A Two-Stage Binarizing Algorithm for Automatic 2D:4D Finger Ratio Measurement of Hands with Non-Separated Fingers

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***Abstract*—2D:4D finger ratios are commonly measured manually. Previous automatic methods have relied on the fingers being spread apart for successful detection. This study proposes an improved automatic finger-ratio measurement approach that does not require the fingers to be spread apart. The approach comprises a two-stage binarizing algorithm. First, the hand is separated from the background. Second, the various fingers are separated such that a unique outline of the hand can be obtained and thus the 2D:4D finger ratio can be measured. The algorithm achieves accurate results of 66% on a test-suite of flatbed scans of two-hand images. Automatic validation of measurement quality is also discussed.**

***Keywords*—2D:4D finger ratio, image analysis, measurements, image binarization**

I. INTRODUCTION

Digit ratio measurements are used in several avenues of research within medicine and psychology [1, 2, 3]. The digit ratio is defined as the ratio of the index finger length (D2) divided by the ring ringer length (D4) and the ratio is also often referred to as the 2D:4D ratio. The 2D:4D ratio can be used as a crude indication of exposure to prenatal sex hormones. The lengths are typically measured from the tip of the fingers to the crevice of the finger where the finger is attached to the hand. Sometimes, the 2D:4D-ratio is computed as the mean of the 2D:4D-ratios measured for the left and the right hand.

Until recently, such measurements were acquired manually from photocopies of the hand or flatbed scans. However, two approaches have been proposed for the automatic measurement of the 2D:4D-ratio [4, 5]. The first approach [4] was designed for one hand measurement of the hand using a mobile handset camera. The idea was to use the built in camera flash to make it easy to separate the hand from the background since the eliminated hand is much brighter than the background. Based on successful binarization of the hand images an outline was extracted and converted to angular coordinates. The derivatives of the angular representations were used as basis for determining the feature points of interest, that is, the fingertips and finger cervices. This approach was designed for one hand, as the other is used to handle the mobile device. Moreover, it was based on the assumption that the fingers are sufficiently spread out and that the hand constitute a plane perpendicular to the viewing angle of the camera.

A two-hand approach for flatbed scans intended for finger ratio research was proposed [5] with an improved image binarization algorithm, as the general binarization algorithms explored did not give acceptable results. Although several advanced binarization algorithms are described in the literature [6, 7] it seems necessary with domain specific algorithms. The binarized images where scanned from one side to the other to construct the finger outlines for the two hands. One assumption was that two hand scans constrains the orientation and position of the hands. These constraints are exploited to simplify the recognition process. However, it also assumed that the fingers of the two hands are spread out.

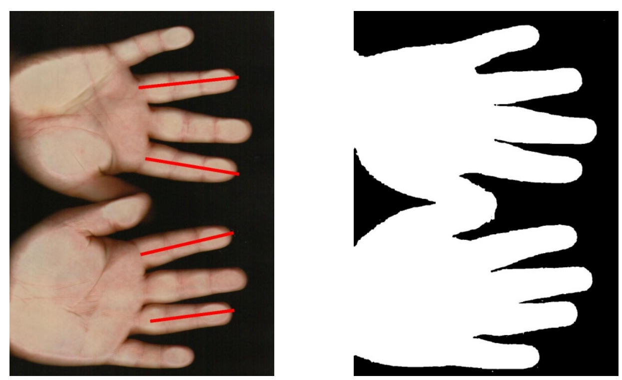

Fig. 1. Original hand image with erroneous finger length measurements (left) and Binarized image using the algorithm proposed in [5] (right).

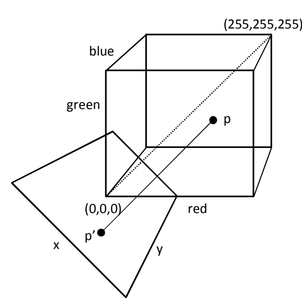

Fig. 2. Projecting a colour in RGB space onto the diagonal plane.

