Digital Anthropometry: Model, Implementation, and Application

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Abstract – *In this paper, we provide a mathematical framework for identifying and measuring human body parts. We used this framework to implement a computer-based measurement for the purpose of automating the usual manual process of anthropometry. To test the computer-based system, we measured the hands of 91 individuals using both the manual and the computer-based system. Based on two-tailed t-test, the computer-based system has the same measurement as the manual system at 5% level of significance.*

Keywords – digital image processing, hand anthropometry, automation

I. INTRODUCTION

Anthropometry is the scientific way of measuring the length of different parts of a human body. Recently conducted anthropometric surveys aim to come up with a database of anthropometric measures of individuals based on their location, gender, and occupation such as the works of Mandahawi et al. [1], Dizmen [2], and Amongo et al. [3]. The data collected in these surveys were used in determining the dimensions of equipment, furniture, and even hand-held devices [4] which can provide users with comfort, safety, and ease of use. Other surveys were conducted to determine the appropriateness of the dimensions of furniture and equipment used by students in schools such as the ones conducted by Panagiotopoulou et al. [5] and Dianat et al. [6]. Surveys to describe the anthropometric characteristics of a certain population were also conducted like in the works of Mandahawi et al. [1] and Laila et al. [7]. In most of these studies, anthropometric measurements were obtained manually. Tools like calipers and tape measures were the instruments used the respective body length of an individual. The manual process of conducting these kinds of surveys usually takes too long as seen in the study conducted by Amongo et al. [1] which took them 19 months (from May 2008 to December 2009) just to survey 284 respondents from CALABARZON sub-region. Moreover, conducting manual anthropometric procedures is prone to error and most of the time results to inaccurate and inconsistent data. Magno and Pabico [8] presented a data set consisting of independently replicated and repeated measurements of the length of the fingers of a subject person *A* collected independently and separately by four different surveyors S_1, S_2, ..., S_4. Their replicated measurement data show that manually measuring the same subject by different people into mean measurements with differences that are statistically non-zero at 5% significance [8]. Since it is not possible to determine which surveyor provided the correct measurement, one can assume that the data set contains inaccurate results. The same data set similarly proves that the manual process results into inconsistent data. In this experiment, the length of the fingers of person *A* were measured by a single surveyor S_1 repeatedly at an interval of 30 minutes. Statistical analysis of the data from repeated measurements show that even the same surveyor manually measuring the same subject at different times results into inconsistent data set. (i.e., differences in the mean measurement are non-zero at 5% significance) [8]. Thus, there is a need for an automated system that will accurately and consistently compute for the dimensions of human body parts. The automated system is run in a machine, the input of which is a set of digital images of the body parts belonging to the individuals who are the subjects of the survey, while the output is a standard report of the anthropometry of the population of individuals. The automated measurement of the body length of a human individual is called anthropometry.

In this research, we developed a method for automatic anthropometry given a digital image of a human body part. This automated measurement of the body dimensions can be done by extensively using the computational ideas both in geometry and computer graphics. In automating the process, the aim is to address the problematic issues of accuracy and consistency that "hound" most manual anthropometric surveys. This provides the researchers an unbiased method in conducting replicated and repeated anthropometric surveys since the bulk of work (i.e., collecting, measuring, analyzing, and archiving data of the body measurements) can already be done by the machine.

In this paper, we present a mathematical algorithm for automatically identifying the respective body parts from human images and automatically measuring them using a hybrid approach utilizing some processes from computer graphics and basic geometry. Also, we discuss the practical method that is employed to implement the model using hand anthropometry as a test case. In this test case, we use the techniques in hand geometry identification, popularly used in biometric and hand geometry applications. Hand geometry is a computational way of measuring the shape of a person's hand, which computes for different hand features like finger length and palm width. The hand geometry technique has been successfully used by Covavisaruch, et al. [9], who extracted 21 features from the digital hand image to verify the identity of a person. The hand geometry techniques will also be used since, when hybridized with computer graphics processes, will be useful in digital anthropometry. With this hybrid approach, fingertips and valleypoints can be located and these points can aid in the respective actual digital measurements of the finger length. We then applied this hybrid implementation to digitally measure the dimensions of 91subjects and compare these digitally computed dimensions with the length of the same set of subjects that were computed manually. The hypothesis is that the mean difference between the manual measurements is not significantly different from zero at 5% statistical significance (i.e., the null hypothesis is accepted if the two measurement techniques have statistically identical results).

