卒 業 論 文 概 要 書

Summary of Bachelor's Thesis

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Title</td><td colspan="5">Research on a Method for Detecting Rib Regions Using Color Information</td></tr>
</table>

1. Introduction

For athletes, increased activity in games and training increases the risk of sports injuries and disorders. Therefore, the prevention of sports injuries that damage the body is of particular importance. One measure to prevent trauma and disability is to ensure coordination throughout the body. It has been reported that increasing the range of motion of the ribs improves body coordination.

An increased range of motion of the ribs allows the entire body to be used in a balanced manner, thereby reducing sports trauma and disability. The measurement of rib motion is an important prerequisite for physical adjustments aimed at increasing the range of motion of the ribs. However, there is currently no method for measuring rib motion from images. Conventional posture estimation models aim to obtain skeletal shapes from images and estimate posture, but not motion.

In this study, we propose a method to measure rib motion from images which were framed from the video. The rib regions are reproduced with red stickers, and the rib motion is measured by color detection from the images which were framed from the video. We also evaluate the accuracy of the proposed method by comparing it with a measurement method using a measuring tape, which is actually used in rehabilitation hospitals.

2. Related works

In related research on physical measurement, SOFTBANK Corporation has developed a sports support service for student athletes and amateur athletes, "AI Smart Coach," in collaboration with Tsukuba University [1]. This service has learning, comparison, and recording functions, and supports improvement of sports skills, such as checking and improving form through skeletal evaluation and tagging functions using artificial intelligence. However, it does not have a function for detecting rib movements.

3. Preliminary experiment

Some hospitals specializing in the treatment of sports injuries have incorporated rib measurement into rehabilitation. The movement of the ribs during exhalation and inhalation is measured with a tape measure and used to analyze the patient's health status and to provide guidance in rehabilitation. This measurement should be performed at the site of large displacement of the ribs.

In this preliminary experiment, we examine the validity of the measurement positions used in hospitals. Fig. 1 shows the measurement positions A and B, which are used in the hospital and the nearby measurement position C on the body. We compare them with the measurement position C to verify whether A and B are valid. The measurement results at rib positions A, B, and C using measuring tape are shown in Table 1.

Table 1. Measurement Results Using Measuring Tape.

	A	B	C
Rib Displacement (cm)	4.0	2.7	2.0

From Table 1, it is confirmed that the displacement of the ribs at measurement positions A and B is greater than that at position C. Therefore, the measurement positions used in the hospital are valid for analyzing rib motion.

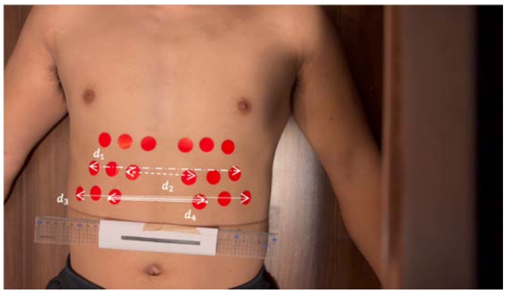

Fig. 1. Measurement Position A, B and C (Distance d_1 to d_4 between left and right edges).

4. Proposed method

4.1 Measurement of Rib Region Displacement by Color Detection Using OpenCV

This study proposes a rib motion analysis method based on color detection using OpenCV. To detect the rib region, 18 red circle stickers with a 2 cm radius are used. Six stickers are placed at each of the rib positions A, B, and C shown in Fig. 1. The distances to be measured are d_1 to d_4 in Fig. 1. Based on the detected area, d_1 to d_4 is calculated as the Euclidean distance in Eq. (1). Let the leftmost coordinate be and the rightmost coordinate be (x_1, y_1) and (x_2, y_2).

$$d^2 = \sqrt[2]{(x_2 - x_1)^2 - (y_2 - y_1)^2}. \qquad (1)$$

Let the displacement of the distance calculated by the above Eq. (1) be Δd, the distance during inhalation be h_{max} , and the distance during exhalation be h_{min}, then the displacement is obtained by the following Eq. (2). Since the coordinates on the image are used, the unit here is pixel.

$$\Delta d = d_{max} - d_{min}. \qquad (2)$$

4.2 Calculation Method Using Scale

A black line with a real size of 10 cm is used as a reference in the image for this experiment, as shown in Fig. 1. The displacement of the rib ΔD (unit: cm) is expressed by Eq. (3).

$$\Delta D = \frac{10}{h_p} \Delta d. \qquad (3)$$

4.3 Calculation Method Using Similarity

This calculation method converts the rib height in pixels to cm using the distance A cm from the camera to the ground, the thickness of the body B cm, and the distance C cm of the width of the angle of view. The camera position for the conversion is shown in Fig. 2. x is the actual distance (cm) at the height of the rib region, The image size is 1920x1080 pixel, and the rib displacement ΔD (unit: cm) is expressed by Eq. (4).

$$\Delta D = \frac{C - \frac{CB}{A}}{1920} \Delta d. \qquad (4)$$

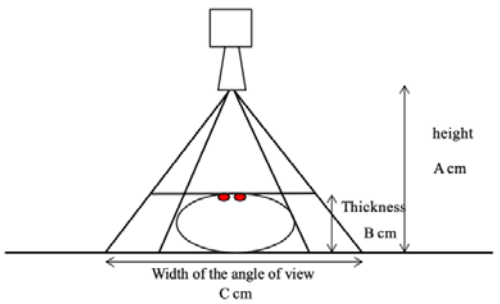

Fig. 2. Camera Position and similarity.

5. Experiment

5.1 Dataset

In this experiment, a camera was placed at a height of 83.7 cm from the floor, with the subject lying on his back on the floor. Nine breaths were taken, and the positions of the ribs were recorded on video. The body thickness was 19.5 cm. The number of moving images was 3090 frames.