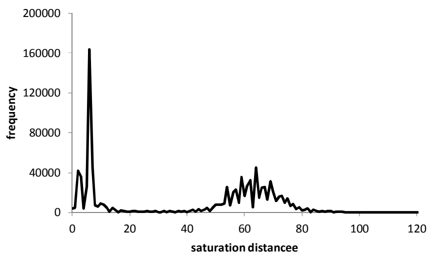

Fig. 3. Saturation histogram of the image in Fig. 1.

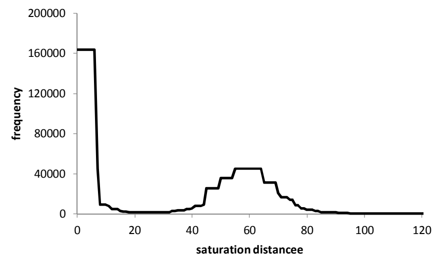

Fig. 4. Max-windowed smoothed histogram of the image in Fig. 1. The first peak occurs at 6 the second at 55 and the valley at 19 givng a threshold of 20.

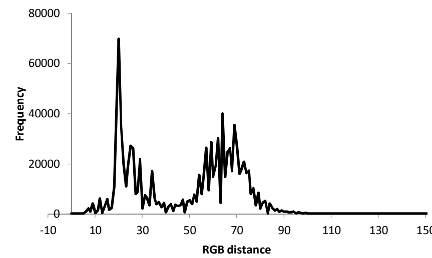

Fig. 5. Saturation histogram form a high resolution image.

Other research that share commonalities with automatic finger ratio extraction is that conducted into gesture recognition [8, 9]. However, the emphasis of gesture recognition is to classify hand postures while the objective of finger ratio algorithms is to make accurate and precise finger length measurements.

However, it is difficult to fully spread out the fingers of two large hands on small A4 scanners. Moreover, when the hand is pressed against the scanner glass the fingers often squeeze out and touch each other. Fig. 1 illustrates this problem as it shows a hand with automatic finger length measurements acquired with the algorithm proposed in [5]. Moreover, Fig. 1 also shows the binarized image used as basis for extracting the erroneous measurements. The objective of this study is therefore to achieve a better separation of the hands and the background through an improved binarization algorithm that is capable of more accurately generate the finger outlines. Another problem with the strategy proposed in [5] is that the binarization algorithm was based on a manually set threshold found through experimentation. This study demonstrates an algorithm for automatically setting this threshold allowing the algorithm to adapt to a wider range of lighting conditions, backgrounds and skin colours.

The overall scope of this research is to provide 2D:4D finger-ratio researchers with a tool for automatic and standardised measurements. Such a tool may help prevent different finger-ratio researchers measuring finger-ratios differently as measurements obtained using different procedures are hard to compare. Furthermore, the tool may help reduce measurement errors. Finally, an automatic procedure may eliminate the need to store hand images as the desired parameters can extracted and stored directly without manual intervention. Storing hand scans are associated with privacy concerns as individuals may be identified from even low quality images using biometric features such as fingerprints [10]. In certain countries, researchers may need to apply for a formal permission to store such information.

II. Method

The 2D:4D finger ratio measurements are achieved by first binarizing the scanned image of the hands. Then the outline of the hands is generated based on the binarized image. Next, the curve of the hand image is analyzed to determine the measurement points that serve as the basis for the 2D:4D measurement. This study focuses on a novel and improved binarizing algorithm as the rest of the algorithm is reported in previous work [5]. The binarization is performed in two steps. First, the hands are separated from the background. Then, the fingers are separated from each other such that a unique hand profile can be detected.

