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Markerless detection of fingertips of object-manipulating hand

MARKERLESS DETECTION OF FINGERTIPS OF OBJECT-MANIPULATING HAND

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ABSTRACT

Most reported works on fingertip detection focus on extended fingers where the hand is not occluded by another object. This paper proposes a machine-vision-based technique exploiting the contour of the hand and fingers for detecting the fingertips when the hand is manipulating a ball, which means that the fingers are closed and the hand is partially occluded. The preliminary result of our on-going research is promising where it can be used to generate a more objective performance indicator for monitoring the progress during hand therapy by using a digital webcam. Being markerless and contactless, the proposed technique will require minimal preparation prior to the therapy.

Keywords: fingertip detection, machine vision, hand rehabilitation.

INTRODUCTION

Machine vision technologies have been embraced by more and more sectors and applications thanks to the more affordable costs of their implementation. In this paper, a possible solution to be used in the health sector, or hand rehabilitation to be more specific, is proposed.

Many stroke survivors need the rehabilitation of the functionalities of their hand through therapies which use repetitive motions [1]. In one kind of the therapies, the patient has to squeeze a flexible exercise ball in his/her hands repetitively [2,3]. One of the challenges is to measure objectively the progress that has been made [4].

The use of machine vision in such an application may offer benefits due to non-contact nature of the technology. The technology can be used to detect the fingers and fingertips which will then allow more objective measurement of the performance. To this point, most of fingertip detection techniques have been developed for human machine interface (HMI), where more natural ways of interaction with the machine are made possible.

In most of the reports, the hand is not covered by any object standing between the hand and the camera. However, many of them are subjected to self-occlusion, where parts of the hands are occluded by the other part of the hand, such as fingers being hidden behind the palm. The occlusion problem adds complexity in the fingertip detection problem for a ball-holding hand.

This paper is organized as follows. Section 2 briefly presents some relevant work. Section 3 describes the algorithm for detection of fingertips of ball-holding or squeezing hands. In section 4, the experimental results are shown and discussed. Finally, the summary of the work is presented in the final section.

RELEVANT WORK

Numerous ways have been proposed and reported to detect fingertips. Kerdzibulvech *et al.* proposed a method for fingertips detection based on Gabor filter kernels for extracting features of the images and neural network combined with the Local Linear Mapping Network (LLMN) for the estimation of the fingertips' positions[5]. The technique is used for guitar-playing hands. of a hand playing guitar.

Another approach that uses grayscale morphology and blob analysis together with a stereo camera has also been proposed [6]. The skin region was extracted by using disparity image information. However, the detection's accuracy was affected by the cluttered background.

Barrho *et al.*[7] proposed a method using Generalized Hough Transform (GHT). The GHT method works by matching a fingertip template with a hand image and probabilistic model for localization of fingertip. However, the outcome of this method shows some false detection since there are some regions which have the same shape as fingertips.

Many proposed finger and fingertip detection techniques are based on skin color segmentation and contour, such as the work by Liao *et al* [8]. The challenge normally includes the effects of the lighting condition and the many variants of skin color depending on the race of the person.

Another fingertip detection technique by using trinocular stereo images for detecting one finger has also been proposed [9]. The technique uses both 2D and 3D information.

PROPOSED ALGORITHM

In this work, a webcam with a resolution of 640 x 480 pixels has been used. Figures 1(a), (b) and (c) show typical examples of a background image, an image of a therapy-ball-holding hand and an image of a ball-squeezing hand respectively. The complex background with a light-emitting source in these particular examples contributes to the variation of the intensity in each image.

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(a)

(b)

(c)

Figure-1. Examples of images used in the work; (a) A background image, (b) A ball-holding hand, (c) A ball-squeezing hand.