5.2 Experiment results

Predicted values of rib motion by the proposed method are compared with actual values measured by the tape. Measurement accuracy was evaluated using the relative error in Eq. (5) and the absolute error in Eq. (6).

$$Absolute\ Error = |Predicted\ value - Actual\ measured\ value|. \qquad (6)$$

$$Relative\ Error = \frac{|Predicted\ value - Actual\ measured\ value|}{Actual\ measured\ value} \times 100. \qquad (7)$$

Tables 2 and 3 show the results of the evaluation of the rib displacements predicted by the calculation methods of 4.2 and 4.3. From values in Tables 2 and 3, the average relative errors were 8.901 and 7.783, respectively.

Table 2. Results of evaluation of rib displacement predicted by Eq. (3) (relative error).

Distance	Rib Displacement(cm)	Relative Error (%)	Absolute Error (cm)
ΔD_1	1.826	8.700	0.174
ΔD_2	0.932	16.50	0.132
ΔD_3	1.314	1.077	0.014
ΔD_4	0.656	9.334	0.056

Table 3. Results of evaluation of rib displacement predicted by Eq. (4) (relative error).

Distance	Rib Displacement(cm)	Relative Error (%)	Absolute Error (cm)
ΔD_1	1.701	14.95	0.299
ΔD_2	0.868	8.500	0.068
ΔD_3	1.224	5.846	0.076
ΔD_4	0.611	1.834	0.011

6 Conclusion

In this research, we proposed a method for measuring rib motion using color detection from images of ribs represented in red. Experimental results showed that the similarity-based method was superior to the scaling method. Both approaches can predict displacement with less than 10% error compared to the measurement method using a measuring tape. Based on the results, trainers at the rehabilitation hospital opined that it would be practical, except that the patient must be naked in the upper body.

Reference

[1] ソフトバンク株式会社, “AI スマートコーチ”, (in Japanese, accessed on 12/24/2023, https://www.softbank.jp/mobile/service/ai_smartcoach /)

Research on a Method for Detecting Rib Regions Using Color Information

A Thesis Submitted to the Major in Computer Science and Communications Engineering,
School of Fundamental Science and Engineering of Waseda University
in Partial Fulfillment of the Requirements for the Degree of Bachelor of Engineering

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Last but not least, I would like to express my gratitude to my parents who give me unwavering support and respect for my every decision. Without their understanding and belief in me, it would have been impossible for me to complete my study.

List of Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Introduction

Sport is not just an exercise for individuals but can extend to the unity and ideals of an organization or group. For example, for South Africa, rugby is deeply rooted in history and culture, and is a source of national pride. Sports are beneficial for improving athletic performance and maintaining health. However, it is also a physical barrier to healthy living. For athletes, over-exertion and poor conditioning during games and training lead to an increase in sports injuries and disorders. Especially in contact sports such as rugby, American football, soccer and basketball, the incidence of injury is higher than in other sports due to physical contact.

A case study of an athlete who was forced to retire due to a sports injury is the case of Masashi Nakayama, a former member of the Japanese national soccer team. In 1994, when Masashi Nakayama became a J-League player, he suffered from Groin-Pain syndrome, which was said to be an injury of unknown cause at the time [1]. Groin pain syndrome [2] is a highly intractable groin pain and is a common injury with a high incidence in soccer and rugby, where players often use cutting back and kicking motions. Later, during treatment, it was discovered that a lack of "overall body coordination (balance)" was a factor in the disorder.

The loss of balance throughout the body causes groin pain syndrome. The ribs play an important role in maintaining this coordination. The ribs are in the torso. Therefore, inadequate movement of the ribs limits the movement of individual limbs such as arms and legs. As a result, excessive use of the extremities in movement leads to disability. Therefore, smooth movement of the ribs improves the coordination of the entire body and prevents symptoms such as Groin-Pain syndrome. Lack of balance throughout the body is often a factor in injuries other than groin pain. Therefore, it is very important to detect imbalances in the entire body prior to injury.

1.2 Thesis Purpose

One measure to prevent injury is to ensure the balance of the entire body, and one possible way to do this is to extend the range of motion of the ribs. Existing posture estimation models provide information on the position of the main skeleton from images. However, they have not been able to detect the position and movement of the ribs surrounding the spine. In this study, we assume that the position of the ribs can be detected and investigate a method for detecting their movement. To locate the position of the ribs, stickers are attached directly to the body. We propose a method to measure the movement of the ribs by obtaining the seal position using a color detection process on the image. The performance of the proposed method is evaluated by comparing it with a measurement method using a measuring tape, which is in reality used in hospitals for rehabilitation treatment. We show that the proposed method enables motion estimation by a non-contact image processing technique instead of detecting the amount of rib motion, which requires contact in the conventional method.

1.3 Thesis Outline

The structure of this paper is as follows.

Chapter 1 is the main chapter and describes the background and purpose of this study.

Chapter 2 describes the research related to this study.

Chapter 3 describes the preliminary experimental results and discussion of this study.

Chapter 4 describes the proposed methodology of this study.

Chapter 5 describes the results and discussion of the evaluation experiments of the proposed method.

In Chapter 6, we present the conclusions and future issues of this study.

Chapter 2 Related Works

2.1 Introduction

This chapter introduces the existing sports analysis services using image processing and AI technologies.

2.2 Sports analysis services using image processing and AI technology [3]

In recent years, advances in real-space sensing technologies such as image recognition and sensors, as well as AI technologies such as deep learning, have led to the introduction of AI in various fields. The wave of AI has also been sweeping into the field of "sports," and is playing a major role in the development of sports. Currently, in the world of ball games (baseball, soccer, basketball, etc.), due to the complexity of tactics, book competition videos and book analysis services have become a major business in the world of recorded games. One example is the Softbank company.

As a related study of physical measurement, SOFTBANK CORP. has developed and started providing a sports support service called "AI Smart Coach [3]" for student sports (club activities) and amateur athletes in collaboration with Tsukuba University. AI Smart Coach" is equipped with learning, comparison, and recording functions, and supports the improvement of sports technology by checking and improving form through artificial intelligence skeletal evaluation and tagging functions. For example, by utilizing the skeletal evaluation of artificial intelligence technology, it is possible to compare one's own filmed form with model videos and to record notes about what one has observed. In addition, the system can be linked to the online class service "Smart Coach," allowing students to take online remote classes with former athletes and professional coaches. Recently, the increasing burden of extracurricular teachers and the shortage of extracurricular instructors in teaching at schools have become topics of discussion, and the "AI Smart Coach" is said to contribute to solving this shortage of human employment [3].

