a differential drive mobile robot (DDRM) mechanism. The wheels used have a diameter of 100 mm with a distance between the wheels of 340 mm. a planetary gearbox DC motor drives each wheel. The castor wheel is mounted on the front side of the robot at a distance of 324 mm from the drive wheel axis. The frame is made of stud bolt material with a diameter of 8 mm, and the chassis is made of acrylic material with a thickness of 10 mm. DDRM configuration on the robot chassis can be seen in Fig.1.

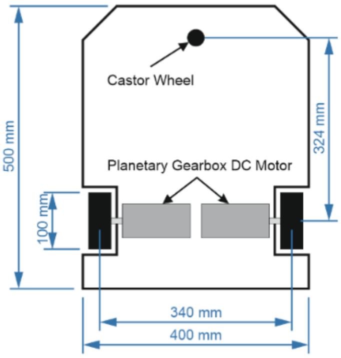

Fig.1. Security robot DDRM configuration

The thermal camera is placed on the top of the robot 1600 mm above the road surface. It is so that the thermal camera is directly facing the subject's face. At the front of the robot, a proximity sensor is installed to keep the distance between the robot and the subject in the range of 500 mm to 1000 mm.

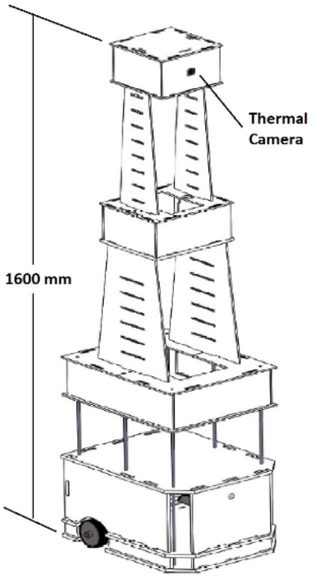

Fig.2. Perspective view of security robot

The thermal camera used is FLIR One pro for android, which by default can only be used on Android smartphones. In order to be connected to a laptop, the thermal camera connected to the android smartphone is operated as a wireless IP camera. The laptop can access the thermal image based on the IP address of the android smartphone. This connection can occur if only the laptop and android smartphone are on the same wifi network. Thermal image processing for measuring body temperature and respiration rate is done on a laptop.

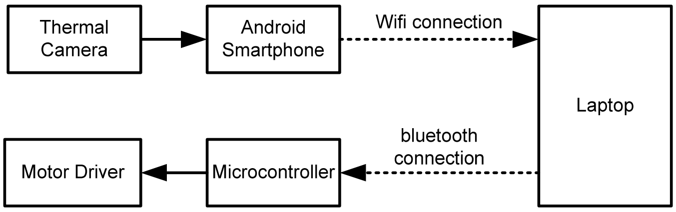

Fig.3. Block diagram of hardware connection

The robot is run manually based on the commands given by the operator. Commands are given through the laptop by pressing a few keys on the keyboard. A microcontroller is used to regulate the rotation of the DC motor installed in the robot. The microcontroller and robot are connected using Bluetooth.

Temperature Measurement Algorithm

The thermal image obtained represents the temperature at which the subject is being measured. In order to find out a person's body temperature, measurements can be made on the skin area. The face is the easiest part to measure because it is almost always in an open position. In this study, temperature measurement is focused on analyzing thermal images in the face area. The algorithm for measuring body temperature is illustrated in Fig. 4.