A. Hand background separation

We assume that a major difference between the hand and the background is the level of saturation, where the hand is more saturated than the background. Effectively, the background can be white, any shade of grey or black, or a combination of these. To determine whether a pixel p represented by the RGB values r, g and b in the colour cube we first project it onto the plane represented by the normal [1, 1, 1] of the RGB colour cube, that is, the diagonal from black (0, 0, 0) via all shades of grey to white (255, 255, 255). This projection is achieved by:

$$x = r - b \tag{1}$$

$$y = g - b \tag{2}$$

Here x and y are the coordinates of the RGB value projected onto the plane. The level of saturation can thus be computed as

$$s = \sqrt{x^2 + y^2} \tag{3}$$

If s is larger than a threshold I the pixel is classified as a hand pixel, otherwise it is classified as a background pixel. Fig. 2 shows the projection from the RGB colour space onto the diagonal plane.

The threshold T is determined by computing a histogram of the saturation values for all the pixels of the image. This leads to a bimodal distribution where the first peak represents the background and the second peak represents the hand pixels. The threshold value is the valley between the two peaks, that is, the lowest point between the two peaks.

The valley is found as follows. First, the histogram is smoothed using a max-window function. That is, the histogram values are replaced by the maximum value of the values under a sliding window. Experimental evaluations revealed 10 to be a suitable window size. Then the first maximum peak is determined by scanning the smoothed histogram from the left until the slope of the histogram is negative, that is:

$$h(i) > h(i+1) \tag{4}$$

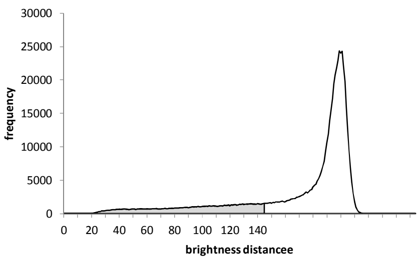

Fig. 6. Brightness histogram of hands in Fig. 1.

Where $h(x)$ is the frequency of x. Here, i is the maximum peak. Values of h below the mean histogram value $\bar{h}$ are not considered as they are unlikely to constitute peaks.

The same procedure is repeated by scanning the histogram from the right until the slope is positive, that is:

$$h(j-1) < h(j) \tag{5}$$

Then j is the second maximum peak. The valley k is imply found by scanning for the minimum histogram value between $h(i)$ and $h(j)$, where obviously $i<k<j$.

Fig. 3 shows the saturation distribution of the pixels of the hands from the scan in Fig. 1. Fig. 4 shows the max-window smoothed distribution using a window size of 10. Here, the two peaks occur at 6 and 55 and the valley, or threshold, occurs at 20.

The dynamic computation of the threshold T means that the algorithm adapts dynamically to different lighting conditions including different backgrounds and different skin types.

B. Finger separation

The second stage of the process involves refining the binarized image by more clearly separating fingers that are close together. This is achieved by relying on the shadows, or darker shades, in the crevices and cracks between the fingers. This is achieved by performing a moderate thinning-like operation. First, a brightness profile of the hand is computed in the form of a brightness histogram. For each foreground pixel in the image represented by r, g and b the brightness simply is computed by:

$$B = \frac{r+g+b}{3} \tag{6}$$

The resulting brightness B is used to build up the brightness histogram. Then, the brightness segmentation threshold L is set by:

$$L = \frac{total}{k} \tag{7}$$

where $total$ is the total number of foreground pixels and k is the proportion of pixels to mark as background. That is, the $1/k$ darkest foreground pixels are to be reclassified as background pixels. Experimental evaluation revealed that k=5 gives good results, meaning that 20% of the pixels are reclassified.