In this section, we introduced sports analysis services based on image processing and AI-based posture estimation. However, none of the sports analysis services have succeeded in detecting ribs by image processing.

2.3 Conclusion

In this section, a sports analysis service using existing image processing and AI technologies was introduced. It was also shown that the sports analysis presented in this chapter is not limited to rib detection by image processing

Chapter 3 Preliminary Experiment

3.1 Introduction

In a preliminary experiment, the displacement of the measurement position is compared and verified in an actual rehabilitation hospital. This chapter describes the purpose, experimental method, results, and discussion of the preliminary experiment.

3.2 Purpose

Some hospitals specializing in the treatment of sports injuries have incorporated rib measurement into their rehabilitation programs. The movement of the ribs during exhalation and inspiration is measured using a measuring tape, and is used to analyze the patient's health condition and to provide guidance in rehabilitation. This measurement should be performed at the site of large displacement of the ribs. In this preliminary experiment, we will verify whether the measurement positions used in rehabilitation hospitals are appropriate.

3.3 Experimental Setting

In a preliminary experiment, the authors will measure the degree of rib distension using a measuring tape, which is performed in rehabilitation hospitals, at the position where the rehabilitation trainer performed the test and at other rib positions and compare the results.

The degree of rib distension is defined as the displacement of the ribs during the writer's exhalation and inhalation. Fig. 1 shows the measurement positions A and B on the body and the nearby measurement position C, which are used in hospitals. In addition to these two positions A and B, position C was defined for comparison, and the validity of A and B was verified by comparison with measurement position C. The three positions A, B, and C are shown in Fig. 1. The three positions A, B, and C are defined as 22 cm, 24 cm, and 26 cm vertically down from the clavicle.

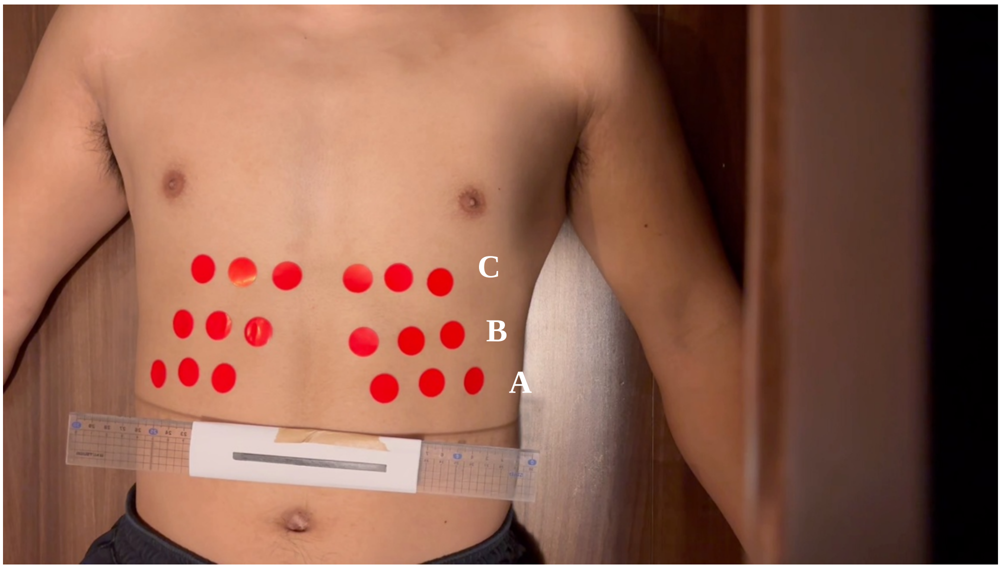

Figure 1. Measurement position A, B and C.

3.4 Experimental Result

The results of the measurements at rib positions A, B, and C using the measuring tape are shown in Table 1 and Fig. 2. They show that the rib displacement at position A is the largest and the variation at position C is the smallest.

TABLE 1 Measurement results of rib displacement using measuring tape.

	A	B	C
Rib displacement (cm)	4.0	2.7	2.0

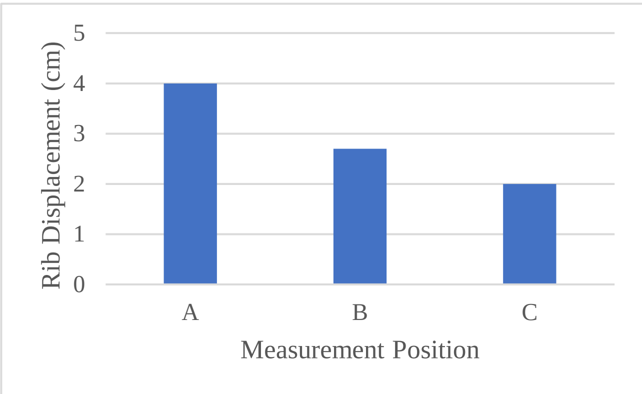

Figure 2. Relation between measurement position and rib displacement.

3.5 Consideration

The results of the preliminary experiments suggest that the measurement positions used in the rehabilitation hospital are effective in measuring rib movements. The measurement positions were equally spaced at 22 cm, 24 cm, and 26 cm from the clavicle, but there was a large difference in the displacement of the ribs between measurement position A and the other two measurement positions, B and C. This indicates that the rib movements become active at 24 cm or more from the clavicle. Therefore, A and B are the appropriate measurement positions for the analysis of rib movement.

3.6 Conclusion

In this chapter, preliminary experiments confirmed that the measurement positions used in rehabilitation hospitals are effective in analysing rib motion.

Chapter 4 Proposed Method

4.1 Introduction

In this chapter, we propose a method for analysing rib motion based on colour detection.