II. Mathematical Modeling

We discuss this section the mathematical model that we used for identifying and measuring the body parts of humans given only an array of points that represent the body part's profile. As a working example, we will use in this section the profile of a human right hand and we will be visually aided by its image as depicted in Fig 1. Given an array C of n two-dimensional points $c_1, c_2, \ldots, c_n$, where each point c_i has coordinates $(x, y) \in \mathrm{I}^2$, C actually composes the profile of the body part, such that the points are sequentially arranged as if the profile is being traced.

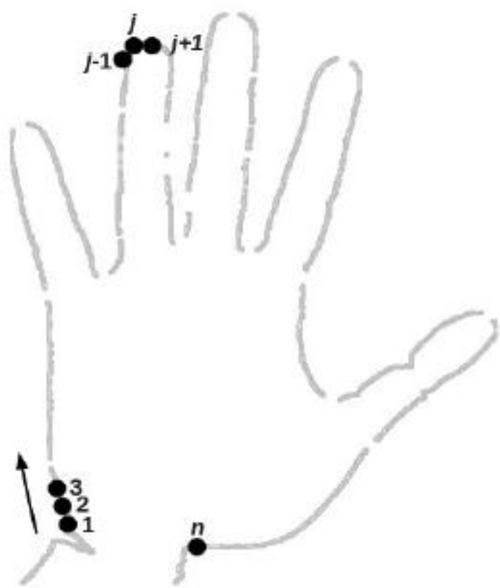

Fig. 1. The array $C$of two-dimensional points (dots in black) that traces a sample hand image in sequential order. Shown here are the indexes 1, 2, and 3 located along the inside part of the wrist. The points j-1,j, and $j+1$are located near the tip of the ring finger. The last point with index $n$is located at the outside part of the wrist. The arrow indicates the direction of the index order.

A. Finding Extrema Points

Using any point $c_r = (x_r, y_r)$ as reference within the profile, but preferably not along the profile, we compute for the length l_{rc} of the line segment between c_r and $c \in C$. For example (refer again to Fig 1 as a reference for this discussion), in measuring the length of the fingers in a right hand that faces the reader, the set of points C composes the profile of the hand traced from the inside part of the wrist that go to the fingers and back to the outside part of the wrist. Here, c_r could be any point along the line segment l_{rc} that represents the wrist. The line plot that will be created if we are to plot the array index i against the computed length of the line segments l_{rc} is similar to that shown in Fig 2. We can see here that the plot resembles that of the finger with nine extrema points: five maxima $M_1 ... M_5$ and four minima $m_1 ... m_4$. These maxima indicate the indexes of the coordinates of the finger tips in C , while the minima locate the C indexes of the coordinates of the fingers' valley points. Mathematically, if we set $l_i = f(i)$, where i is the index of C and $f(i)$ is a function that describes the graph in Fig 2, then these extrema can be located in C by computing for the derivative of $f(i)$ with respect to l_i as in Equation 1. If we set the derivative to zero as in Equation 2 and compute for i, we then can find the indexes in C of the five maxima and four minima, respectively.

