Detection of human fatigue level based on changes in skin color using RGB sensor

F A Priambudi1,3, S Herodian2 and L Saulia2

1 Graduate School, Mechanical Engineering and Biosystem Department, Bogor Agriculture University, Dramaga-Bogor Indonesia
2 Mechanical Engineering and Biosystem Department, Bogor Agriculture University, Dramaga-Bogor, Indonesia.
3 Corresponding author, Email: fauzanazharip1@gmail.com

Abstract. Decreased work capacity could be caused by fatigue, which is a state of decreased efficiency and endurance. Fatigue can be measured using various methods, one of them is based on heart rate. Measurement of fatigue levels based on heart rate has been widely carried out, one of them is the use of contactless measurement. The objective of this research was to detect human fatigue levels using an RGB sensor based on changes in skin color with image processing technology. This research started from testing of the data intake system, followed by image data retrieval in the form of images before and after physical activity and fatigue levels data using the step test method. Image data capture is performed using an RGB sensor in the form of a Kinect 360 and mirrorless camera, while fatigue levels data used a pulse monitor. The next step was processing data using a simple linear regression method to see the level of correlation between the results of image processing in the form of changes in the RGB color of the skin with changes in fatigue levels based on changes in heart rate. The results of simple linear regression showed significant RGB color changes toward changes in fatigue levels with a correlation value reaching 0.8 when using mirrorless camera then Kinect 360. This result showed that the use of mirrorless camera is better. The average correlation value of 20 subjects at all points above 0.6 on the two sensors used. Each of the RGB color components had a significant change. This showed that there was a relationship between changes in RGB with fatigue level changes so that the method of detecting fatigue levels based on changes in skin color can be done.

1. Introduction

The role of humans in industry cannot be ignored because until now in the production process there is still a dependence between the tools of work and humans or in other words the interaction between humans, tools and materials, and the work environment. According to Wignjosoebroto’s research [1] from various matters concerning human problems in interacting with the working tools that they operate, humans are often seen as the source of all errors or workplace accidents (human error). Human error may occur due to work fatigue because work fatigue experienced by workers can reduce the level of concentration when operating a work tool.

Work fatigue is a state of decreased efficiency and endurance at work. The term fatigue refers to the weakening of the workforce to carry out an activity, resulting in a reduction in work capacity and endurance [2]. Work fatigue can be identified from changes in heart rate (HR) in humans. The pattern of the measured heart rate can indicate the level of fitness, fatigue, and blockage in the arteries [3].

Heart rate measurements, for now, can use an Electrocardiogram (ECG) and Photoplethysmograph (PPG). ECG records the activity of the heart muscle through several electrodes based on changes in
electrical charge in the heart muscle. However, the use of ECG measurement techniques still uses special devices that require humans to use them in certain body parts (contact measurement) [3]. Unlike the case with ECG, PPG is an optical sensor-based measurement technique that can detect changes in blood volume in microvascular skin tissue [4]. The PPG method allows the use of contactless measurement.

Based on the principle of heart rate measurement in the PPG technique, it's possible that the RGB sensor also can be used as a sensor to capture color changes in skin tissue [4]. Image processing is performed on the results on the RGB sensor so that the RGB change value is obtained. The RGB change value will be compared with the HR value. If the HR value can be estimated through image data obtained by the RGB sensor, then it shows that the RGB sensor can be used as a work fatigue monitoring tool. The objective of this research to detection human fatigue level using an RGB sensor with image processing technology and find out its correlation to actual measurements. The use of this system is intended to facilitate the measurement of the level of fatigue to make it more practical without using special devices.

2. Materials and methods

2.1. System Testing
This research begins with testing the system by preparing hardware in the form of RGB sensors on the Kinect 360 and Mirrorless camera, and software in the form of the Kinect SDK. Both components must be calibrated. The system is designed using the Kinect SDK created by Microsoft to operate the Kinect 360 on Windows devices. The system is created by using the programming language in Visual Studio to get applications that can process the input captured by Kinect 360 to produce the desired output, in this case, a digital photo/image. This research focuses on capturing RGB data so that in processing input data, the program that we set in the SDK centers on Color Frame Source, which is one of several Kinect Data Sources. Furthermore, input data is collected using the WPF function to facilitate storage into repository [5].

