Self-assessment Application of Flexion and Extension

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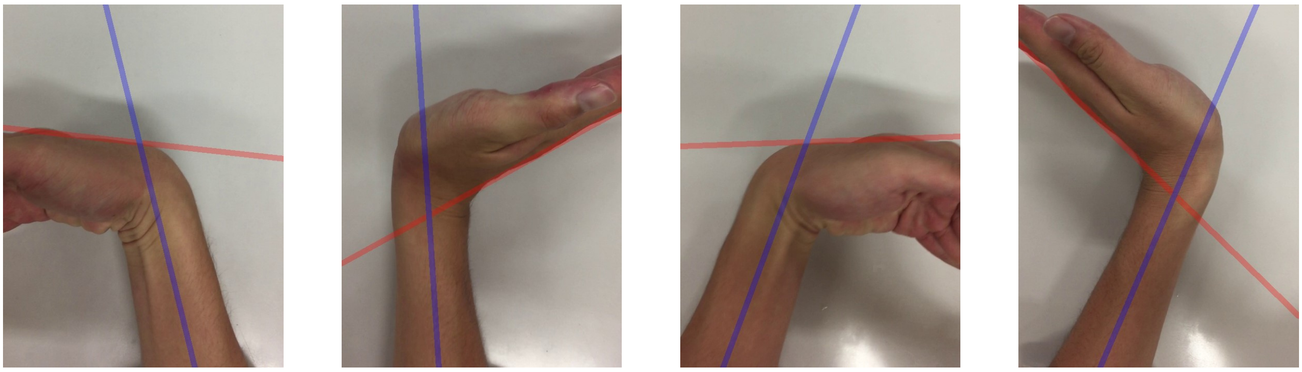


Flexion (right hand): 69.8° | Extension (right hand): 64.9° | Flexion (left hand): 67.6° | Extension (left hand): 69.0°

Fig. 1: Overview of the proposed method. The system calculates a middle line of the arm and an outside line of the back of the hand based on user inputs. Afterward, flexion and extension are calculated. The numbers at the bottom of each figure are estimated values.

***Abstract*—The measurement of range of motion during medical examination is a basic procedure in diagnosis and treatment evaluation. However, accurate measurement requires experience, and it is difficult for patients to measure range of motion by themselves. If patients can easily and accurately measure the range by their own, it will encourage patients to continue rehabilitation and will be useful for helping patients to determine when they should see a doctor. We developed a wrist flexion and extension measurement system using images captured by a smart phone so that patients can measure range of motion without expert knowledge or experience. First, the system calculates a middle line for the forearm and an outside line for the dorsal hand based on user inputs. Afterward, the angle formed by these lines is calculated. The experimental results show that the average absolute errors are 4.82° for flexion and 8.74° for extension.**

***Index Terms*—range of motion, self-assessment, hand surgery**

I. Introduction

Orthopedic disease and surgery often cause functional decline accompanied by a reduced range of motion (ROM) in the affected joint. Medication and rehabilitation usually improve ROM, so the measurement of ROM during medical examination is a basic procedure in evaluation. Accurate measurement requires experience, thus patients rarely measure ROM by themselves. If patients can easily and accurately measure ROM, it will encourage them to continue rehabilitation and can help them to determine when they should see a doctor.

Self-taken digital photographs and line tracings of wrist ROM showed good correlation to goniometer measurement at home photography-based method for measuring wrist ROM [1]. Also, gyroscopes in smart phones have showed possibilities. Self-measured wrist ROM by wrist-injured and wrist-healthy study participants using a built-in iPhone feature as compared with a universal goniometer [2]–[4]. Here we developed a wrist flexion and extension measurement system using images captured by a smart phone so that patients can measure ROM without expert knowledge or experience. Our approach is closely related to Ymashita et al. [5]. They used Hilditch thinning algorithm and Hough transform.

II. Method

The user places one of the hands in maximum flexion (or extension) on a plane, such as a desk, and takes a picture of the hand with a smart phone in the other hand. The background color should not be close to the color of the hand and should be a solid, plain color to make it easier to detect the hand area in the next process. The user takes images of maximum flexion/extension for the left and right hands, so there are four input images. Examples of input images are shown in Figure 1 (note that estimated lines are drawn on the input images in the gures).