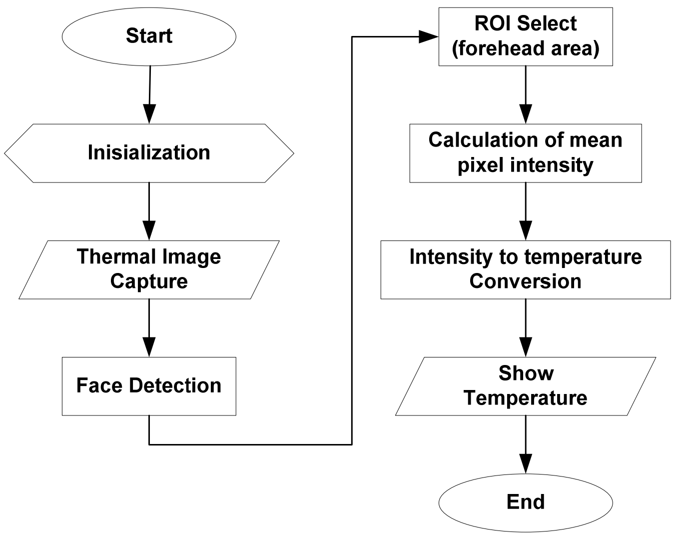

Fig.4. Flowchart of temperature measurement algorithm

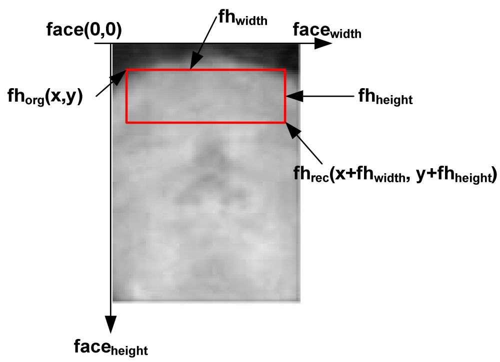

Fig.5. face thermal image

Body temperature measurement is carried out in several steps. The first step is to take a thermal image of the subject from 30cm to 100cm from the camera. The thermal image has some information, one of which is a thermal image on the face area. In order to take an image on the face area, a face detection method is used using the haar cascade classifier. In the haar cascade classifier, the position of the face is shown in the initial coordinate variables, face width, and face height. This variable is illustrated in fig 5. The initial coordinates are presented in the form of the Cartesian coordinates of the image (x-axis, y-axis), while the face width and height are in terms of the number of pixels.

After the face position is known, the ROI selection process is carried out. ROI selection aims to determine the position of the forehead from the facial image that has been obtained. Based on the illustration in fig 5, the forehead position is searched using equation (1).

$$(1)\quad \left.\begin{array}{l} fh_{org}\,(x) = face(x) + (face_{width} * 0.1) \\ fh_{org}\,(y) = face(y) + (face_{height} * 0.1) \\ fh_{rec}\,(x) = face(x) + (face_{width} * 0.9) \\ fh_{rec}\,(y) = face(y) + (face_{height} * 0.3) \end{array}\right\}$$

Where $fh_{org}(x)$ is the location of the origin pixel of the forehead on the x-axis, $fh_{org}(y)$ is the location of the origin pixel of the forehead on the y axis, $fh_{rec}(x)$ is the location of the end pixel of the nose on the x-axis, $fh_{rec}(y)$ is the location of the final pixel of the nose on the y-axis. After the forehead position is known, the average pixel intensity is calculated. Calculation of the average value of pixel intensity is carried out using equation (2).

$$(2)\qquad I_{Mean}(k) = \frac{\sum_{x=0,y=0}^{x=m,y=n} I_{gray}(k,x,y)}{mn}$$

Where $I_{Mean}(k)$ is the average value of the pixel intensity in the k-frame. m is forehead width in pixels. n is forehead height in pixels. Meanwhile $I_{gray}(k,x,y)$ is the pixel intensity of the thermal image on the k-frame at coordinates (x,y). After the average pixel value is known, it is converted to temperature using equation (3).

$$(3)\quad Temp\,(k) = Min_{temp} + \left(\frac{Max_{temp} - Min_{temp}}{255}\, I_{Mean}(k)\right)$$

Where Temp(k) is the body temperature in the k-frame in °C. Mintemp is the minimum temperature measured from the thermal image. Maxtemp is the maximum temperature measured from the thermal image. Mintemp and maxtemp values are obtained based on the capabilities of the thermal camera. This value is shown at the top of the thermal image. The illustration can be seen in fig.6.

Fig.6. minimun and maximun temperature in the thermal image

Respiration Rate Measurement Algorithm

Respiration rate measurement is done by analyzing the temperature change signal (U) in the nose area. So the measurement of respiration rate begins in the same way as measuring temperature. However, the ROI is used in the nose area. The analyzed temperature change signal must have a data length of 256 samples. The thermal camera used has a framerate of 10 fps, so it takes 25.6 seconds to sample. In order to speed up signal analysis, the temperature change signal is resampled four times. This method shortens the analysis time to 4 times faster because the length of data that needs to be taken is at least 64 data. In this study, the data taken is 70. The measurement process of respiration rate can be seen in fig 7.

The resampled signal (S) is then filtered using a Butterworth low pass filter. The cutoff frequency used is 1 Hz. It aims to eliminate high frequencies because, in general the human respiratory frequency is around 0.5 Hz. The filtered signal (F) is then processed to determine the respiration rate. There are two ways to measure respiration rate. The first is based on the Peak-to-peak time interval and the second is to find the dominant spectrum using the fast Fourier transform.

