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Research Article
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Validation of Two-Dimensional Digital Photogrammetry Measurement for Hand Anthropometric Dimensions

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Abstract

The surface anatomy of a human hand and dimensional features like size, shape, etc., influence the functional aspects of hand uses. The anthropometric measurement of various hand dimensions can provide the fundamental data to support several ergonomically design of equipment/tool to improve work efficiency, comfort, and safety. Traditionally, anthropometric measurements for different dimensions in a standardized posture are time-consuming and costly. Hence, the objective of this paper was to compare the accuracy of various hand dimensions measured by using manual and ImageJ processing software methods. In the research 20 participants were selected randomly for measurement of 22 different hand dimensions by manual and 2D image processing methods. During the experiment stationary bench was used for taking a photograph of hand to maintain the predetermined distance for each participant. Set digital caliper to zero before taking any measurement. The mean and SD of the measured data was found to be a similar and statistical analysis of t-test revealed that there was no significant difference between the manual and photo anthropometric results as the p>0.05. The correlation coefficients of measured dimensions were also similar in both methods ranging from 0.902 to 0.993 respectively. Further, the time required by both the means does not have a significantly different. However, 2D image process have better advantages as there was no involvement of participants during the measurement procedure.

Keywords: Image J; Hand anthropometry; Direct anthropometry; Photography; Digital caliper

Introduction

The dimensions or sizes of the human hand are imperative for two primary reasons: protection and function. The evaluation of the physical measurements of the human hand provides a metric description for establishing the compatibility of human-machine interaction in the design of manual systems e.g., the design of hand tools, knobs and controls, personal equipment, consumer appliances in the home and industry. The physical dimensional and anatomical features of the human hand influence the functional aspects of hand uses [1]. Anthropometry of hand is useful for determining various aspects of modern machinery [2]. Therefore, the information on the range of sizes variation and dimensions of the human hand constitute a paramount part of the knowledge of the human body represented by anthropometric data [3]. Anthropometric data provide the information on static dimensions of the human body in various standard postures. To design any products for human use, human factors engineering/ergonomics have to entirely rely on anthropometric data to obtain the output an ergonomically compatible [4]. Poor design in ergonomic hand tool is a crucial factor contributing to biomechanical stresses and increasing the risk of cumulative trauma and carpal tunnel syndrome disorders of workers [5].

The scientific research conducted by various researchers on different photo anthropometry methods, but each one included some deficiencies [6]. The anthropometry studies are divided into three categories: (a) Manual anthropometry, (b) two-dimensional (2D) photography and (c) three-dimensional (3D) photography. The manual method of obtaining measurements involves an expert measuring the dimensions of the participant at critical locations in a standardized posture for a specified duration of time. It becomes necessary to get critical measurements of a person through electronic means with non-invasive methods [7]. The expert who is measuring by direct manual anthropometry with the help of Vernier caliper and measuring tape should possess the adequate skill. However, during measurement, some errors may occur due to the pressure of measuring tools on soft-tissues of human body skin. Nowadays, most of the anthropometry studies are carried out by imaging and computer software analysis, and we know modern advanced methods such as 3D scanning are costly. The science of image processing has resulted in distinct attractions to anthropometry and has expanded its applications in various fields. Some researcher also suggested image-based anthropometric measurements which are quite comparable both regarding accuracy and the repeatability to traditional measurement methods performed by experienced anthropometrists [8,9]. From biomechanics points of view there is a direct relationship between musculoskeletal injuries and occupational risk factors and working with unsuitable hand tools and equipment can exacerbate various health hazards [10]. There is always difficulty in controlling all potential sources of error is such that it has been said that accurate values are seldom measured in anthropometry [11]. On the importance of ergonomics in the design and development of tools and equipment, the existence of an anthropometry database is essential, and the database should be up-to-date.

Therefore, developing a simplified and quick anthropometric data measurement would encourage researchers to gather the necessary information effortlessly. The objective of this study is to compare the accuracy and consistency of measured human hand dimensions measured by using 2D image processing software with the direct

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method.

Methods

Participants

The participants for this research purpose consisted of 20 students from North Eastern Regional Institute of Science and Technology (NERIST), Arunachal Pradesh, India. All the participants were selected randomly, and they belonged to the same ethnic group, and all were right-handed. Though, the ethnic group does not have any influence on the outcome of the research as this study has mainly intended to compare two measurement methods of hand dimensions. None of the students was suffering from any kind abnormal disabilities and musculoskeletal disorder at the time of the experiment. Each of the students has initiated the purpose of the study and obtained written consent for their participation.

Measurement procedures

Anthropometric measurement of 22 human body dimensions was selected and followed the measurement protocol based on ISO 7250-1 standard [12]. The individual wellbeing is very much dependent on their proportional and geometric relationship. Therefore, implementing body dimension database of a targeted population supports essential health and safety requirements in the field of machinery safety and personal protective equipment [13].