2.2. Data Retrieval
The process of data retrieval is using a Mirrorless camera, Kinect 360 and pulse monitor. The subjects used in this study were 20 people, 10 men, and 10 women. Subjects were students aged between 20-22 years with Sundanese and Javanese races. The treatment given to the subject is a division based on light skin color and dark skin color with a portion of half of each subject. Subjects were given the burden to carry out a physical activity in the form of a step test at regular intervals for approximately 25 minutes. Step test is done by stepping up and down the step test bench (height 20 cm). Step test is carried out in 3 stages, each step cycle step increases by 10 bpm (beat per minute). The step test starts from 50 bpm or equal to 25 cycles/minute.

Capturing images on the subject is done in a closed room without light, the lighting comes only from the spotlight so that the light can be adjusted so the intensity of the light obtained is suitable for measurement. Also, the background in the image taking place uses a black cloth so that the reflection of light due to the spotlight is not too large. Measurement of light intensity in the taking room is measured using a Lux meter. The distance from the sensor to the object is set such that the image capture position is the same. This is done so that the light captured by the sensor is constant. The image is taken after the measurement of the pulse at each stage without repetition. Data obtained from the Kinect 360 and Mirrorless camera will be processed using image processing methods into raw data in the form of changes in the value of each RGB. The change in RGB values analyzed is the color on the cheeks, forehead, and back of the subject's hand. Furthermore, the data obtained from the pulse monitor using the step test method will be processed into data on the level of fatigue that occurs in each respondent.
2.3. Data Analysis and Data Processing

Data processing will be carried out after all data is obtained, in the form of HR data and RGB data. HR data is processed by taking the values of R, ST1, ST2, and ST3. R value is obtained from the average HR for 2 minutes in each rest cycle, then the smallest value is taken from the average that has been obtained. ST values are obtained from the average HR during the step test for 30 seconds before resting. Furthermore, each ST value is reduced by the R value so that the delta values HR1, HR2, and HR3 are obtained. RGB data is processed after separated into 4 points on each image taken, scilicet forehead, right cheek, left cheek, and back of the hand. Furthermore, the image data that has been shared is entered into the RGB reading program so that the values Red, Green and Blue are obtained in each section.

The value of each component in the RGB data is not only processed directly to determine the level of correlation is also carried out further processing to combine the three color components into a single unit that is hexadecimal color or hex color index. The hex color index is a combination of the three components of the colors Red, Green, and Blue in the form of a code combination of letters and numbers that represent the results of the merging of colors [6]. The color code can be converted into a decimal number form that can be seen in equation 1. The hex color index is then processed into hex delta by reducing the hex value during the step test with the hex value at rest. The hex delta value will be compared with the HR delta value using quantitative methods.

Variable:

\( d \) : Code in Hex Color Index

\( r_{xy} \) : Correlation coefficient

\( n \) : Number of digits

\( x \) : Level of fatigue by RGB sensor

\( y \) : Level of fatigue by step test method

\[ \text{decimal} = (d_{n-1} \times 16^{n-1}) + \cdots + (d_2 \times 16^2) + (d_1 \times 16^1) + (d_0 \times 16^0) \] (1)

The quantitative method is in the form of multiple linear regression analyses with the Ordinary Least Square (OLS) approach to determine the relationship between fatigue levels and changes in skin color. Statistical analysis of regression analysis was carried out after the regression model was obtained by the OLS method. The parameter used to determine the relationship between the two dependent and independent variables is the correlation coefficient (r) [7]. The equation of the correlation coefficient (r) can be seen in equation 2.

\[ r_{xy} = \frac{n \sum x_i y_i - (\sum x_i)(\sum y_i)}{\sqrt{n \sum x_i^2 - (\sum x_i)^2} \cdot n \sum y_i^2 - (\sum y_i)^2} \] (2)

The correlation coefficient is the magnitude or strength of the relationship between the independent variables and the dependent variable simultaneously. R values range from -1 to 1. The more the value of r approaches -1 or 1, the better the relationship between the two variables [7].