$$d(l_i) = d(f(i)) \quad (1)$$

$$0 = d(f(i)) / d(l_i) \quad (2)$$

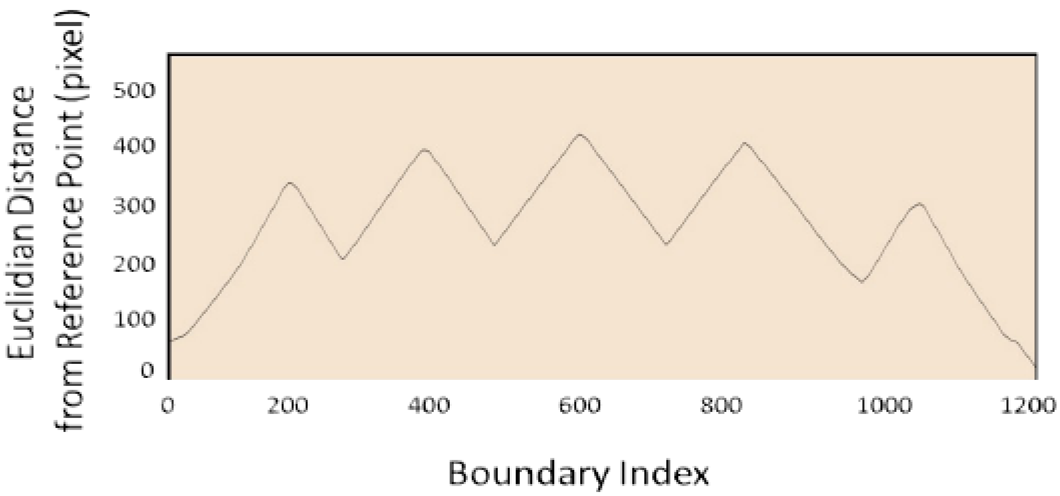

Fig 2. The plot of array index $i$vs. length of line segment l_{ri}showing nine extrema points: five maxima points and four minima points.

B. Length Computation

From the minima points, the line segments that connect the contiguous minima can be considered as the respective bases of the fingers. For example, m_1m_2 is the base of the ring finger. Thus, using the points identified in Fig 3 as references, and utilizing the ideas in geometry such as that of isosceles triangle (e.g., $\Delta m_1M_2m_2$ for the ring finger), we can find the respective length of the fingers as follows:

•*Pinky* - For this finger, a third point m^*_1 in C that composes the triangle is missing. However, we are given already the other equal side of the triangle (i.e., M_1m_1). We are sure that the index in C of m^*_1 has a lower index value than that of M_1. To be able to obtain this point, we utilize the procedure used in geometry in constructing an isosceles triangle. By rotating M_1m_1 about M_1, the intersection of the swinging endpoint m_1 with the line whose points have array index less than that of M_1, we can find m^*_1. With this, the base segment $m^*_1m_1$ becomes the base of the pinky finger. We compute for the bisection point b_1 of $m^*_1m_1$ and connect b_1 with M_1. The line segment M_1b_1 approximates the length of the pinky.

•*Ring* - As already discussed above, we connect m_1 and m_2 to obtain the ring finger's base segment m_1m_2. The line segment created by M_2 and the bisection point b_2 of m_1m_2 will approximate the ring finger's line segment M_2b_2.

•*Middle* - The line segment m_2m_3 represents the middle finger base segment. The bisection point b_3 of m_2m_3 and the maxima point M_3 define the middle finger line segment M_3b_3. This line segment approximates the middle finger's length.

•*Index* - Similar to the pinky, the third point m^*_4 in C that composes the index finger triangle is missing. However, the line segment M_4m_3 composes the isosceles triangle. The third point can be computed by rotating M_4m_3 about M_4 and taking note of the intersection with the points in C. We select m^*_4 whose index value is between M_4's and m_4's. The line segment whose end lines are M_4 and the bisection point b4 of $m_4m^*_4$ approximates the index finger's length.

•*Thumb* - Computing for the length of the thumb has a similar procedure with that of the index finger. The line segment M_4m_4 composes the isosceles triangle, whose third point is missing. However, we are sure that the index value of that third point is between that of M_5 and

n. Following the procedure in the index finger, we rotate M_5m_4 about M_5 and obtain the intersection point m^*_5 in C whose index value in C is between that of M_5 and the value n. The line segment defined by the bisection point b5 and the maxima M_5 approximates the length of the thumb.