The input image like Figure 2 (a) is binarized using Otsu's method [6] in order to detect the hand area. It will not work well to binarize the input image as it is (Figure 2 (b)) because of a shadow in the input image. In order to remove the shadow, the image is converted to HSV (hue, saturation, value) space. Then, the V (brightness) of all pixels is set to the same value. As a result, the brightness of the entire image becomes

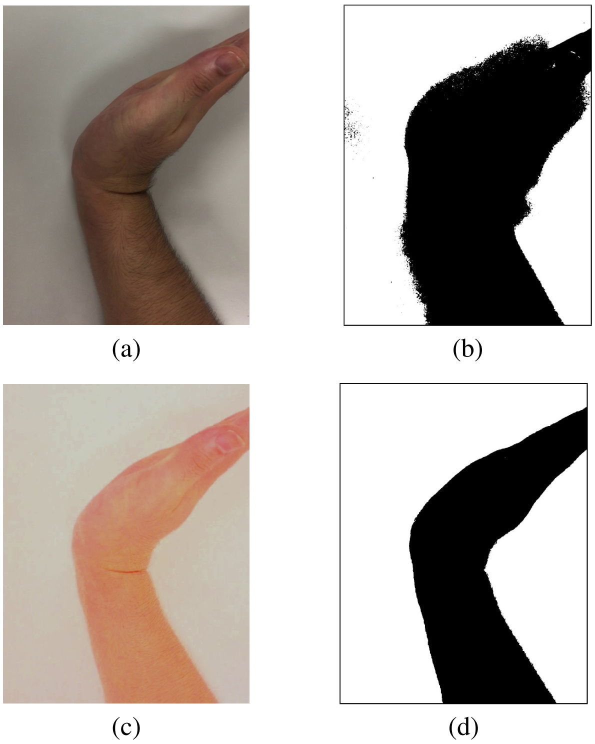


Fig. 2: The binarization process. (a) An input image; (b) The result of Otsu's method on (a); The input image which brightness is uniform; (d) The result of Otsu's method on (c).

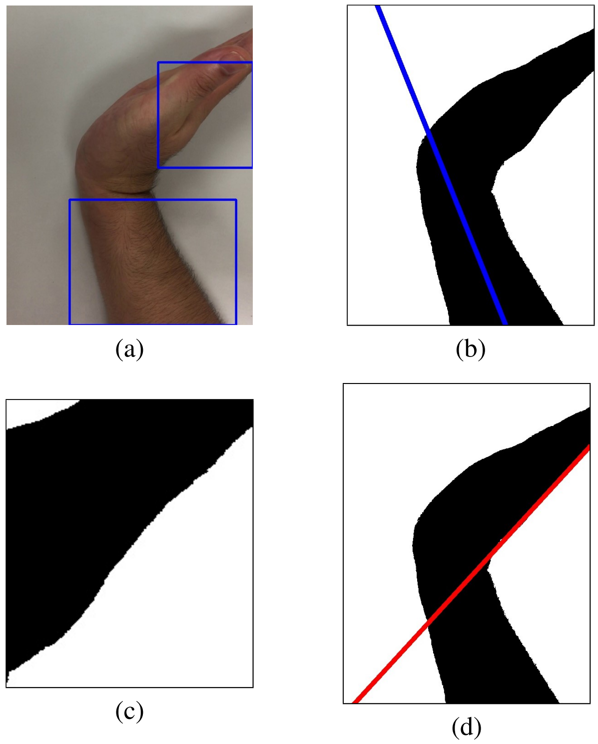


Fig. 3: The midline of the forearm detection and the outer line of the dorsal hand detection process. (a) An user input example. It is to indicate the ares where the entire arm is shown and the boundary area of the back of the hand; (b) The result of the midline of the forearm detection; (c) The enlarged picture of the upper area in (a); (d) The result of the outer line of the dorsal hand detection.

uniform, and the shadow will be removed (Figure 2 (c)). This is because shadows are different in brightness from other areas. After this, return the image to RGB (red, green, blue) space, convert it to grayscale, and then binarize the image using Otsu's method. As can be seen from Figure 2 (d), by setting V to the same value, the image can be binarized while removing the effect of the shadow, so the hand area be detected more accurately.

Flexion and extension are actually an angle formed by the long axis of the radius and the long axis of the dorsal side of the second metacarpal bone. The proposed method replaces the long axis of the radius with the midline of the forearm and the long axis of the second metacarpal bone with the outer line of the dorsal hand. In order to calculate the two lines, the user is asked to indicate the areas where the entire arm is shown along with the boundary area of the back of the hand as shown in Figure 3 (a). The process for calculating two lines from the areas is as follows:

- **The midline of the forearm**
  The pixels at the average position in the X axis direction in the binary image generated in the previous process are extracted. The parameters of the line are calculated from these pixels (Figure 3 (b)).
- **The outer line of the dorsal hand**
  The background can be divided into two or more areas in the area the user indicated (Figure 3 (c)). The areas outside the maximum area are removed in order to extract pixels at the boundary between the hand and the background. The parameters of the line are calculated from these pixels (Figure 3 (d)).