2.4. Research Procedure

The research procedure to be carried out can be seen in figure 1. First system that used must be tested before. The system to be tested is the RGB reading system for the captured images. The RGB value reading program is performed by processing an application that is different from the image capture application. The reading program is expected to be able to read RGB values in the processed image and then directly input to the spreadsheet application. The program is built with simple logic using Visual Basic, which reads each RGB value at each pixel processed image then is divided by the number of

\[ \text{decimal} = (d_{n-1} \times 16^{n-1}) + \cdots + (d_2 \times 16^2) + (d_1 \times 16^1) + (d_0 \times 16^0) \] (1)
pixels read. The other tested system is an image capture system using the Kinect 360. A sensor that can operate optimally requires supporting software. The supporting software that used to operate Kinect 360 is the SDK (Software Development Kit) from Microsoft. The library that is available in the SDK can be used directly in the construction of an RGB image capture system on Kinect 360 [8]. The interface of RGB image capture system on Kinect 360 with SDK can be seen in figure 2, while the running program for reading RGB values can be seen in figure 3.

![Flowchart of the research procedure](image)

**Figure 1.** Flowchart of the research procedure
Figure 2. The interface of RGB image capture system on Kinect 360 with SDK

Figure 3. Running program for reading RGB values

After the system can run well the research procedure can then be done. Starting from taking RGB data and actual data simultaneously, continued with the processing of each data, then compared and look for the correlation value.

RGB data retrieval is done in a closed room without light. In capturing an image the position of the subject sitting on a bench that has been provided as high as 45 cm. The position of the picture taken is close up the face and hands raised parallel to the cheeks. Kinect 360 distance from the subject is 70 cm with a height of 110 cm, while the distance of the Mirrorless camera from the subject is 80 cm with a height of 115 cm. In the room there are 2 spotlights with lumens intensity of 45-56 lumens, depending on the height of the subject. Black cloth becomes the background for capturing data. These conditions are carried out so that capturing data is not disturbed by outside light and the light in the room can be adjusted as needed. Because the working principle of the RGB sensor is to capture light reflection, these conditions need to be done to reduce noise on the camera that affects the captured image. Examples of RGB data retrieval results can be seen in figure 4.
Figure 4. Image capture results on (a) Kinect 360 and (b) Mirrorless camera

After obtaining images on each subject it will be divided into 4 section points by trimming using an image processing application. Trimming the image is done by determining the center position of each image and taken the distance to each part of the same length and dimensions made the same cut. This is done so that each piece on the subject is not much different, because it will affect the reading of the RGB value. Examples of how to crop images in an image processing application can be seen in figure 5. The results of the image cuts on one subject at each point can be seen in figure 6.

Figure 5. How to crop images in an image processing application

Figure 6. Results of captured image at each point (a) right cheek (b) left cheek (c) forehead (d) and back hand

Figure 5 shows one example of trimming the image on the subject. The main comparison is taken from the distance between the pupils. From the pupils drawn perpendicular to the right and left cheeks of the same length ie 1-2 cm depending on the subject. The midpoint of the line between the pupils is drawn towards the forehead with a distance of 2-3 cm depending on the subject. In the back of the hand,
a comparison is taken from the middle finger of the second segment. Pulled perpendicular to the back of the hand along 5-6 cm depending on the subject.

3. Result and Discussion

3.1. Calibration

Calibration will be carried out to get accurate image data retrieval results. Calibration is done by taking pictures that have been measured in the previous RGB values. RGB values taken through the sensor will be compared directly with measured RGB values and the equation is obtained. The results of this calibration equation are used to input the RGB value to be processed in the data processing stage. Camera calibration results can be seen in Table 1.

| Value | Y = aX + b | R² |
|-------|------------|----|
| R     | 1.0454     | -3.9442 | 0.990 |
| G     | 0.986      | 2.1648  | 0.999 |
| B     | 0.9817     | 2.1703  | 0.998 |

Once it is known that the RGB sensor has a good image capture to measurement from the calibration results above, then a comparison is made between the results of the measured RGB value, namely the skin meter with the RGB value on the subject to determine whether the measuring instrument used has a good level of accuracy or not. Accuracy testing is performed on both RGB sensors, on Mirrorless camera and the Kinect 360. The results of the accuracy testing can be seen in Figure 7.