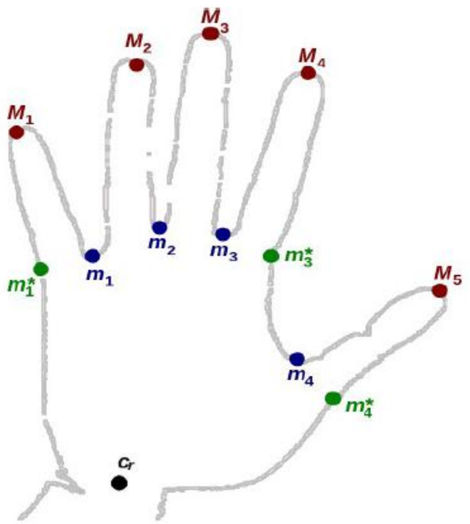

Fig 3. A profile of a right hand (palm facing the reader) showing the maxima and minima points, as well as the arbitrary $c_r$and the unknown points. Maxima are colored red, minima are colored blue, $c_r$is colored black, and the unknown points are colored green.

IV. IMPLEMENTATION

We implement the above mathematical algorithm hybridized with computer graphics algorithms to come up with a computer-based, automatic system for anthropometry we termed as digital anthropometry. The process for the digital anthropometry is summarized as follows:

- We gather digital colored images of the human body part (i.e. hand), making sure that the background has a contrasting color with the skin color of the subject. Each image is represented as a two-dimensional array I_{RGB} of red, green, and blue components, where each component represents the reflected light from the respective surfaces of objects (in this regard, only the skin and the background).

- We then convert the images into corresponding binary images to separate the body part from the background. Each binarized image $I_{0\text{-}1}(i,j)$ has its components $I_{0\text{-}1}(i,j) = 1$ if $I_{RGB} > Th$, for an image component indexed at the ith column and jth row, where Th is some threshold value; else $I_{RGB}(i,j)= 0$.

- From $I_{0\text{-}1}$, we obtain the respective image coordinates of the boundary of the foreground (i.e., the hand) using some edge detection techniques such as a series of erosion and dilation processes. This boundary will form our C discussed above.

- With C, we converted the mathematical algorithm discussed in subsections II.A and II.B to a simple iterative numerical process because the function $f(i)$ described in Equation 1 is not continuous.

- Finally, we convert the respective length computed in step 4 above into the real-world unit of measurement following a simple ratio and proportion procedure. The ratio and proportion process will also determine if the collected images needed some transformation first (i.e., scaling, rotating and translating) before the actual conversion takes place.

A. Digital Image Acquisition

The images were taken using a digital camera and the body part (in this case the hand) was placed rested against a dark, plain background. The hand can be of any position but for the sake of convenience, the subjects were asked to place their hands in a downward position (the wrist is in the upper edge of the image) with the palm laying flat on the surface of the background. The body part was carefully laid out so that the fingers do not stick to one another. To capture the exact real-world measurement and to account for variation in the camera angle with respect to the surface of the background, a *5cmx5cm* reference box was also taken along with the hand. If in the image, the reference box does not appear to be a square, some image transformation processes will be performed, such as scaling, rotating, and translating to bring the reference box into its square shape. A total of four hand images were taken from each subject: (1) Left hand in relaxed position; (2) Left hand in extended position; (3) Right hand in relaxed position; and (4) Right hand in extended position. Figure 4 shows the hand images captured from one subject.