4.2 Measurement of rib area displacement by colour detection using OpenCV

4.2.1 Definition of the distance

In this research, we propose a rib motion analysis method based on colour detection using OpenCV. To detect the rib region, 18 red stickers with a diameter of 2 cm are used. Six stickers are placed at each of the rib positions A, B, and C shown in Fig. 4. The distances to be measured are d_1 to d_4 shown in Fig. 3.

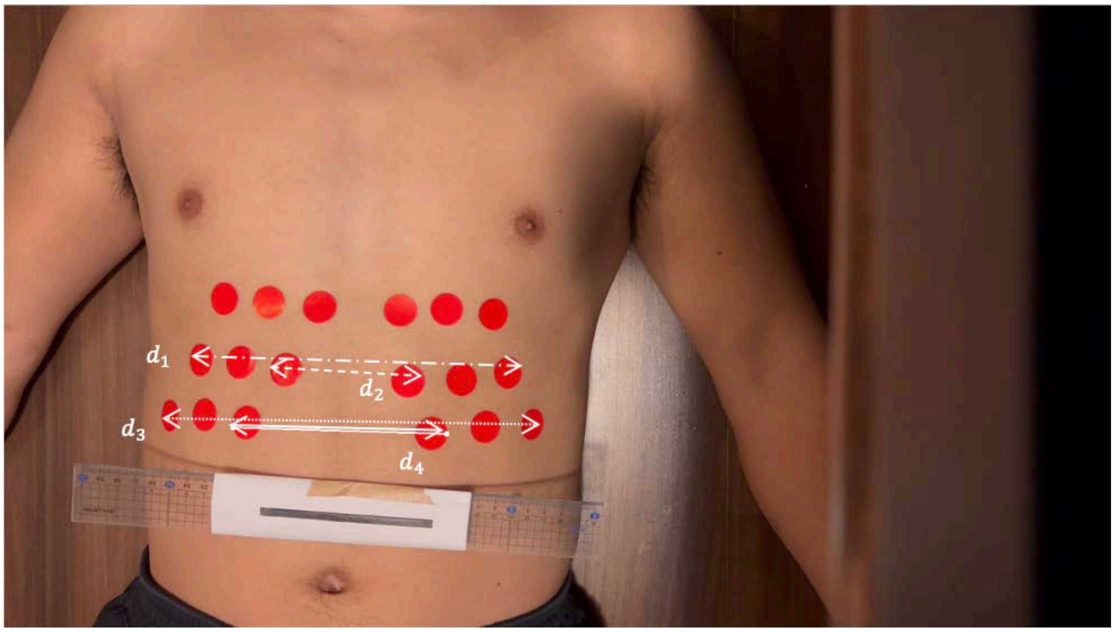

Figure 3. Distance d_1 to d_4 between left and right edges.

From the detected red region, d_1 to d_4 are obtained using the Euclidean distance in the following Eq. (1) where the left edge coordinates are $(x_1,\ y_1)$ and the right edge coordinates are $(x_2,\ y_2)$,

$$d = \sqrt[2]{(x_2 - x_1)^2 - (y_2 - y_1)^2}\,. \tag{1}$$

Let the displacement of the distance calculated by the above equation 1 be Δd, the distance during inhalation be h_{max}, and the distance during exhalation be h_{min}, then the displacement is obtained by the following equation 2. Since the coordinates on the photograph are used, the unit here is pixel,

$$\Delta d = h_{max} - h_{min} . \tag{2}$$

Since the unit obtained above is pixel, it is necessary to convert pixel to cm. Therefore, 4.2.1 and 4.2.2 below show the calculations for converting to actual dimensions.

4.2.2 Calculation method using scale

A black line with a real size of 10 cm is used as a reference in the image for this experiment, as shown in Figure 3. The displacement of the rib ΔD (unit: cm) is expressed by Eq. (3).

$$\Delta D = \frac{10}{h_p} \Delta d , \tag{3}$$

where:

ΔD (unit: cm) = the displacement of the rib,

h_p= the length of the black line in the image.

4.2.3 Calculation method using similarity

This calculation method converts the rib height in pixels to cm using the distance A cm from the camera to the ground, the thickness of the body B cm, and the distance C cm of the width of the angle of view. The camera position for the conversion is shown in Figure 2. x is the actual distance (cm) at the height of the rib region, expressed by Equation 4. The image size is 1920x1080 pixel, and the rib displacement ΔD (in cm) is expressed by Eq. (5).

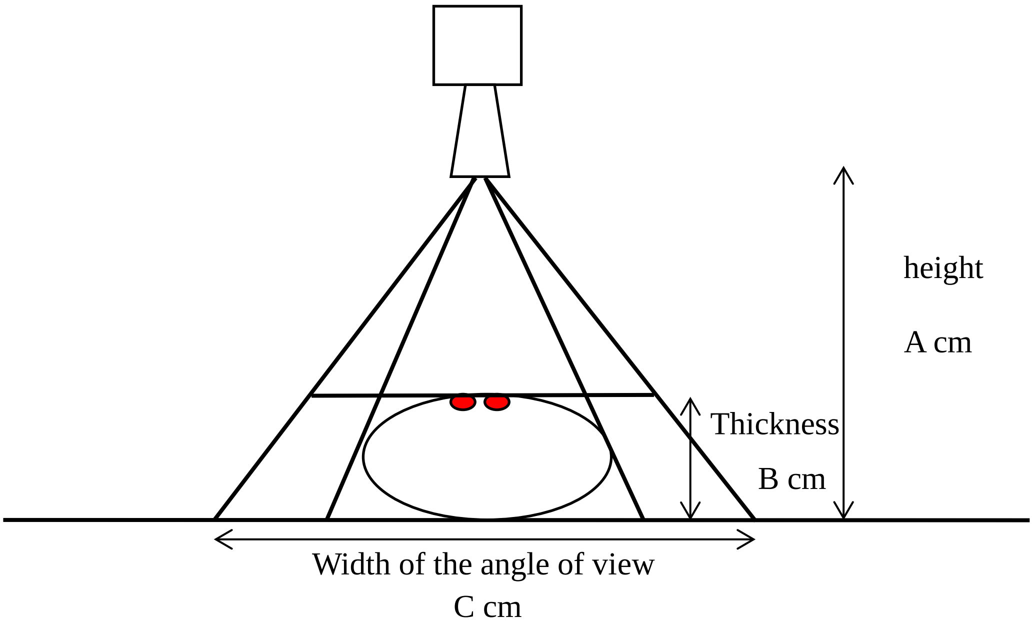

Figure 4. Camera position and similarity.

$$C : x = A : (A - B) .$$

$$x = \frac{C \times (A - B)}{A} = C - \frac{CB}{A} . \tag{4}$$

$$\Delta D = \frac{x}{1920} \Delta d = \frac{C - \frac{CB}{A}}{1920} \Delta d . \tag{5}$$

4.3 Conclusion

This chapter describes the actual measurement method using a measuring tape and the rib motion analysis method based on colour detection proposed in this study.