![Figure 7](image)

**Figure 7.** Results of the accuracy testing of RGB sensor on (a) Mirrorless camera (b) Kinect 360

Based on figure 7, it can be seen that the level of accuracy on Mirrorless camera is better than the Kinect 360. On Mirrorless camera the reading of Green values is better than the other two color components, while the Kinect 360 reads Blue values at best, each having a value above 0.9 However, the reading of the Red and Green values on the Kinect 360 is fairly low but still has values above 0.6. This shows that reading the RGB values using the two measuring devices is feasible to use. From the results of the level of accuracy, the use of Mirrorless camera for reading RGB values will be better.
3.2. Step test method results

Step test is carried out to measure the respondent's HR to obtain the actual level of fatigue. HR measurements are carried out using a pulse monitor. Transmitter or sensor of the device is mounted on the ring finger so that the heart rate can be detected and measured properly, then manually measured heart rate will be recorded and input into a spreadsheet application. In the measurement, several things need to be considered, for example, the installation of sensors on the index finger must be attached should not be loose. Measurement of the level of fatigue with a step test needs to be done so that will be a known correlation between changes in HR value with changes in the value of RGB. Footsteps during the step test are adjusted to the sound of a digital metronome that has been set according to the cycle of each step test so that at each increase in the digital metronome cycle it needs to be reset. An example of the results of step test data in a graph on the subject can be seen in figure 8.

Figure 8. HR graph of the subject during the step test

Figure 8 shows the subject's heart rate increases with increasing step test cycles. At rest after doing a step test the HR value of the subjects could not return under normal conditions. This is because a rest period of only 10 minutes is not enough to return them to its original state. However, this condition is not too problematic because the changes that occur in R1 to R3 are not too large, which almost happened in all subjects. But in some subjects, the lowest HR value is found in R2. This is because, at the beginning of measurement (R1), the subject's heart rate is irregular which illustrates that the subject's heart rate is still unstable, due to the subject's adjustment to the measurement methods and measuring devices they use. The results of taking the step test data in the form of HR (bpm) for each subject will be processed to get an HR delta to show changes in the level of fatigue that occurs. The HR value used to calculate the HR delta is the value of the average heart rate data for each cycle. The data used at rest is the average heart rate for 1 minute when the HR value is the most stable (usually present 1-3 minutes before ST1) at rest. HR measurement when resting is done for 10-15 minutes, it is expected to get the heart rate back to normal before doing activities. HR value at rest is used as a comparison and subtraction of HR step test values so that the delta HR is obtained. Data processed by the HR step test values can be seen in table 2.

Table 2 shows that the value of HR delta increases with increasing step test cycles. This shows that the increase in fatigue in each subject in each cycle increases. Each subject has a value that varies between the displacement of each cycle. This shows that everyone has their respective capacities in responding to the increased fatigue that occurs. Fatigue data in the form of delta HR will then be used to determine its correlation with changes in the value of RGB.
Table 2. The results of processed step test data

| Subject | Delta HR | Subject | Delta HR |
|---------|----------|---------|----------|
|         | HR1      | HR2     | HR3      | HR1      | HR2     | HR3      |
| 1       | 35,583   | 37,250  | 47,250   | 11       | 31,917  | 35,417   | 44,083   |
| 2       | 31,000   | 35,000  | 40,167   | 12       | 33,083  | 43,750   | 44,583   |
| 3       | 52,417   | 53,917  | 60,417   | 13       | 29,000  | 34,333   | 34,500   |
| 4       | 30,333   | 32,167  | 36,333   | 14       | 37,333  | 39,000   | 42,500   |
| 5       | 16,667   | 18,000  | 19,500   | 15       | 39,300  | 52,800   | 60,300   |
| 6       | 10,000   | 39,167  | 47,333   | 16       | 38,167  | 48,286   | 53,667   |
| 7       | 30,417   | 47,583  | 54,750   | 17       | 30,107  | 31,583   | 33,583   |
| 8       | 14,667   | 47,833  | 54,500   | 18       | 31,167  | 35,667   | 46,167   |
| 9       | 26,083   | 30,417  | 37,417   | 19       | 25,731  | 26,231   | 35,064   |
| 10      | 23,167   | 25,500  | 31,500   | 20       | 44,000  | 47,500   | 54,833   |