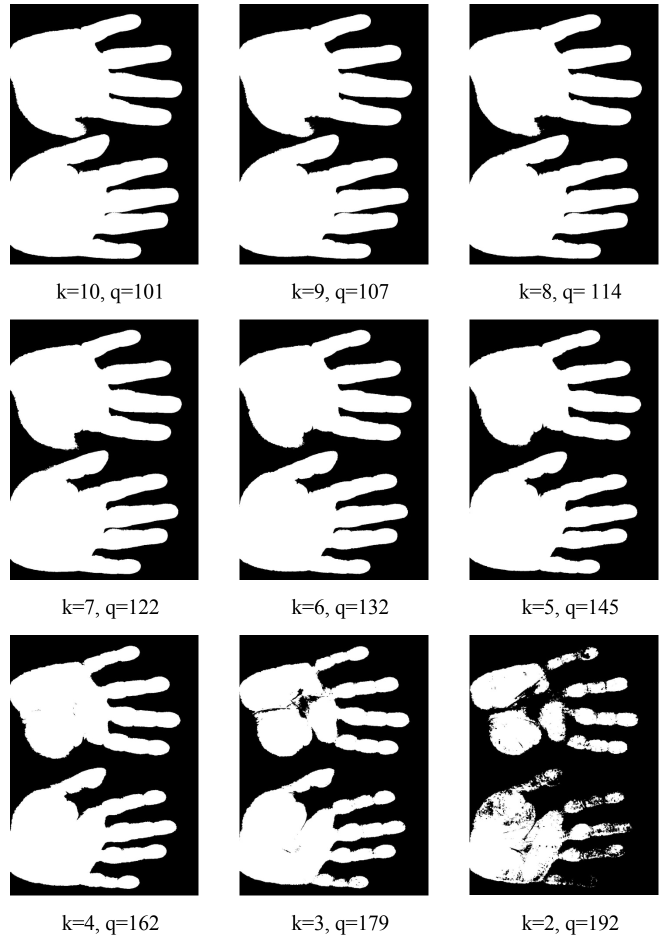

Fig. 7. Improved binarized hand.

Fig. 8. Finding the centroid of the hands, centroid of the two hands respectively and the hand tilting angle.

The threshold q is found by summing consecutive elements of the histogram until the sum matches L. That is:

$$q = \arg_q \left[\min \left| \sum_{i=1}^{q} h(i) - L \right| \right] \tag{8}$$

Foreground pixels are swapped to background pixels if their brightness is below this threshold. Otherwise, they remain foreground pixels.

Fig. 6 shows the brightness histogram of a hand scan with k set to 5. The shaded left part of the histogram represents pixels that will be reclassified from foreground to background pixels. The pixels that are represented by the right part of the histogram remain foreground pixels.

TABLE I. EXPERIMENTAL RESULTS

Test	overall ratio	left ratio	right ratio	difference left right	left D2	left D4	right D2	right D4	threshold
ring1	0,93	0,91	0,95	-0,04	806,5	883,8	874,1	918,5	204
straight2	0,87	0,87	0,86	0,01	783,0	896,6	789,2	918,9	192
rotated1	0,88	0,89	0,87	0,02	822,0	922,7	806,4	929,8	172
ring2	0,88	0,89	0,86	0,02	791,0	890,6	801,6	927,5	193
rotated2	0,87	0,89	0,85	0,04	821,5	918,9	791,3	927,6	152
straight4	0,88	0,90	0,86	0,05	825,1	913,3	794,1	925,8	163
straight5	0,86	0,90	0,82	0,08	811,9	906,3	756,8	924,8	174
straight3	0,63	0,88	0,39	0,49	782,1	888,8	307,9	799,1	198
straight1	0,56	0,85	0,26	0,59	784,0	917,9	244,9	925,5	205

Fig. 7 shows the resulting binarized images with k ranging from 10 to 3. With large values of k the effect of the finger separation binarization step is small and with smaller values of k the effect is larger. With very small values of k a large proportion of the image is converted to background and one may risk that the shades caused by the finger joints result in the hand becoming disjoint.

C. Rotation

The finger-ratio detection algorithm assumes that the two-hand finger-scans are oriented such that all the fingers point rightwards. To ensure that images satisfy these assumptions a hand orientation step and possible rotation step are employed.

1) Landscape portrait adjustments

First, a check is performed to determine if the image is in portrait orientation. If the image is in landscape orientation it is rotated 90 degrees to ensure that it is in portrait orientation. For an image to be in portrait orientation the height must be larger than the width.

