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Measuring 2D:4D finger length ratios with Smartphone Cameras

Frode Eika Sandnes
Institute of information Technology, Faculty of Technology, Art and Design,
Oslo and Akershus University College of Applied Sciences, Oslo, Norway
Frode-Eika.Sandnes@hioa.no

***Abstract*— Finger length ratios have received much attention among researchers as the 2D:4D ratio has been linked to several physical and mental characteristics. This study explores the feasibility of using a Smartphone as an instrument for measuring finger length ratios. The approach taken in this study is to use the Smartphone camera to take freehand photos of the hand which is subsequently subjected to image analysis. Measurement procedures include hand near and far from the body, palms up or down, or hands in mid air versus hands resting on a flat surface. Experimental evaluations show that the most accurate measurements are achieved by resting the hand on a surface with the palm facing up. These results are comparable to those achieved with conventional procedures with an error of 1%.**

Keywords—2D:4D digit ratio; Smartphone; image processing

I. INTRODUCTION (*Heading 1*)

The Smartphone is increasingly used as a simple medical and health measurement instrument [1]. Smartphone displays can be used to perform visual acuity checks, that is, checking users' vision and check for colorblindness [2]. Smartphone accelerometers can be used to monitor physical activity [3] and Smartphone microphones can be used to measure a person's lung function [4]. Smartphone cameras and powerful LED-flash can be used to measure the users pulse by detecting the subtle oscillating changes in finger skin color [5, 6] and face [7]. Similar techniques have also been attempted to measure blood pressure [8, 9].

Most of the medical parameters mentioned represent physical status and varies according to various conditions and contexts. Other parameters are more constant such as the digit ratio. The digit ratio is usually referred to as the finger length ratio of two fingers – usually the index and ring finger. Fingers, or digits, are numbered from one starting with the thumb to the little finger labeled number five. The index finger is thus D2 and the ring finger is D4. Low digit ratios are often pointing to a high exposure to testosterone in the uterus. A study of 137 individuals found that the mean digit ratio for males is 0.947 (SD = 0.029) and 0.965 (SD = 0.026) for females [10].

Of the many studies of digit ratios, high digit rates have been connected hormones [11, 12], gender [13] and aggression [14, 15, 16]. Digit ratios have also been connected with the big five gender-related personality traits [17], that is, openness to experience, conscientiousness, extraversion, agreeableness and neuroticism. They have also been linked to development [18] and cognition [19] to mention a few. Thus, digit ratio measurement may be of interest to both individuals and health personnel.

TABLE I. 2D:4D FINGER LENGTH RATIO INTERPRETATION

Description	Range	Interpretation
Very low	< 0.96	Autistic (extreme Type S)
Low	0.96-0.99	Aspie (extreme Type S) Neurotypical male (Type S) Female with a "male brain" (Type S)
High	0.99-1.01	Neurotypical female (Type E) Male with a "female brain" (Type E)
Very high	> 1.01	Extreme Type E Notie (Type "N")

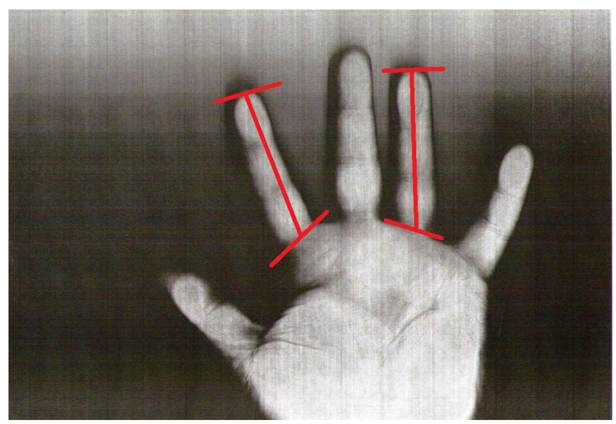

Fig. 1. Measurement procedure based on a photocopy of a hand (Reference digit ratio measurement of 0.96).

One procedure for determining the 2D:4D ratio is to take a photocopy of both the left hand and the right hand and for each hand measure the length of the index finger and divide it by the length of the ring finger using a ruler (see Fig. 1). Next, the mean of the two ratios is computed. The finger begins at the fingertip and end at the root crevice. A common interpretation of the 2D:4D finger length ratio is given in Table I.