Finally, the angle a made by the two lines is calculated as equation (1).

$$a = \arctan\left(\frac{s_1 - s_2}{1 + s_1 s_2}\right), \tag{1}$$

where s_1 is the slope of the midline of the forearm, s_2 is the outer line of the dorsal hand, and a is the estimated flexion (or extension).

III. Experiments

Sixteen hands of eight healthy adult males without complaints in the wrist were subjects. For the maximum flexion and extension angles, the estimated value of the proposed method was compared with the measured value by licensed hand surgeons who used a goniometer.

Table I shows the results, and the absolute error in total is $4.82 \pm 3.93°$ for flexion and $8.74 \pm 4.63°$ for extension. Fig. 1 shows the estimation results for the two lines of subject 7.

IV. Discussion

Inter-examiner reliability is $0.8 - 0.9$ in measuring flexion and extension, and it is said that surgeons' skill has an

TABLE I: Results [deg.] for "measured" refer to the values measured by a hand surgeon, and the results for "estimated" refer to the estimated values using the proposed method. "error" indicates absolute error.

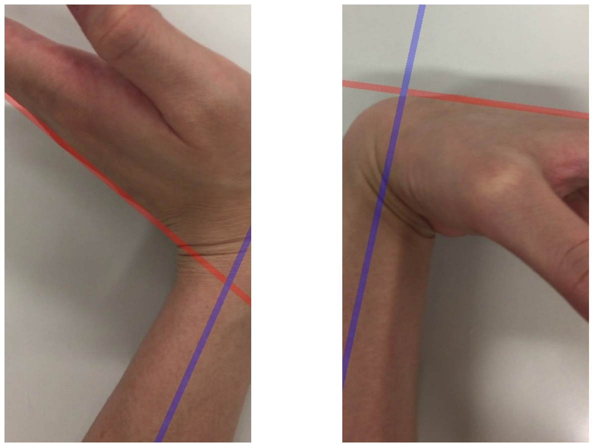
subject ID	hand	flexion measured	estimated	error
1	right	70.0	69.9	0.1
	left	65.0	70.6	5.6
2	right	64.0	55.8	8.2
	left	70.0	74.7	4.7
3	right	73.0	72.9	0.1
	left	80.0	75.1	4.9
4	right	88.0	85.3	2.7
	left	92.0	85.5	6.5
5	right	60.0	71.8	11.8
	left	60.0	47.0	13.0
6	right	65.0	65.3	0.3
	left	70.0	64.9	5.1
7	right	70.0	69.8	0.2
	left	65.0	67.6	2.6
8	right	80.0	71.2	8.8
	left	78.0	80.4	2.4
subject ID	hand	extension measured	estimated	error
1	right	67.0	61.4	5.6
	left	70.0	59.0	11.0
2	right	65.0	64.2	0.8
	left	82.0	66.6	15.4
3	right	78.0	80.7	2.7
	left	78.0	82.7	4.7
4	right	80.0	70.4	9.6
	left	87.0	73.8	13.2
5	right	70.0	55.8	14.2
	left	70.0	64.1	5.9
6	right	65.0	72.1	7.1
	left	70.0	53.5	16.5
7	right	72.0	64.9	7.1
	left	83.0	69.0	14.0
8	right	77.0	71.5	5.5
	left	80.0	73.5	6.5

influence. This method showed that it is possible to measure flexion and extension with errors within almost 10% for a user without experience measuring the ROM of the wrist joint.

In the extension images, the back of the hand was sometimes bulging compared to in the flexion images (Figure 4). As a result, extension was often estimated to be smaller than the actual. The error of extension was larger than that of flexion in most cases.

V. Conclusion

In this paper, we estimated flexion and extension using only images captured by a smart phone. In the proposed method, first, the brightness of the input image is made uniform in order to remove the shadow, and the hand is detected by binarization. Next, the user indicates the positions of the forearm and dorsal hand, and the middle line of the forearm and the outer line of the dorsal hand are detected. The lines are regarded as the long axis of the radius and the long axis of the second metacarpal bone. The angle between the two lines was taken as the flexion or extension. The absolute error in total is $4.82 \pm 3.93°$ for flexion and $8.74 \pm 4.63°$ for extension.



(a) (b)

Fig. 4: The enlarged pictures of subject 4's results. (a) Left extension; (b) Left flexion.

In the future, machine learning will be carried out on the obtained data in order to increase accuracy, and it will be applied to the measurement of radial flexion and ulnar flexion and the ROM of fingers. Ultimately, we aim to be able to instantaneously measure the ROM of finger, wrist, and elbow joints using a video. We would like to include our system in the system that quantifies and visualizes the rehabilitation effect, with the hope that it encourages early medical consultation when the ROM decreases.

Acknowledgment

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