Figure-2 shows the diagram of the proposed algorithm, which uses the difference between the background image and the input image to determine the region of interest (ROI) and eliminate the background, which helps the reduction of the processing time. However, a simple difference between the current image and the reference does not give a good result as the lighting condition may have changed. This problem was exacerbated as bright fluorescent lights were present in the background. An improved result has been achieved by employing normalized RGB color space which reduces the effects of intensity of light. The detection of skin and ball is also improved by eliminating the intensity from the images as otherwise the shadow of the fingers on the surface of the ball has a damaging effect on the detection.

Normalized RGB values, R', G' and B' are derived by using the following equations:

$$R' = \begin{cases} \frac{1}{\sqrt{3}} if R+G+B=0 \\ \frac{R}{R+G+B} otherwise \end{cases}$$

$$G' = \begin{cases} \frac{1}{\sqrt{3}} if R+G+B=0 \\ \frac{G}{R+G+B} otherwise \end{cases} \quad (1)$$

$$B' = \begin{cases} \frac{1}{\sqrt{3}} if R+G+B=0 \\ \frac{B}{R+G+B} otherwise \end{cases}$$

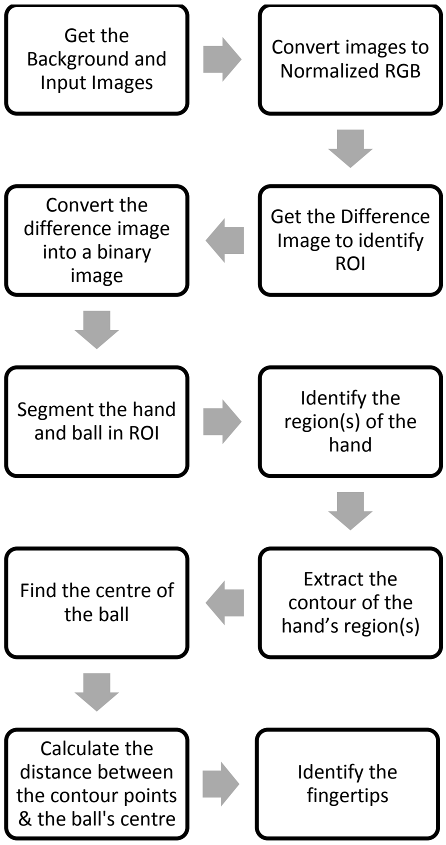

Figure-2. Proposed algorithm for fingertip detection.

A difference image is then obtained from the normalized RGB images. Now, by using the black and white version of the difference image, the largest blob is identified which is assumed to be the region of hand and ball together. This step will eliminate many small unwanted regions. Figure-3 shows a typical result of the masked input image at this stage, which constitutes the ROI.

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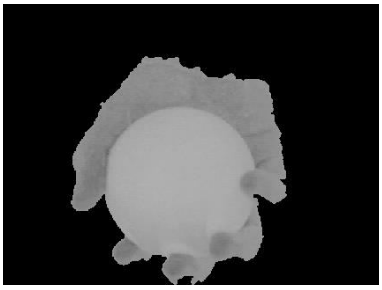
(a)



(b)

Figure-3. Masked input image, (a) RGB, (b) Normalized RGB - G channel.

The next step is to separate the segments of the hand and the ball. Different reported techniques have tried, however, the result was not satisfactory, which is thought this is due to the relative similarity of the color of the ball used with that of the hand. It was found that the G channel of the normalized RGB provided a good discrimination between the two segments. Figure-4 shows the histogram of this channel of the ROI, showing two peaks. The higher peak belongs to the ball, while the lower one belongs to the hand. A moving average filter was applied to the histogram in order to improve the reliability in determining the local minimum between the two peaks.