The objective of this study is to explore the feasibility of using a Smartphone camera to determine the index ratio based on freehand camera shots. Although previous work has addressed the recognition of body gestures [21, 22, 23] this study focuses specifically on digits ratios assuming the hand is in a stretched state.

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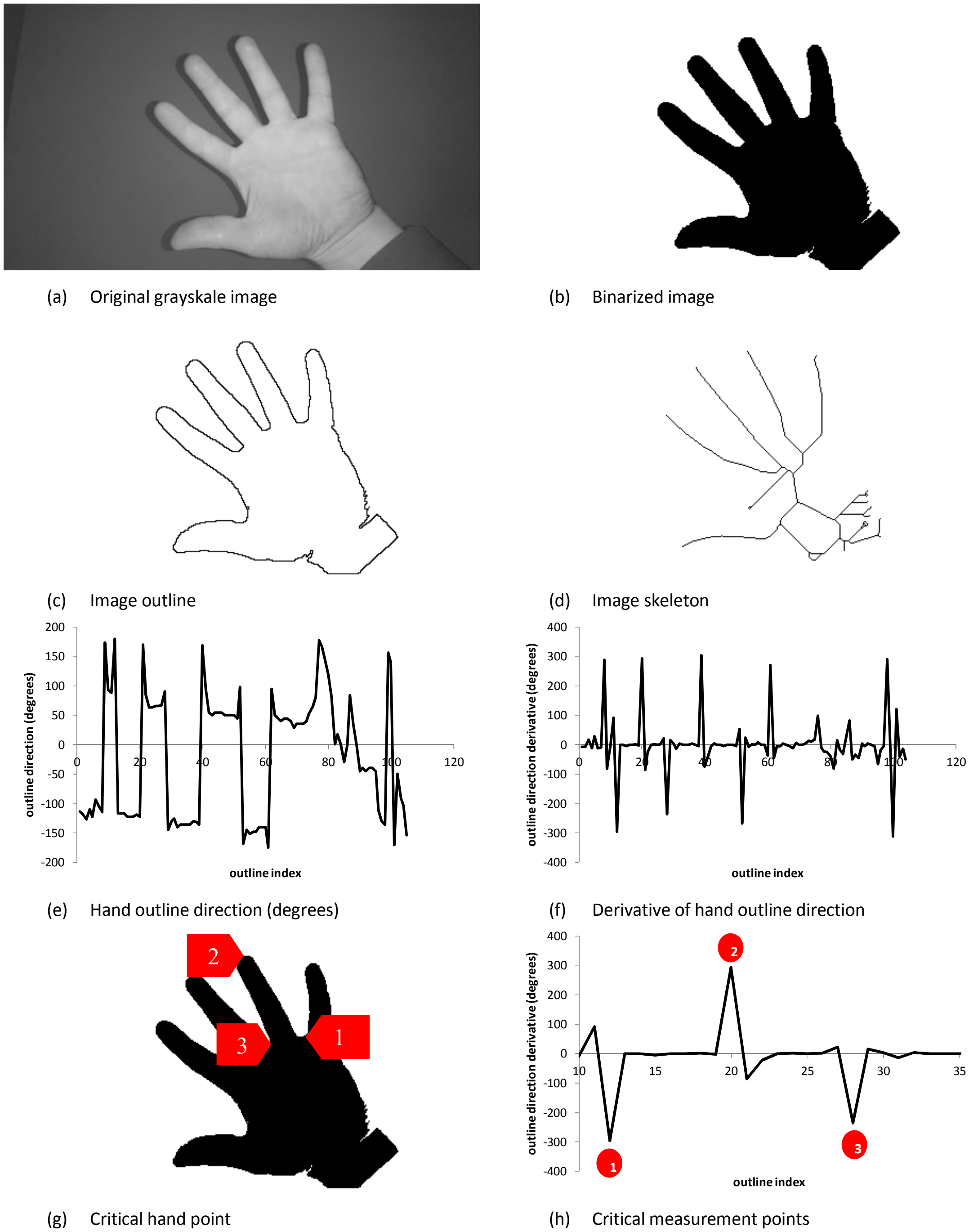


(a) Original grayscale image (b) Binarized image (c) Image outline (d) Image skeleton (e) Hand outline direction (degrees) (f) Derivative of hand outline direction (g) Critical hand point (h) Critical measurement points

Fig. 2. Hand image preprocessing steps. (a) Original grayskale image, (b) binarized image, (c) image outline, (d) image skeleton, (e) hand outline direction (degrees), (f) derivative of hand outline direction, (g) critical hand point and (h) critical measurement points.