Chapter 5 Experimental Results and Discussion

5.1 Introduction

In this chapter, we conduct an experiment to evaluate a rib motion analysis method based on colour detection and describe the results and discussion. In the experiment, the measurement accuracy was evaluated by comparing it with the measured values obtained by the actual measurement method using a measuring tape.

5.2 Data Set

In this experiment, a camera was placed at a height of 83.7 cm from the floor, with the subject lying on his back on the floor. Nine breaths were taken, and the positions of the ribs were recorded on video. The body thickness was 19.5 cm. The number of moving images was 3090 frames. The file format of the video was mp4. Fig. 5 shows a schematic diagram of the camera position during the recording.

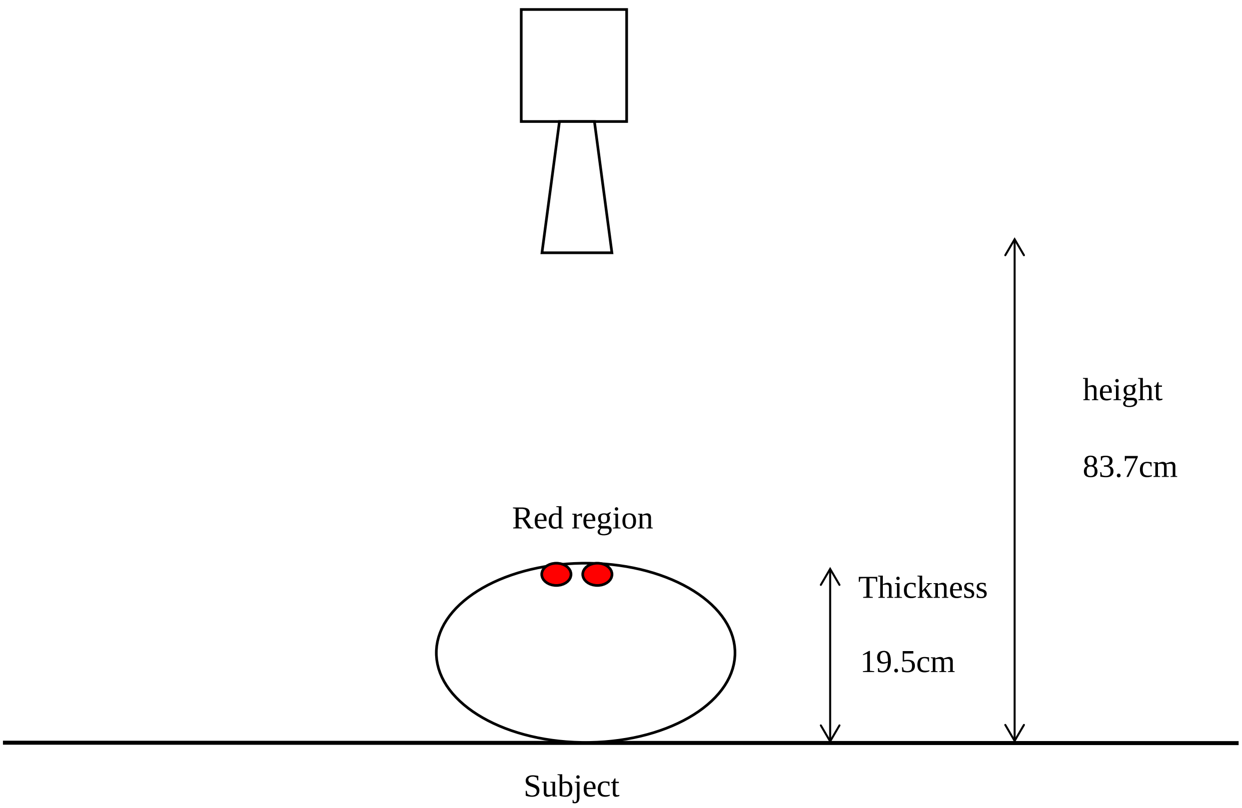

Figure 5. Overview diagram of the camera's position.

5.3 Evaluation Metric

This research compares the predicted values of rib motion by the proposed method with the actual measured values of ribs obtained by the measurement method using a measuring tape. Measurement accuracy was evaluated using the relative error in Eq. (6) and the absolute error equation in Eq. (7).

$$Absolute\ Error = |Predicted\ value - Actual\ measured\ value| \tag{6}$$

$$Relative\ Error = \frac{|Predicted\ value - Actual\ measured\ value|}{Actual\ measured\ value} \times 100 \tag{7}$$

5.4 Measurements of rib displacement using measuring tape

In this section, the actual measuring tape is used to measure the displacements of d_1 to d_4 in Fig. 3 during inhalation and exhalation. The displacements for the measured distances are shown in Table 2 below.

TABLE 2. Actual rib displacement using a measuring tape.

	Rib Displacement□ cm□
Δd_1	2.0
Δd_2	0.8
Δd_3	1.3
Δd_4	0.6

The rib displacement obtained above is the actual measured value explained in the 5.3.

5.5 Results of rib area displacement measurement by color detection using OpenCV

Figures 6, 7, 8, and 9 show graphs of the distance calculated from Euclidean in Eq. (1) on the y-axis and the number of frames when the video is framed as a continuous image on the x-axis.