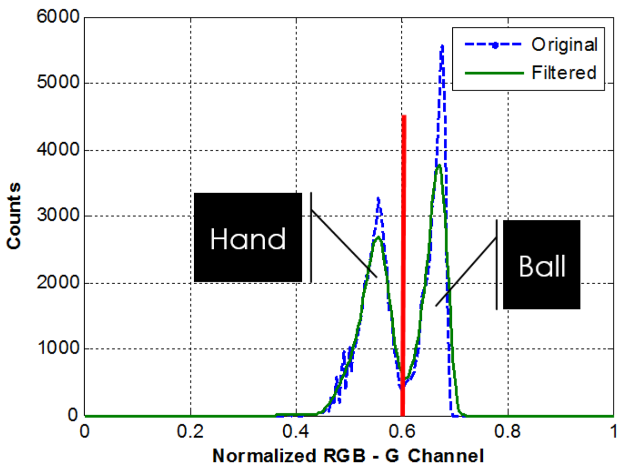


Figure-4. Histogram of the G channel of the normalized RGB of the ROI.

Once the hand segments have been identified, morphological operations are performed to remove undesired blobs and holes. Then, the contour of the hand segment is then obtained. The contour is the boundary edges of the blobs that are part of the hand. The Euclidean distance from the center of the ball to each of the pixel in the boundary is, in turn, calculated in order to help identify the tip of the finger, which will be assumed to have the closest distance to the center of the ball. Although this assumption is not always right, however it is deemed sufficient for the purpose of approximate quantitative measurement of the movement of the squeezing fingers.

The hand contour's distance is calculated by using the following equation:

$$r_{hc}(x, y) = \sqrt{(x - x_{bc})^2 + (y - y_{bc})^2} \quad (2)$$

where (x,y) are the coordinates of the pixel location, rhc = the hand contour's Euclidean distance to the centre of the ball, and (xbc, ybc) are the coordinates of the center of the ball.

Prior to the calculation of the distance, the center of the ball has to be identified. The ball's circle is detected by using Hough transform, which gives the location of the centre and the radius of the ball.

Figure-5 shows an example of a plot of the boundary distances vs angles, assuming the centre of the ball is the pole of the polar coordinate system. For the determination of the fingertips, only the inner boundary is considered. As can be seen from the plot, the contour line is rather not smooth which results in false local minima during the identification of the fingertips. Therefore, a conditional rule is used that when the distance between two local minima is below a set threshold, then the lower one will be used.

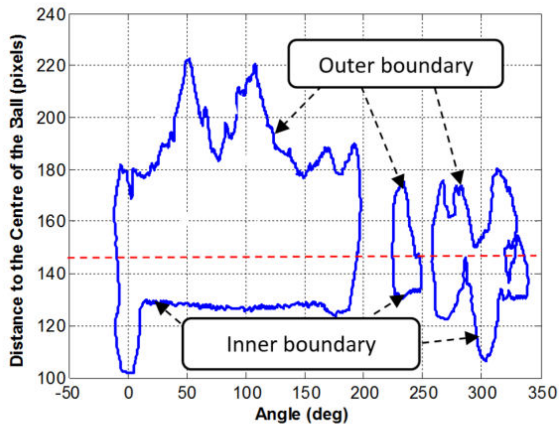


Figure-5. Plot of distances (radii) to the boundary of the hand segments vs the angle.

EXPERIMENTAL RESULTS

Figure-6 shows the results of the detection algorithm for both squeezed and non-squeezed modes. The red dots signify the detected fingertips, while the yellow

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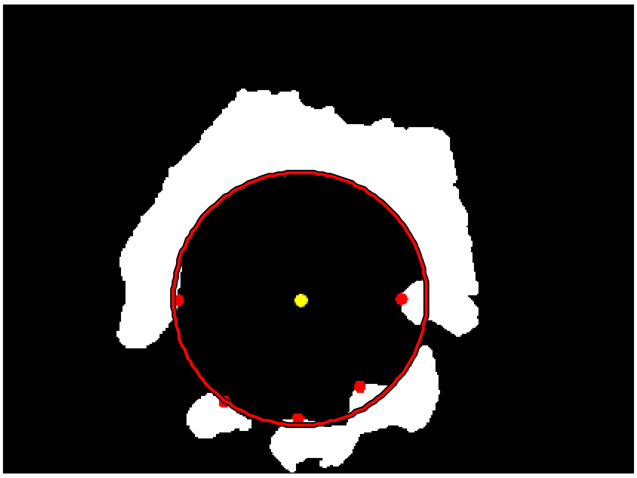
dot signifies the detected center of the ball. The red circle represents the detected ball.