3.3. RGB sensor method results
The results of taking pictures that have been cut to the point will then be processed with an RGB reading program that directly input into the spreadsheet application. The graph of changes in the value of RGB based on changes in the step test cycle can be seen in Figure 9.

Figure 9. Changes in the value of Red to the step test cycle on 5 subjects

Figure 9 shows the change in the value of Red to the step test cycle that has increased. In some subjects fluctuating changes can be seen, as well as in some other subjects there are changes that are very far, due to changes in the subject's position when image captured. This represents the result of all components of the RGB value. Changes in the fluctuating RGB value will affect the correlation value that will be obtained. The RGB values that have been obtained will be processed into a hex index color then the delta is taken according to the step test cycle. HR1 is the delta of step test 1 (ST1) minus rest 1 (R1). The delta results are then used as a reference to determine the correlation with changes in fatigue levels based on changes in RGB.
3.4. Data processing and analysis

The data processing is done using a simple linear regression method to get the correlation value between changes in fatigue level (delta HR) with changes in skin color (delta RGB). The correlation level is indicated by the high and low r obtained, with a value between -1 to 1. The closer to -1 or 1, the higher the correlation value. HR delta values of 20 subjects taken as an increase in the level of fatigue that occurs will be compared with the RGB delta values (hex color index) at each point in the face and hands to determine the correlation value. The results of the correlation coefficient of the level change in the hex color index with changes in the level of fatigue can be seen in Table 3.

Table 3. The results of the correlation coefficient of the level change in the hex color index with delta HR

| Subject | Mirrorless camera | | | | Kinect 360 | | |
|---------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
|         | Forehead | Right cheek | Left cheek | Hand | Forehead | Right cheek | Left cheek | Hand |
| 1       | -0.861 | -0.763 | 0.114 | 0.999 | -0.966 | 0.045 | -0.996 | 0.772 |
| 2       | 0.228 | -0.985 | -0.856 | 0.832 | 0.790 | 0.927 | 0.881 | 0.251 |
| 3       | 0.998 | -0.089 | 0.998 | 0.970 | -0.945 | -1.000 | -0.922 | -0.974 |
| 4       | 0.992 | 0.999 | 0.558 | 0.184 | 0.965 | 0.511 | 0.943 | -0.964 |
| 5       | -0.897 | -0.806 | -0.994 | -0.469 | 0.866 | 0.930 | -0.689 | -0.369 |
| 6       | 0.986 | 0.976 | 0.992 | 0.850 | -0.716 | 0.138 | -0.907 | 0.095 |
| 7       | -0.998 | -0.974 | 0.999 | -0.754 | -0.998 | -0.974 | 0.999 | -0.754 |
| 8       | -0.345 | 0.978 | -0.859 | -0.911 | -0.130 | -0.995 | 0.849 | 0.871 |
| 9       | 0.941 | -0.947 | 0.339 | 0.358 | 0.995 | 0.815 | 0.571 | -0.682 |
| 10      | -0.536 | -0.077 | -0.161 | -0.999 | -0.731 | -0.717 | -0.648 | -0.964 |
| 11      | 0.753 | 0.967 | 0.704 | -0.424 | 0.205 | 0.197 | 0.378 | -0.999 |
| 12      | 0.999 | 0.872 | 0.953 | 0.879 | 0.999 | 0.967 | -0.055 | 0.970 |
| 13      | -0.758 | 0.537 | -0.629 | -0.719 | 0.585 | -0.980 | -0.655 | -0.705 |
| 14      | -0.179 | -0.295 | 0.000 | -0.960 | -0.777 | 0.797 | 0.000 | -0.789 |
| 15      | -0.602 | -0.593 | -0.698 | -0.207 | 0.633 | 0.901 | 0.295 | 0.969 |
| 16      | 0.833 | -0.643 | 0.879 | 0.884 | 0.747 | 0.173 | -0.028 | 0.997 |
| 17      | -0.640 | -0.987 | -0.940 | -0.966 | 0.917 | -0.861 | 0.934 | -0.573 |
| 18      | 0.798 | 0.997 | 0.302 | -0.399 | 0.032 | 0.152 | -0.767 | -0.434 |
| 19      | -0.915 | -0.863 | -0.992 | -0.134 | -0.997 | -0.980 | -0.939 | 0.963 |
| 20      | 0.955 | 0.197 | 0.857 | 0.045 | -0.677 | -0.608 | -0.909 | 0.669 |