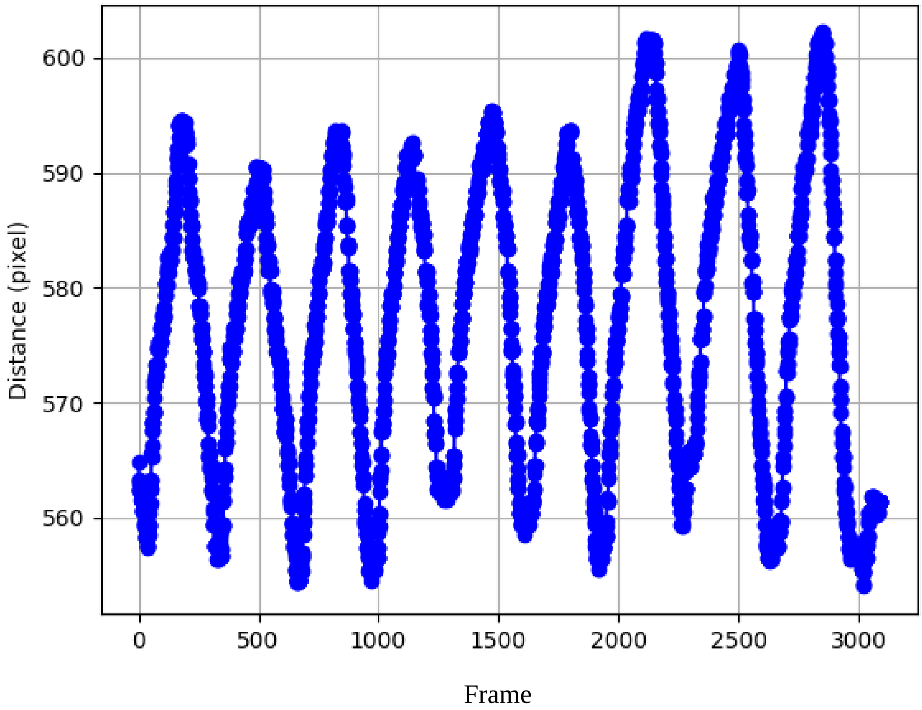

Figure 6. The relation between d_1 and frames.

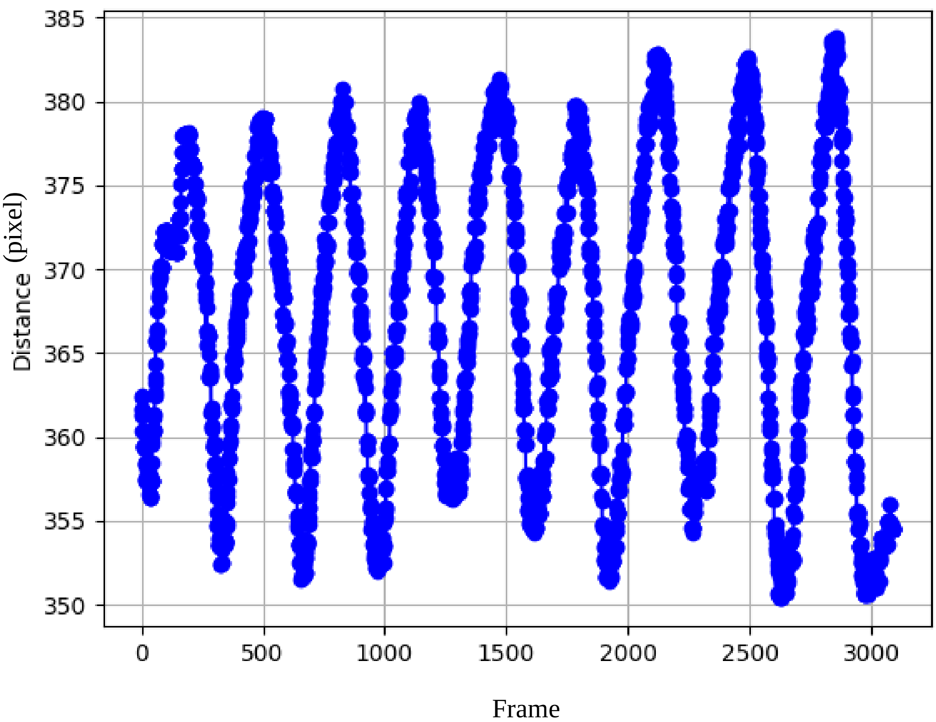

Figure 7. The relation between d_2 and frames.

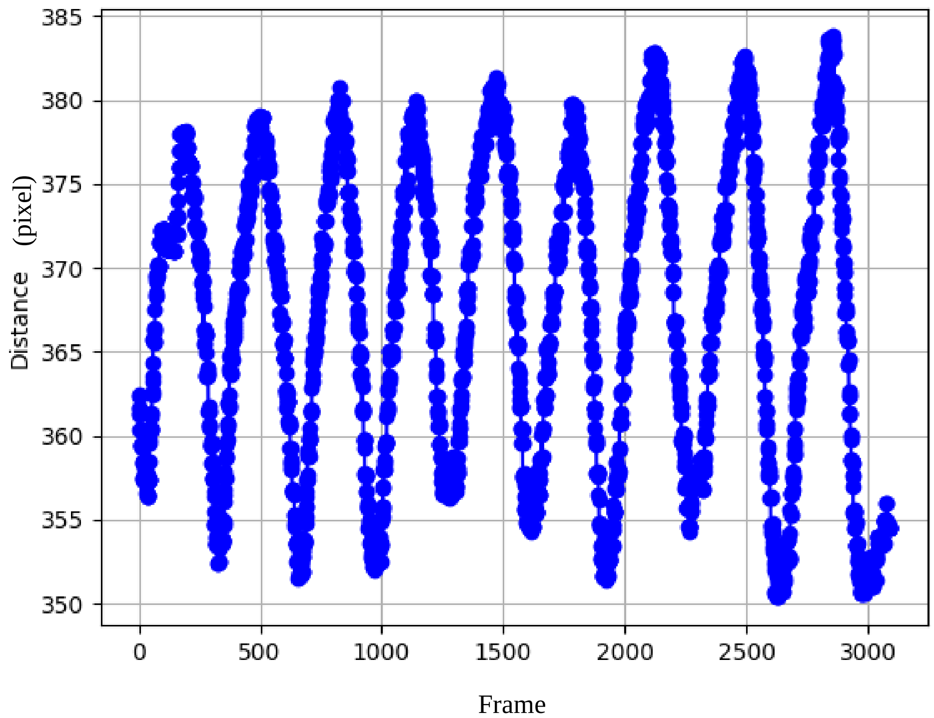

Figure 8. The relation between d_3 and frames.