2) Micro image rotation

Next, the tilt of the two hands is determined. The tilt detection is performed in several steps (see Fig. 8). First, the centroid of the hands is computed by finding the midpoint of all the hand pixels. That is:

$$[x_c, y_c] = \left[\frac{1}{N}\sum_{i=1}^{N} x_i, \frac{1}{N}\sum_{i=1}^{N} y_i\right] \tag{9}$$

Here x_i,y_i are all the pixels labelled to be part of the hands and N is the number of hand pixels. This centroid is assumed to lie between the two hands. Therefore, the hand image is divided into two halves separated by the vertical line y_c. The centroid computation is thus repeated for the upper half and the lower half, respectively, giving the two new centres $[x_{top}, y_{top}]$ and $[x_{bottom}, y_{bottom}]$. The angle of tilt A is then

$$A = 180 - a\tan 2(x_{bottom} - x_{top}, y_{top} - y_{bottom}) \tag{10}$$

To reduce the computational load it is only necessary to consider a subset of the image pixels in order to get a sufficiently accurate result. A total of 100×100 regularly spaced pixels were sampled in the above computation. Moreover, the comparatively expensive image rotation step is only performed if the tilt is larger than ± 5 degrees as small angles have little effect on subsequent processing.

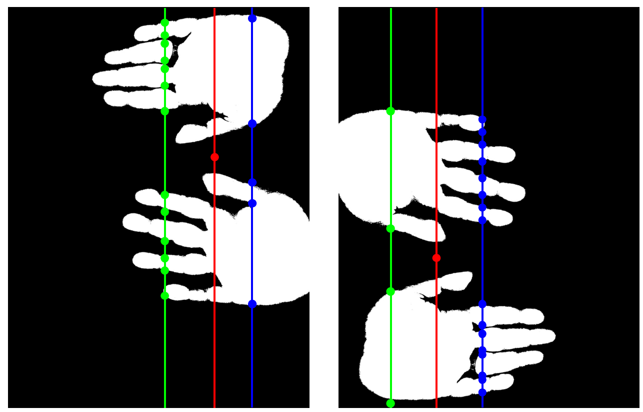

Fig. 9. Determining if the fingers are pointing left or right.

3) Macro Image rotation

The final rotation detection step is to determine whether the fingers are pointing left or right. If the fingers are pointing left the image must be rotated by 180 degrees in order for the finger to point right.

Fingers are detected by scanning the image vertically. The finger side will lead to more transitions between background and hand pixels compared to the palm side (see Fig. 9).

The finger direction detection involves dividing the image into two halves along the vertical line x_c, that is, the vertical midpoint of the hand. For each side the binarized image is scanned vertically from top to bottom from one side to the other. If two consecutive pixels are different the difference is counted. After this step, there will be a sum of difference for each respective image half, namely left and right.

If the sum of differences on the right side is larger than the sum of differences on the left side, it is an indication that the finger are pointing rightwards. However, if the sum of differences for the left side is larger than that of the right side, the image needs to be rotated 180 degrees, that is

$$left > right \tag{11}$$

To speed up computation only a subset of 100×100 pixels was considered.

Fig. 10. Selection of an image before (top) and after (bottom) the median filtering operation.

D. *Noise removal*

To further eliminate noise in the binarized image and enhance the hand contour a median filter is used. Experimentation reveals that a median filter with a size similar to 1% of the image gives good results. For example a 31×31 median filter was used for images with a resolution of 2548×3508 pixels. To achieve computational efficiency an adaptation of a generalised median filter was implemented. It comprises a sliding window that is moved across all the images of the image. For each pixel assessed the majority of pixels determine the final pixel value. For example, if the 961 pixels of a 31×31 window contains 481 or more white pixels the current pixel is set to white, otherwise it is set to black. Fig. 10 shows a small region of a binarized image before and after applying the median filter.