II. Camera Approach

This section explains the Smartphone camera approach proposed for measuring digit ratios. The principle of the approach is for the user to hold the hand in the air and point the Smartphone at the hand (see Fig. 3) such that the hand fills the viewfinder leaving some spaces on the edges with the camera LED-flash enabled. Assuming that the user has fair skin and is not standing in front of a highly reflective background the LED flash will ensure that the hand becomes brighter than the background (see Fig. 2 (a)).

A. Analysis

The image of the hand is first converted to grayscale (see Fig. 2 (a)) and then binarized (see Fig. 2 (b). Next the outline of the binarized image is computed (see Fig. 2 (c). It was found that the outline gives a better basis for subsequent analysis than image skeletons (see Fig. 2 (d)) because the skeleton algorithm produces results that are difficult to interpret for wide hand type objects as it is hard to identify the root of the fingers from the skeletons. Note that this study employs the ImageJ implementation of gray conversion, binarization, outline, tracing and skeleton algorithms.

Instead, the outline is traced (in this instance in anticlockwise direction) and the trace is divided into 100 equally spaced sections. Note that this number was arbitrarily selected and another number may be used. For each section the angular direction of the trace is computed (see Fig. 2 (e) using

$$a = \arctan(x_i - x_{i-1}, y_i - y_{i-1}) \tag{1}$$

Here x_i and x_{i-1} represents every *n*'th trace points and *a* the angular direction of the outline at point *i*. This plot clearly shows the traces of the fingers. The length of the five fingers are revealed through the five relatively flat plateaus and the finger tips and finger crevices are indicated by the sharp drops or steep rises. Therefore, the derivative of the directional trace is computed (see Fig. 2 (f)) using

$$\delta a = a_i - a_{i-1} \tag{2}$$

Where δa is the derivative of the direction, and a_i and a_{i-1} are two consecutive directions along the trace at positions *i* and *i-1*, respectively. This curve illustrates the rate of directional change as a function of trace index. The five positive peaks represents the tips of the five fingers from the little finger to the thumb going from left to right. The four negative peaks represent the crevices between the five fingers. The location of the *D2* and *D4* fingertips are thus the points associated with the index of the fourth and the second peaks, respectively.

The root of D4 is computed as the midpoint between the points associated with the first and second negative peaks, that is, the crevice between the little and the ring finger, and the crevice between ring finger and long finger. Or more specifically

$$\left[\frac{x_{crevice1} + x_{crevice2}}{2}, \frac{y_{crevice1} + y_{crevice2}}{2}\right] \tag{3}$$

Here ($x_{crevice1}$, $y_{crevice1}$) and ($x_{crevice2}$, $y_{crevice2}$) are the coordinates of the crevice between D1 and D2 and the crevice between D2 and D3, respectively. This is illustrated in Figs. 2 (g) and (h) where the two crevices are indicated by points 1 and 3, respectively, and the tip of the ring finger is indicated by point 2.

Next, the length of the finger is thus computed as the Euclidean distance between the tip and the root of the finger, namely

$$L = \sqrt{\left(x_{tip} - x_{root}\right)^2 + \left(y_{tip} - y_{root}\right)^2} \tag{4}$$

where (x_{tip}, y_{tip}) and (x_{root}, y_{root}) are the coordinates of the tip and root of the finger, respectively. A similar procedure is performed for identifying the length of the index finger. However, the there is not an immediate crevice between the index finger and the thumb. But, the hand has a sudden change in angle, or breakpoint, where the finger is attached to the hand. This is visible through a smaller peak. Although this peak is smaller it can be indentified because the peaks of interest are relatively evenly spaced.