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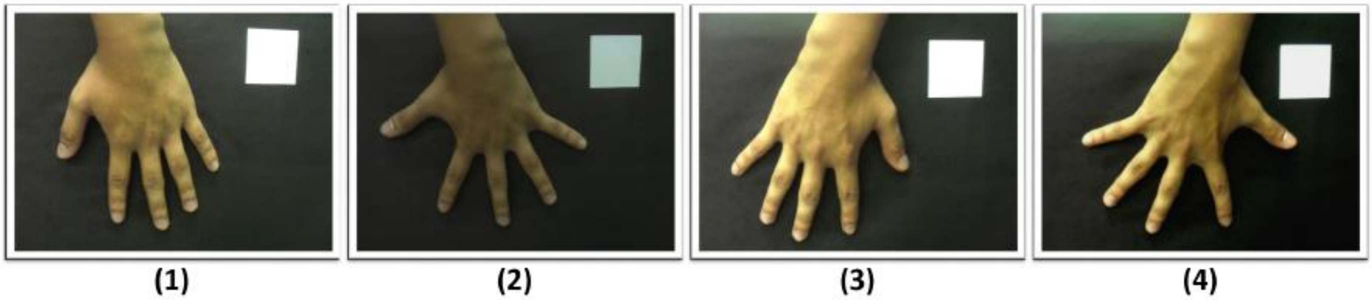

Fig 4. Samples of hand images digitally taken from one subject.

B. Image Pre-Processing

The color images were converted to grayscale and median filter was applied to remove the noise in each image. The grayscale image was then converted into a binary image through thresholding. The binary image was then eroded to remove the remaining noise and then dillated twice in order to obtain the shape of the body part. What remains is a set of points that traces the boundary or profile of the body part. The boundary of the foreground image consists of the $(x, y) \epsilon \mathrm{I}^2$ coordinates of the points that describe the profile of the body part. This boundary is the *C* described in Section II.

C. Locating Fingertips and Valleypoints

After *C* has been identified, we computed the reference point c_r as the midpoint of the line segment c_1c_n. To be able to locate the fingertips and valleypoints, the distance from the reference point to each of the point along the boundary of the hand was computed using L_2-metric (i.e., Euclidian distance) shown in Equation 3. Figure 2 shows a graph of the Euclidian distances between the reference point and the points along the boundary of the hand image.

$$d(c_r, c_i) = ((c_{rx} - c_{ix}) + (c_{ry} - c_{iy}))^{1/2}, \forall i = 1, ..., n \quad (3)$$

D. Measuring the Hand Dimensions

After locating the baselines and the fingertips, the respective actual measurements were obtained following the algorithm discussed in Section II.B. A total of fourteen dimensions were measured: The five finger length and the distance from the fingertip of the pinky and the thumb when the hand is in relaxed and in extended positions for both the left and for the right hands. The descriptions of the hand dimensions are summarized in Table 1 and are visualized in Figure 5 following the works of Magno and Pabico [10].

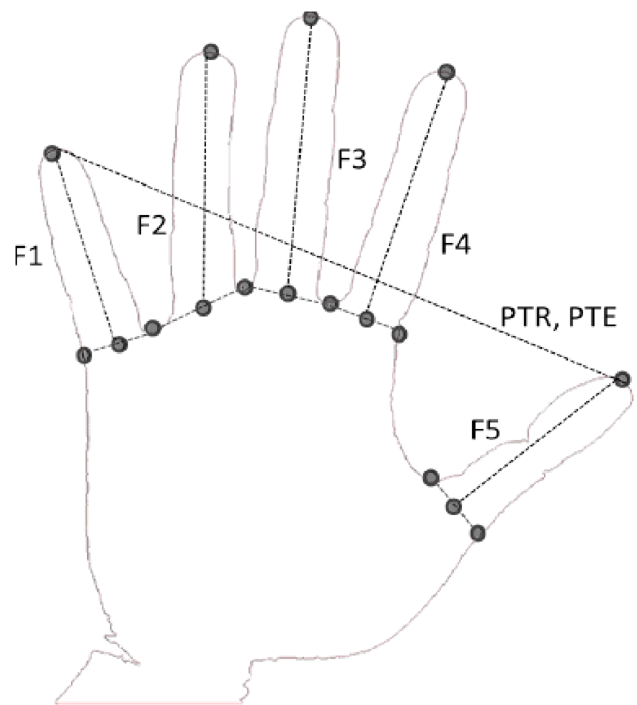

Fig 5. Hand Dimensions measured in the study. This figure is in color in the electronic copy of this paper printed with permission from Magno and Pabico [10] and the Philippine Society of Information Technology Educators Foundation, Inc. (PSITE).