III. Experimental Evaluation

To test the accuracy of the proposed approach a set of the authors own hand scans were acquired using a Ricoh A3 office scanner. The fingers were held together and for each scan the hands were removed and repositioned on the scanner glass. Two of the scans show the author wearing a silver ring, two of the scans show the hands purposely twisted such that the fingers point towards each other. The hands were positioned parallel in relation to each other in the remaining scans.

The results are summarized in Table 1. This table lists the scan name, the overall finger ratio, the left and right finger ratios respectively, the difference between the left and the right scans and the finger lengths of the four fingers measured in pixels. The table is sorted according to increasing left-right finger difference.

The results reveal that 6 of the 9 results are relatively consistent (66%) giving a finger ratio of 0.86-0.88. A characteristic of these observations are that the difference between the finger ratios of the two hands are relatively small, that is, in the range of 0.01 to 0.08. Moreover, the left finger ratio is consistently larger than the right finger ratio. The scan named *ring1* has the smallest difference of -0.04. Although, the absolute difference is similar in magnitude to the successful measurements, it is the only negative difference. This indicates the presence of an influential measurement error. This is confirmed by the high finger ratio of 0.93 which is approximately 0.05 higher than those of the successful measurements.

Next, the last two scans in the table, *straight3* and straight1 both have too low overall finger ratios of 0.63 and 0.56 respectively. These are easily identifiable through their large differences between the left and right finger ratios of 0.49 and 0.59, respectively. By inspecting the finger length column, it is obvious that in both cases it is an incorrect measurement of the right D2 (index finger) that causes the mistake as these are comparatively much shorter than the three other fingers.

Another characteristic of the three scans that resulted in the least accurate measurement is that they have the highest brightness thresholds of 198, 204 and 205, respectively. However, the successful measurements yield brightness thresholds in the range of 152-193. This suggests that the brightness threshold also may be used as an indicator of measurement quality.

The results do not indicate any effect of the ring or the tilting of the hands. The method thus appears to be robust to various hand angles and basic jewellery.

Figs. 11 and 12 show the scans and results for the best and the worst measurement.

IV. Limitations of This Study

The approach presented herein assumes an unsaturated background for successful hand segmentation. The method is unlikely to be effective if the background is saturated or the hand is unsaturated. For example, the strategy may not work with black and white scans. Moreover, the method is relatively reliant on low levels of image noise. Next, one of the key assumptions of the method is that both hands are present and that these hands are placed in a certain way. The current method will not be able to handle single hand scans and hands with arbitrary orientations. Finally, the tests are performed with a very limited set of hand scans. To properly validate the effectiveness of 2D:4D ration extraction methods and more extensive test-suite should be employed, representing different hand shapes, skin colours and obtained with different scanners that use different lighting technologies.

V. Conclusions

An improved simple domain specific binarization algorithm for separating hands from the background and enhancing the finger outlines were proposed. The improved binarized images greatly improved the extraction of the 2D:4D finger ratio measurement from images where the fingers are close together. The binarization strategy first determines a saturation threshold using the valley point in the bimodal saturation distribution. Next the foreground pixels are subject to a second stage where the darkest portion of the pixels is reclassified as background pixels. Experimental evaluations revealed that setting this portion to 20% gave acceptable results. The results suggest that the difference between the left and right digit ratios as well as the brightness threshold can be used as indicators of measurement quality. The implications of this study are that finger ratio researchers can be given more accurate and neutrally obtained measurements. Future work includes making the method more robust to image noise and less dependent on saturation levels, making the method able to handle each hand independently with arbitrary orientations, and finally developing a general and easy to use open source tool for finger ratio measurement for use by the 2D:4D finger ratio research community.