Since we are interested in a ratio, the actual unit of measurement is less important as it cancels out. The length calculations can thus be performed using arbitrary pixel units. The digit ratio given the two lengths L_{D2} and L_{D4} is thus

$$ratio = \frac{L_{D2}}{L_{D4}} \tag{5}$$

B. Error

The procedure involving taking a photo of the hand is ubiquitous as it can be performed anywhere. However, there are several sources of error. For instance, the fingers may not lie in the same plane, but point in slightly different directions. Moreover, the camera may not be completely perpendicular to the plane of the hand causing projection distortions.

III. Experimental Evaluation

A. Procedure

The experiments were conducted using a Sony Xperia Z1 Smartphone. Six configurations were evaluated to see which one is most suitable for acquiring an accurate index ratio measurement (see Table II).

For each configuration the author used the Smartphone to take a snapshot of the hand with the flash enabled. The flash ensures that the skin of the hands becomes brighter than the background, which is further away from the camera lens. A total of six configurations where tested, namely three with the hand facing away from the camera (palm down) and three with the hand facing towards the camera (palm up). The palm down configurations are easier to execute, but is harder to read as the root of the fingers are not clearly indicated. The palm up configuration is more strenuous to execute, but is easier to analyze due to the crevice in the hand indicating the beginning of each finger.

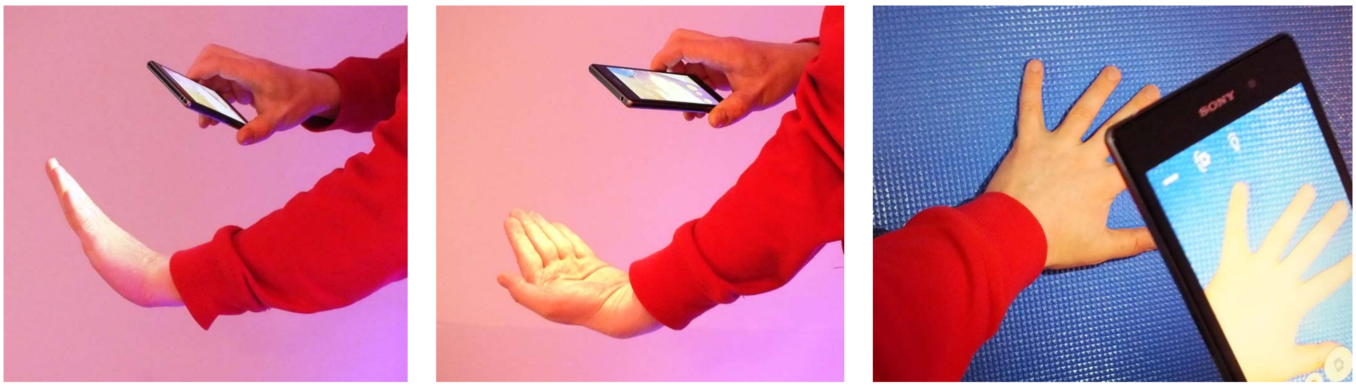
The three conditions included the arm stretched out with the hand far from the lens, the hand closer to the lens covering the viewfinder and hand resting on a surface. The rationale for differentiating between near and far measurements was to see if the images with the hand further away has less effects of perspective distortion. For both condition best attempts were made to make the fingers straight and span a geometric plane. The flat condition was included to see if the results are improved by a assisting the hand with a geometric plane as support.

The author was the only participant, but the experiment was repeated five times for each configuration to achieve reasonable measurements of the mean index ratio and measurement spread. For each repetition the hand was closed and released before put back into position and reopened. Thus, a total of 30 index ratios were acquired.

The algorithm outlined above was implemented using the ImageJ framework implemented in Java and Microsoft Excel with manual intervention for the sake of simplicity.

TABLE II. MEASUREMENT CONDITIONS

Condition	Palm down	Palm up
Far	Arm stretched, palm pointing away. The hand freely makes up a plane perpendicular to the camera.	Arm stretched palm facing camera. The hand freely makes up a plane perpendicular to the camera.
Close	Back side of the hand fills the viewfinder. The hand freely makes up a plane perpendicular to the camera.	Palm of the hand fills the viewfinder. The hand freely makes up a plane perpendicular to the camera.
Flat	Palm rests on a surface.	Back side of the hand rests on a surface.



(a) Palm down (b) Palm up (c) Palm flat

Fig. 3. Measurement configurations.