Table 1. Hand Dimension Definitions. This table is printed with permission from Magno and Pabico [10] and the Philippine Society of Information Technology Educators Foundation, Inc. (PSITE).

Code	Hand Dimension	Definition
F1	Fingertip to root (thumb)	From the tip of the thumb to the line found at the root of the finger when palm is facing up, measured for both left and right hands
F2	Fingertip to root (index finger)	From the tip of the index finger to the line found at the root of the finger when palm is facing up, measured for both left and right hands
F3	Fingertip to root (middle finger)	From the tip of the middle finger to the line found at the root of the finger when palm is facing up, measured for both left and right hands
F4	Fingertip to root (ring finger)	From the tip of the ring finger to the line found at the root of the finger when palm is facing up, measured for both left and right hands
F5	Fingertip to root (pinky finger)	From the tip of the pinky finger to the line found at the root of the finger when palm is facing up, measured for both left and right hands
PTR	Pinky to thumb (relaxed)	From the tip of the pinky finger to the tip of the thumb when the hand is relaxed, measured for both left and right hands
PTE	Pinky to thumb (extended)	From the tip of the pinky finger to the tip of the thumb when the hand is extended, measured for both left and right hands

IV. Application: Hand Anthropometry

We manually measured the length of the fingers of 91 subjects. At the same time, we also took the digital photograph of the subjects' hands. We measured two hand positions: (1) fingers relaxed; and (2) fingers extended. For each digital image, we used the methodology outlined in Sections II and III. The mean results of the two measurements, manual and digital anthropometry, for each hand dimension are shown in Table 2.

To determine whether there is a significant difference between the manual anthropometric procedure and automatic anthropometry, we performed a two-tailed paired t-test on the data testing the hypothesis at $\alpha = 0.05$. The result of the test (Table 2) shows that there is no significant difference between the length computed via manual anthropometric procedure and the automatic anthropometry using digital image processing techniques.

Table 2. Comparison of means of the finger length as measured by manual and by digital anthropometry and their corresponding t-values. (Note: ns means that the difference between the manually and digitally measured length is not different from zero at 5% significance level.)

Hand Dimension	Mean Length (manual)	Mean Length (digital)	t-value	Remarks
F1 Right	5.95	5.48	1.30×10^{-04}	ns
F2 Right	6.92	7.22	4.02×10^{-04}	ns
F3 Right	7.73	8.05	3.09×10^{-03}	ns
F4 Right	7.12	7.48	2.25×10^{-04}	ns
F5 Right	5.68	5.56	5.41×10^{-03}	ns
PTR Right	14.11	13.37	1.67×10^{-07}	ns
PTE Right	18.17	17.72	6.48×10^{-08}	ns
F1 Left	5.95	5.28	3.82×10^{-03}	ns
F2 Left	7.02	7.43	2.15×10^{-05}	ns
F3 Left	7.74	7.4	1.91×10^{-06}	ns
F4 Left	7.05	8.06	3.79×10^{-02}	ns
F5 Left	5.71	5.36	2.19×10^{-03}	ns
PTR Left	14.07	13.32	5.57×10^{-05}	ns
PTE Left	18.84	17.17	3.40×10^{-09}	ns

V. CONCLUSION

We developed a mathematical algorithm for locating parts of a body and measuring their respective length given only the coordinates of the profile. We used this mathematical algorithm to implement a computer-based anthropometry with hand anthropometry as an example. We applied the digital hand anthropometry techniques using the 91 subjects and measured the length of the five fingers as well as the length of the expanded and relaxed fingers. We compared the digital and manual measurements using the two-tailed t-test at 5% significance. Based on the statistics, the digital measurement is not significantly different from the manual measurement. Therefore, we can use this system to conduct measurement studies not only of the hand but the of the other parts of the human body as well.

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