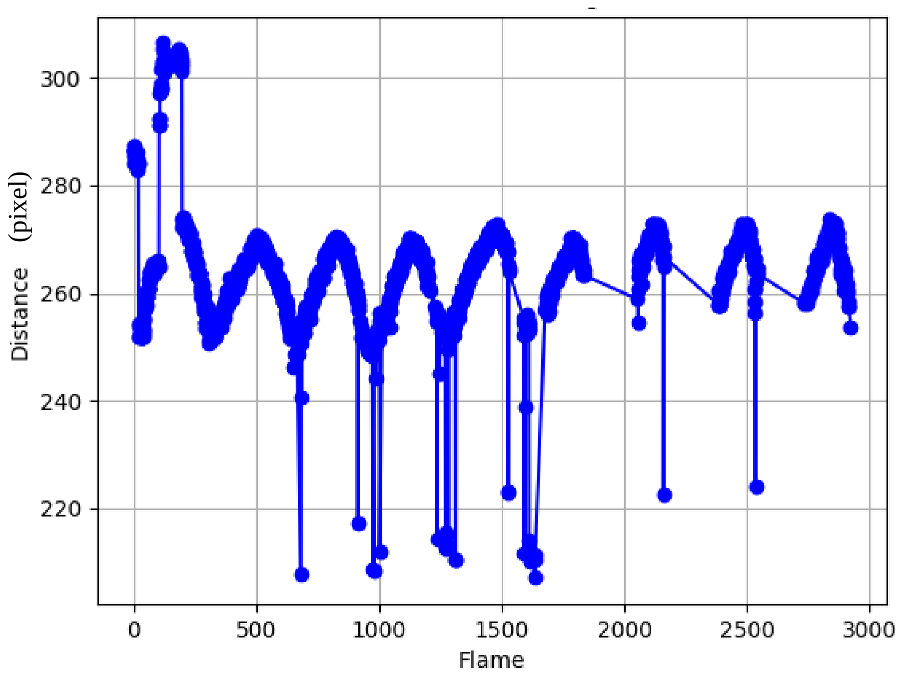

Figure 9. The relation between d_4 and frames.

The displacements from d_1 to d_4 are denoted as $\Delta d_1, \Delta d_2, \Delta d_3, \Delta d_4$. Focusing on the above figures 6 to 9, the waveform represents respiration itself. Inhalation is at the top of the wave and expiration is at the bottom of the wave. However, as Fig. 9 clearly shows, there is an outlier because the light reflection interferes with the detection of the red color in d_4.

Based on this, Table 3 shows the average value of the displacement of the distance from Δd_1 to Δd_3 during 9 times of exhalation and inspiration, and the displacement of Δd_4 during the frame number 240 to 540 in Fig. 5.4, where the maximum value of Δd_4 is during inspiration and the minimum value during exhalation.

TABLE 3 Rib displacement measured by color detection.

	Rib displacement (pixel)
Δd_1	54.44
Δd_2	27.80
Δd_3	39.18
Δd_4	19.55

5.5.1 Conversion results based on calculation method using scale

Table 4 shows the results of converting Table 3 to actual size using Eq. (3). Tables 4 and 5 show the results of the evaluation compared to the actual measured values obtained in 5.4.

TABLE 4 Rib displacement predicted by Eq. (3).

	Rib displacement ΔD (cm)
Δd_1	1.826
Δd_2	0.932
Δd_3	1.314
Δd_4	0.656

TABLE 5 Results of evaluation of rib displacement predicted by Eq. (3) (relative error).

	Rib displacement ΔD (cm)	Relative Error (%)
Δd_1	1.826	8.700
Δd_2	0.932	16.50
Δd_3	1.314	1.077
Δd_4	0.656	9.334

TABLE 6. Results of evaluation of rib displacement predicted by Eq. (3) (absolute error).

	Rib Displacement ΔD (cm)	Absolute Error (cm)
Δd_1	1.826	0.174
Δd_2	0.932	0.132
Δd_3	1.314	0.014
Δd_4	0.656	0.056

5.5.2 Conversion results by calculation method using similarity

Table 7 shows the results of converting Table 3 to actual size using Equation 4. Tables 8 and 9 show the results of the evaluation compared to the actual measured values obtained in 5.4.

TABLE 7. Rib displacement predicted by Eq (4).

	Rib Displacement ΔD (cm)
Δd_1	1.701
Δd_2	0.868
Δd_3	1.224
Δd_4	0.611

TABLE 8. Results of evaluation of rib displacement predicted by Eq. (4) (relative error).

	Rib displacement ΔD (cm)	Relative Error (%)
Δd_1	1.701	14.95
Δd_2	0.868	8.500
Δd_3	1.224	5.846
Δd_4	0.611	1.834

TABLE 9. Results of evaluation of rib displacement predicted by Eq. (4) (absolute error).

	Rib Displacement ΔD (cm)	Absolute Error (cm)
Δd_1	1.701	0.299
Δd_2	0.868	0.068
Δd_3	1.224	0.076
Δd_4	0.611	0.011

5.5.3 Availability of red area due to reflection of light

The availability of red regions due to light reflection is listed in Table 10. Figure 10 shows an image in which only red areas are detected using OpenCV and the rest are displayed in black.