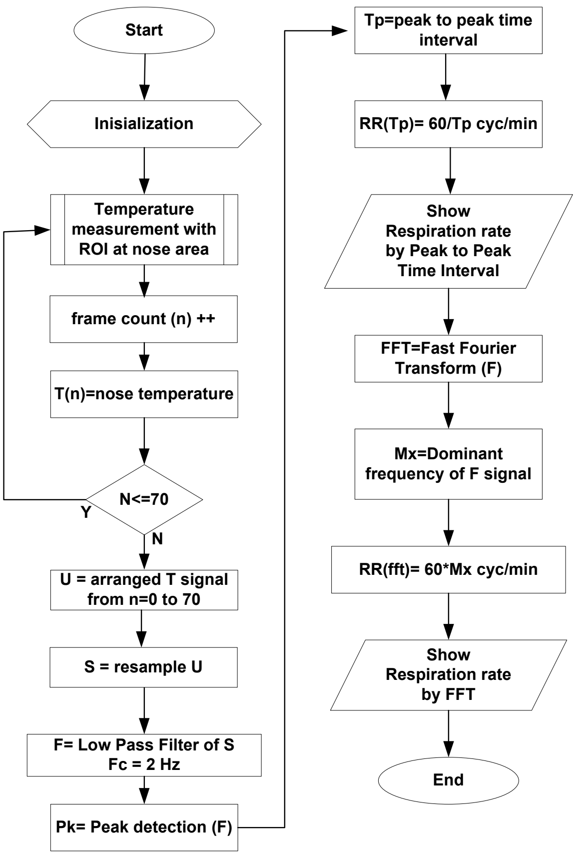

Fig.7. Flowchart of reapiration rate measurement algorithm

Based on fig 8., it can be seen that the filtered signal (F) has four peaks. Signals from the first peak and second peak indicate one respiratory cycle. The duration between the first and second peaks is called the interval time (tint). By entering the interval time value into equation (4), the respiration rate can be known.

$$(4)\qquad RR = 60/t_{int}$$

$$(5)\qquad RR = 60 * f_{peak}$$

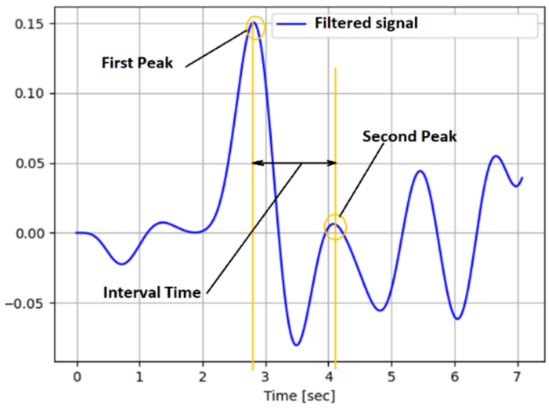

Fig.8. Peak of filtered signal (F)

The filtered signal (F) has information about the respiratory signal. The dominant frequency that occurs between 0 Hz to 1 Hz is considered to represent the respiratory frequency. In order to determine the value of the dominant frequency, the Fast Fourier Transform (FFT) is used. Fig 9 shows the spectrum of the F signal after processing using FFT. From the figure, the dominant frequency (fpeak) is at a value of 0.5 Hz. By entering the fpeak value into equation (5), the respiration rate value is obtained.

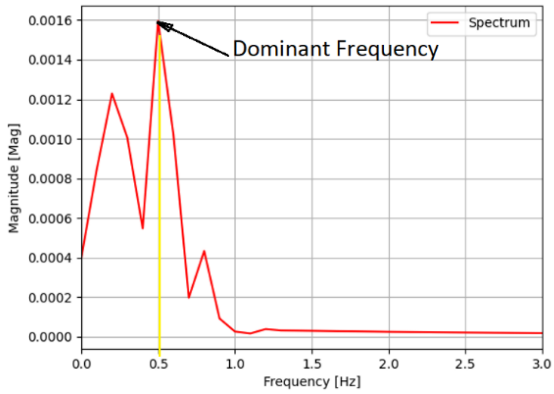

Fig.9. Spectrum of filtered signal (F)

Result and Discussion

Body temperature measurement is done by analyzing the thermal image in the forehead area. The comparison data used is the temperature measured by the infrared thermometer. Body temperature measurements were carried out on 20 subjects with a measurement distance of 50cm from the camera. Measurement subjects have varying ages. The data from the temperature measurement test results are shown in Table 1.