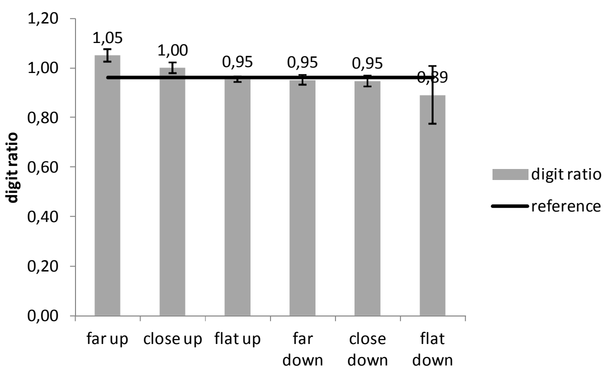


Fig. 4. Mean index ratios. Error bars show standard deviation.

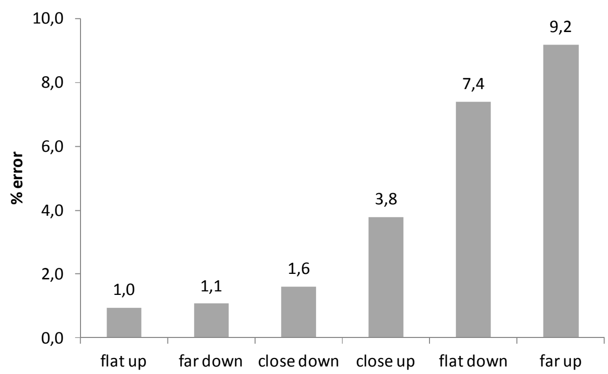


Fig. 5. Percentage index ratio error

IV. RESULTS

Fig. 4 shows mean digit ratios for the six conditions with the error rates showing the spread in the data. The horizontal line shows the reference (true) digit ratio acquired using the photocopy method (digit ratio of 0.96). A one-way anova confirms that the results using the different methods are statistically different ($F(5,24) = 5.7; p < .002$).

Fig. X shows the percentage error of each condition relative to the reference measurement. Clearly, the condition where the hand is held flat with the palm facing up achieved the most accurate measurements with 1% error.

This was closely followed by the condition where the arm is held out straight and the palm faces away from the camera with an error of 1.1 %. Surprisingly, the condition where the hand is placed flat down on a surface had the second worst accuracy and the largest spread in data. This is probably due to the uncertainty in determining the root of the fingers. With the exception of this measurement, all the conditions have relatively small spread suggesting that the measurements in each condition are consistent.

The condition where the hand is stretched out far with the palm facing the camera achieved the least accurate results. This is probably due to the fact it is hard to hold a posture where the fingers constitute a geometric plane.

Fig. 4 shows a clear trend where measurements taken with the palm facing the camera all overshoots the reference digit index, that is, a too high value. Likewise, all the conditions with the palm facing away from the camera undershoots the reference, that is, the value is too small. We can thus conclude that when the hand is facing the camera we risk getting a too high digit ratio, and with the palm away from the camera the digit ratio may be too small.

In conclusion, it is recommended that procedures based on free hand camera captures use the hand on a flat surface with the palm facing up. Moreover, it is unlikely that it will be easily possible to capture accurate digit ratios from hands in arbitrary photographs, without the need for complex three dimensional hand models.

V. CONCLUSIONS

This study assessed the feasibility of measuring digit ratios using the Smartphone built in camera and LED flash. The flash overexposes the hand making it easy to separate the hand from the background with simple algorithms. The image of the hand is first converted into grayscale, then binarized and finally the outline is extracted and traced. The outline trace is converted from Cartesian to an angular representation. The first derivative of the angular trace is used to identify the fingertips and finger crevices.

Six measurement conditions were experimentally evaluated. The results show that the most accurate measurements are achieved when the hand is placed with the fingers spread on a flat surface, such as a table, with the palm of the hand facing up.

The procedures discussed herein assume active initiative from the users. One question is if it is possible to measure digit ratios automatically from arbitrary images without the consent of the users. One could imagine third parties would want to collect digit ratio information about users for various purposes from innocent applications such as tailored advertising to more sinister applications. Such possibilities raise ethical questions that should be considered carefully, especially as digit ratios correlate statistically with certain characteristics and in itself do not provide hard evidence on individual level.

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