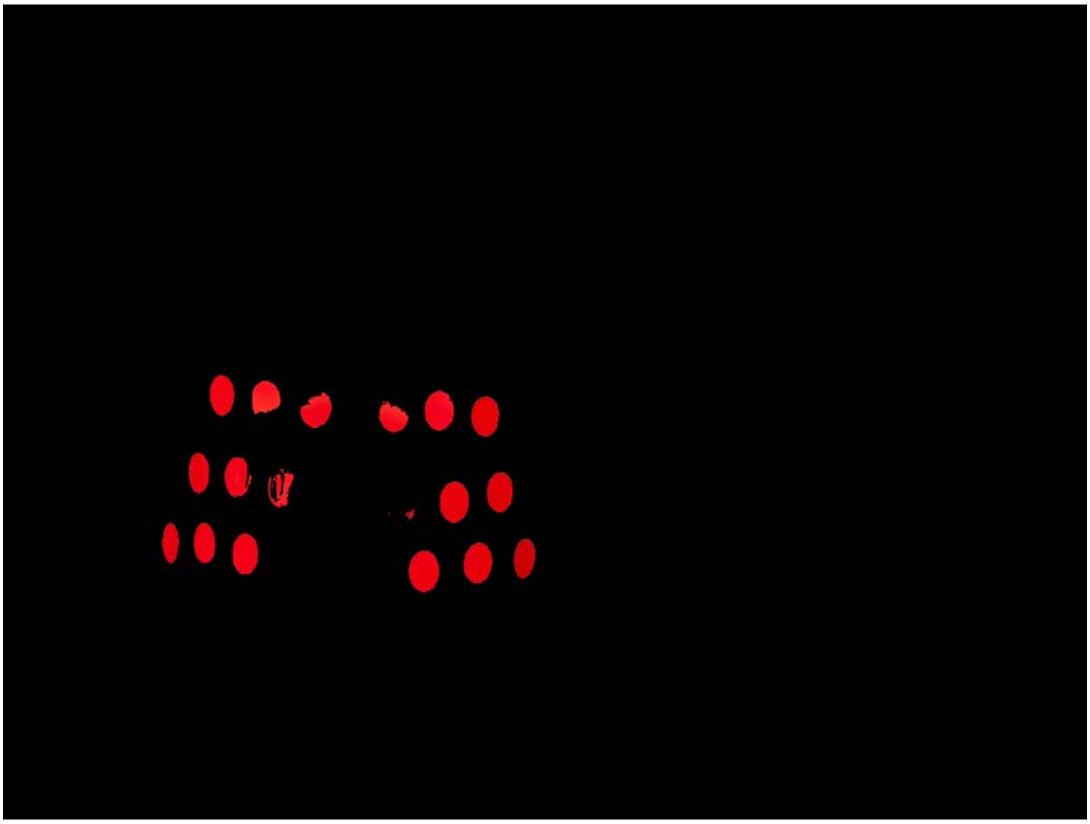

Figure 10. detected red areas and the rest in black.

TABLE 10. Red area detection availability.

	Detected or not detected
Δd_1	detected
Δd_2	detected
Δd_3	detected
Δd_4	detected

5.6 Discussion

From Fig. 9, it could be seen that there is an outlier in the graph. This outlier is due to the effect of light reflection. It seems that the reflection of light causes red areas to appear white, and this effects areas that should be red are judged to be white, and other red coordinates in the photograph are obtained. Although we tried to reduce the amount of reflected light, we could not completely prevent the reflection of the red area during the displacement of the red area during respiration. Otherwise, the waveform graphs in Fig. 4.1 to 4.3 show clean waveforms, with the maxima of the waveforms representing inhalation and the minima of the waveforms representing exhalation.

From Tables 5, 6, 7 and 8 by comparing the average relative error between the method using the calculation method using the scale and the method using the similarity, the method using the scale was 1.118% larger than the method using the similarity. Furthermore, Tables 5, 6, 7 and 8 confirm that Δd_2 has a lower average absolute error than Δd_1 and Δd_3 has a lower average absolute error than Δd_4. A possible reason for this is that Δd_2 and Δd_4 are distances that exist closer to the plane than Δd_1 and Δd_3. In this measurement method, the Euclidean distance was used to measure the image from one direction, so the position closer to the center of the body could be measured more accurately. On the contrary, Δd_1 and Δd_3 are located on the outer side of the ribs, and the measurement is less accurate than Δd_2 and Δd_4 because the roundness of the body must be considered.

5.3 Conclusion

In this chapter, we evaluate the measurement results of the actual measurement method using a measuring tape and the proposed method in color detection by using relative and absolute errors. As a result, it is found that the measurement method in color detection has a low relative error to the actual measurement method and is a highly accurate evaluation method.

Chapter 6 Conclusions and Future Works

6.1 Conclusions

Rib movements are important in rehabilitation. However, conventional methods cannot detect rib movements from images. In this study, we clarified effective measurement positions for analysing rib motion and proposed a measurement method based on colour detection.

The ribs are marked with red stickers, which can be detected using image processing. Using the detected red region, the distance displacement between specific coordinates was compared with the distance displacement actually measured with a measuring tape. The distances calculated in pixel coordinates in the image were converted to a real-world scale by following two approaches. They are the scale calculation method using a reference object and the similarity calculation method using the distance from the camera to the body and the floor.

The values converted by each calculation method were compared with the values actually measured with a measuring tape. Then, they are evaluated by absolute and relative errors. As a result, the relative error was about 8.9% for the scale method and about 7.8% for the similarity method. This result indicates that the similarity method is superior to the relative error. Therefore, it was confirmed that the measurement method using image processing is reasonably accurate as the method using measuring tape.

A specialist physician at a hospital specializing in rehabilitation has opined that "this technique is not practical in that the patient must be naked in the upper part of the body, but it is practical except for that condition."

6.2 Future Works

In this research, we used images taken from the frontal view of the subject to perform red detection of the rib region reproduced with a red sticker. In reality, rib motion is three-dimensional, and an image taken from one direction is not sufficient. Therefore, it may be necessary to obtain more accurate results by capturing three-dimensional images from three directions and measuring the red area obtained from the images. In addition, since the distance was calculated without considering the distortion of the camera, it was necessary to consider the calibration of the camera.

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