(a)

(b)

Figure-6. Results of the detection algorithm; (a) non-squeezed, (b) squeezed.

Although the algorithm does not always identify the actual tip of the finger, it provides a promising result for applications such as the hand therapy monitoring where it offers a more objective performance indicator of the user. Figure-8 demonstrates the measured relative distances of the fingertips that are normalized by the measured radius of the ball in order to compensate the change in the distance between the ball and the camera. The figures provide indications how far the user manages to squeeze the ball.

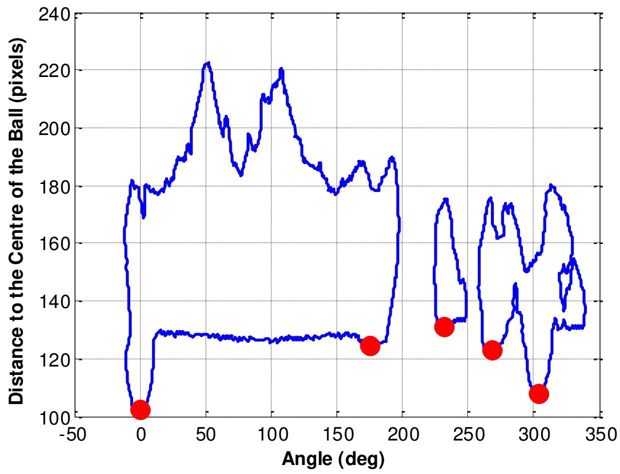


Figure-7. The contour plot with the detected fingertips (red dots).

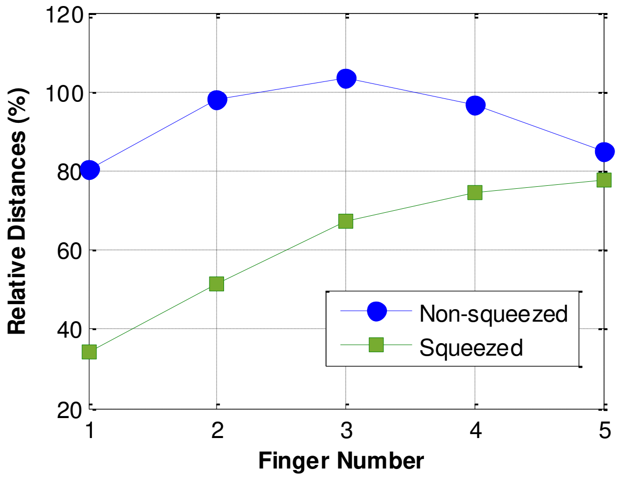


Figure-8. Comparison of the measured relative distances between the squeezed and non-squeezed modes.

CONCLUSIONS

An algorithm for detection of fingertips when the hand is holding and squeezing a ball by using an ordinary webcam has been proposed in our on-going research work. The technique utilizes normalized RGB in order to reduce the effects of changing intensities between images. Due to similarity of the colors of both hand and ball, many skin detection techniques were found not to be effective. The separation of the hand and the ball segments is achieved also by using the normalized RGB color spaces. Finally the contour of the detected hand (skin) is used to identify the fingertips. The preliminary results are promising where they can offer a more objective indicator for some hand therapy. In addition, being markerless and contactless, the proposed technique will require minimal preparation prior to the therapy, which is a very useful feature for both the patient and therapist.

In the future, more features maybe incorporated in order to improve the reliability of the technique. A more thorough study will also be conducted in order to evaluate the performance of the proposed technique.

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