In order to validate the measurement results on the subject using a thermal camera, an infrared thermometer is used. Based on the experimental results, the mean error is 0.642, and the Root Mean Square Error is 0.83, with an accuracy of 98.21% and a standard deviation of 0.536.

Furthermore, the respiration rate measurement test was carried out using two methods, namely the peak-to-peak interval and the fast Fourier transform. In testing the measurement using the peak-to-peak interval, it still uses data from 20 subjects. The test results data using this method are shown in table 2.

In this method, the calculation is compared with the Respiration rate reference value manually. Based on the experimental results, the mean absolute error was 4.5, Root Mean Square Error was 5.177 with an accuracy of 77.83% and a standard deviation of 2.626.

Table 1. Body temperature measurement thermal imaging vs infrared thermometer

Subject	Age (years)	Temperature (^{O}C)		Absolute Error
		Thermal Imaging	Infrared Thermometer	
1	30	35.7	36.1	0.1
2	30	36.1	36.8	0.8
3	23	36.6	36.1	0.0
4	19	35.9	35.2	0.2
5	19	35.4	35.1	1.8
6	23	35.1	35.3	1.5
7	19	36.8	35.8	0.1
8	21	35.6	35.1	0.6
9	19	36.8	35.9	0.6
10	22	36.2	35.3	1.4
11	20	35.8	35.6	0.2
12	19	36.7	36.7	1.6
13	19	36.3	36.7	0.7
14	21	35.9	35.2	0.7
15	23	35.9	36.3	0.5
16	19	35.1	36.3	0.4
17	24	36.3	36.2	0.3
18	23	36.7	36.0	0.4
19	22	35.1	35.3	0.2
20	22	36.7	36.2	0.8
Mean			35.9	0.642
Accuration (%)				98,21
Standard Deviation				0.536
Root Mean Square Error				0.83

Table 2. Peak to peak interval-Based

Subject	Age (years)	Respiration rate (Cycle per minute)		Absolute Error
		Peak to peak interval	Reference	
1	30	22	19	3
2	30	31	22	9
3	23	22	19	3
4	19	26	25	1
5	19	22	17	5
6	23	15	23	8
7	19	22	17	5
8	21	15	18	3
9	19	14	23	9
10	22	22	18	4
11	20	31	23	8
12	19	22	19	3
13	19	22	19	3
14	21	22	22	0
15	23	19	17	2
16	19	19	24	5
17	24	22	18	4
18	23	22	25	3
19	22	25	17	8
20	22	25	21	4
Mean			20.3	4.5
Accuration (%)				77.83
Std Deviation				2.626
Root Mean Square Error				5.177

The next method using the fast Fourier transform (FFT), this method's test results are shown in Table 3. Based on the experimental results, the mean absolute error is 4.1, Root Mean Square Error is 5.206 with an accuracy of 79.8% and a standard deviation of 3.291.

Table 3. Fast Fourier Transform-Based

Subject	Age (years)	Respiration rate (Cycle per minute)		Absolute Error
		FFT	Reference	
1	30	19	19	0
2	30	23	22	1
3	23	25	19	6
4	19	24	25	1
5	19	22	17	5
6	23	17	23	6
7	19	19	17	2
8	21	12	18	6
9	19	16	23	7
10	22	15	18	3
11	20	9	23	14
12	19	18	19	1
13	19	16	19	3
14	21	16	22	6
15	23	17	17	0
16	19	17	24	7
17	24	21	18	3
18	23	23	25	2
19	22	21	17	4
20	22	16	21	5
Mean			20.3	4.1
Accuration (%)				79,8
Std Deviation				3.291
Root Mean Square Error				5.206

Conclusion

Based on the tests that have been carried out, the body temperature measuring system has a measurement accuracy of up to 98.21% with a standard deviation of 0.536. The root mean square error (RMSE) obtained is 0.83. The ability of measuring body temperature obtained is quite good, but the measurement of respiration rate obtained has a lower accuracy. Based on the peak to peak interval method, the accuracy obtained is 77.83% with a standard deviation of 2.626. Meanwhile, the fast Fourier transform obtained an accuracy of 79.8% with a standard deviation of 3,291.

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