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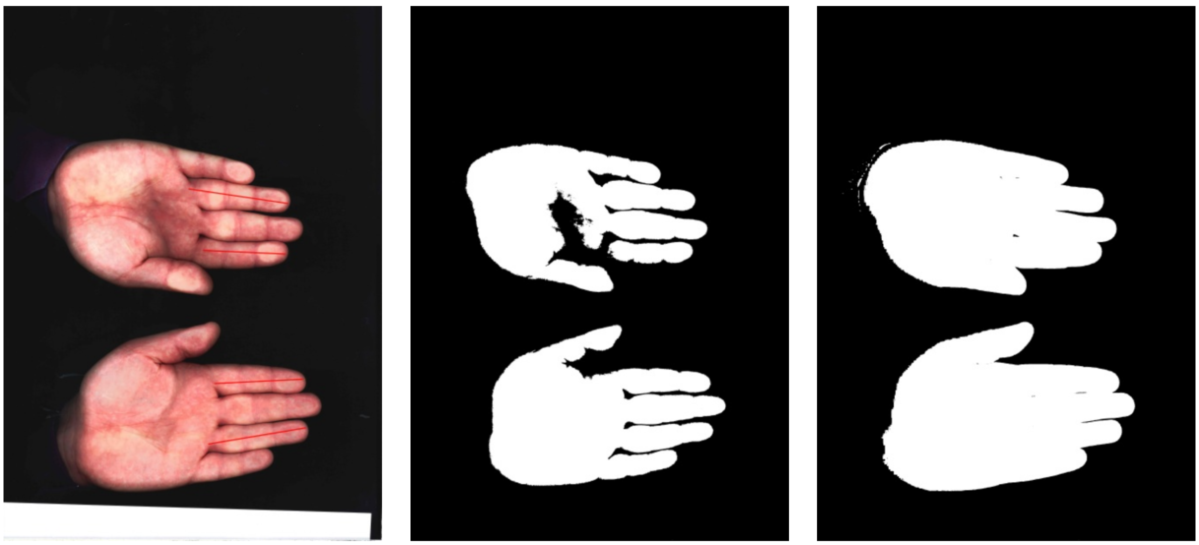

Fig. 11. The best scan (straight2).

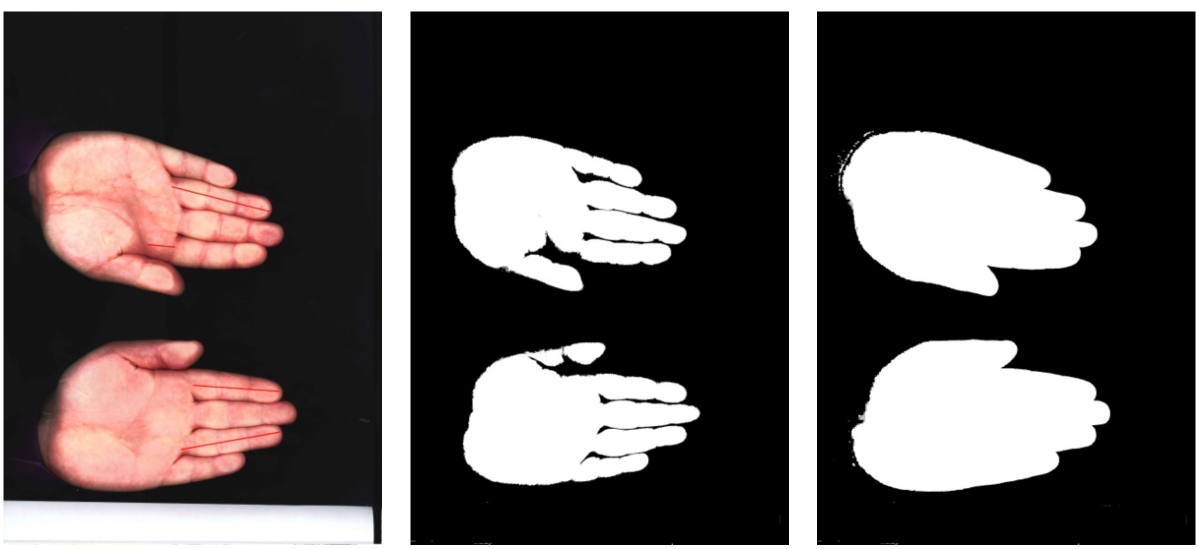

Fig. 12. The worst scan (straight1)