Table 3 shows the correlation levels of the combined RGB derived by hex color index with changes in fatigue levels. The highest correlation value was found on the forehead with an average of 0.761 using Mirrorless camera, while the lowest correlation value was found on the hands with an average of 0.647. Kinect 360 on the forehead has the best correlation value with an average of 0.734. Subject number 12 has the best correlation value in all parts of the measurement with values above 0.8. In some subjects such as subject number 10 and 15, there was almost no correlation at all in each section taken. Though in some subjects only occur at some point only. This can occur due to errors when an image captured. The results obtained indicate a significant change in changes in the level of fatigue to changes in RGB. Errors occur only in 6-7 subjects caused by errors in data retrieval. In detecting changes in fatigue levels, RGB color changes can be shown from the image taken after and before fatigue occurs by using the two
RGB sensors used. The results of the correlation show the use of Mirrorless camera is better than the use of camera on the Kinect 360.

Some errors that occur due to image capturing a subject that is only done once. The sensitivity of the RGB color readings is very high which should be done in taking RGB color change data repeatedly, so the values obtained are actual and accurate. The use of Kinect 360 in determining color changes by taking pictures after and before they are deemed unsuitable because the colors captured by the Kinect 360 are inaccurate, indicated by the results of lower correlations and different RGB values of skin meter parameters.

Poor correlation value is also caused by several things that affect changes in skin color on the subject. Changes in skin color not only occur due to workload but can be influenced by the initial conditions of the subject, health, and psychological. Initial conditions and the subject's health that is not uniform at the time of measurement affect the results obtained because the skin discoloration that occurs can be different from normal conditions. Psychological on each subject also affects the results of measurements made, changes in skin color can occur if the subject feels embarrassed or depressed during the measurement. To overcome the errors that occur, data retrieval can be done in real-time within a certain time interval. RGB sensors on the Kinect 360 as well as on Mirrorless camera can use this method. The use of data retrieval in real-time can minimize errors that occur so that we get a better correlation value. Likewise, with HR data retrieval, it is recommended to use tools with high accuracy in order to obtain maximum results.

4. Conclusions and Suggestions

4.1. Conclusions
The results of the analysis of determining the level of human fatigue based on changes in the value of RGB using a simple multiple linear regression method shows a high enough correlation value. From the parameter of determining the level of fatigue that is the HR delta shows significant results on changes in the value of RGB, with a correlation value above 0.6 so that the correlation value can be accepted. In the forehead and right cheek, the correlation value obtained in most subjects reached 0.8 using a Mirrorless camera. This shows the use of Mirrorless camera better. The average correlation value of 20 subjects at all capture points was above 0.6 on the two RGB sensors used. This shows that the determination of the level of human fatigue using a RGB sensor with image processing methods can be used.

4.2 Suggestions
The image capture method should be done repeatedly so that the noise obtained is not too large. Multiple shot settings when image capturing are recommended so that the data obtained is more than one. A real-time image capture method with a video camera can also be done to reduce errors in data retrieval. The method of data retrieval in real-time can minimize errors that occur so get a better correlation value. Likewise, with HR data retrieval, it is recommended to use tools with high accuracy to obtain maximum results.

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