To compare the anthropometric measurement of hand dimensions by manual and 2D image methods of the selected students were called in the in the laboratory of Department of Agricultural Engineering, NERIST. In the study twenty-two measurements of right-hand including hand length, handbreadth, palm length, small finger length, ring finger length, etc., were considered for analysis by the manual method and 2D image method. Each of the students was allowed to relax and remains calm their hand while taking the measures in manual mode and taking a photograph. All the participants were allowed to take three readings each for a particular dimension in both manual and 2D image methods. The measurement procedure for hand sizes was in accordance with NASA recommendation [14].

Measuring instruments

The instruments used for measurements were the digital Vernier caliper and measuring scale. The caliper was set to zero before taking any measurement, and the resolution of the caliper was 0.01 mm having the precision of 0.01 mm. In 2D image methods, clear picture of the palm was taken by a camera having and was analyzed with software shown in (Figure 1). During the research, while using the stationary bench for taking photographs of palm the camera was placed at a fixed position to reduce errors in 2D image method. The image taken was analyzed in image processing software called ImageJ.

The analysis of the software ImageJ was based on counting the pixels per unit of length and values entered into the right table. As soon as the image was open in the software, using the ruler next to hand, the number of pixels/unit of length was defined, and a line was drawn between the desired points, finally obtained the distance between then was noted for analysis.

Statistical analysis

Statistical analysis was performed for the interpretation of the results obtained from both the measurements. A student's t-test sample was analyzed on 22 different parameters that had been measured with manual and 2D image-based methods. A t-test is most commonly applied when the test statistic would follow a normal distribution. The level of significance was set at $p<0.05$, providing a level of confidence of 95%. Analyses of correlation were also performed to evaluate the extent to which two variables have a linear relationship to each other. The statistical analysis was computed using commercially available statistical software, i.e. Statistical Package for the Social Sciences (SPSS) version 20.0.1 (IBM Corporation, USA).

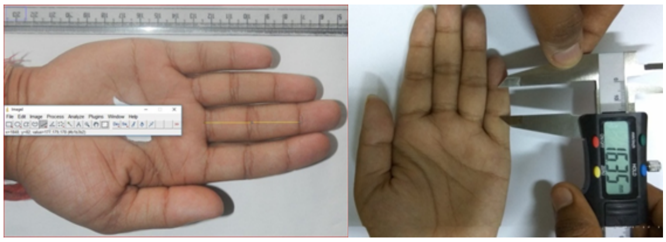

Figure 1: Image analysis through software and manual measurement.

Results and Discussion

Participant physical characteristics

The selected students for the research purpose have their ages ranged from 19 to 21 years old, body weight from 48 to 61 kg, and heights from 152 to 169 cm respectively. The physical characteristics of participants like age, weight, height, BSA, and BMI has given in Table 1. According to published BMI classifications [15], individuals are considered underweight when their BMI is <18.5; within the normal range when their BMI ranges between 18.5–24.9; overweight when BMI ranges between 25–29.9, moderately obese when BMI ranges between 30–34.9, severely obese when BMI ranges between 35–39.9 and very severely obese when BMI is 40 and above. For this study participant who had a BMI within the normal range were selected for the research purpose.

Statistics of hand anthropometric data measured by manual and image 2D methods

The descriptive statistics of hand anthropometric data measured by manual and 2D image methods was shown in Table 2. The maximum value was found to be hand length with the value of 205 and 204 mm in manual and 2D image methods. However, the mean value, standard deviation value and range found to be similar in both the means with 178 mm, ± 14 mm and 45 mm respectively. The minimum value was determined to be a middle phalanx of a small finger with 23 and 24 mm having a range of 12 and 13 mm. However, the SD remains same with ± 3. The mean and SD value does not differ from each other except by the amount of ± 1.

Comparison of manually and 2D image measurement methods

The paired sample Students' t-test analyzed the measurement of the manually and 2D image methods for various hand dimensions. The finding implies that the average value of hand dimensions in Students't-test in two approaches has no significant difference ($p>0.05$) as shown in Table 3. The maximum and minimum values of p were in hand length and distal phalanx of the middle finger with 0.937 and 0.252 respectively having t-value of -0.080 and -1.164 respectively. Two methods were compared between various dimensions of hands using t-test. It was observed that for all the measurements by two different

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Particulars	Min	Max	Average	SD
Age (year)	19	21	19.9	0.9
Weight (kg)	48	61	55.7	3.8
Stature (cm)	152	169	161.8	5.1
BSA (m^2)	1.4	1.7	1.6	0.1
BMI (kg/m2)	19.1	23.4	21.2	1.3

SD: Standard Deviation; BMI: Body Mass Index; BSA: Body Surface Area

Table 1: Physical characteristic of participated students.

Parameters	Mean ± SD		Range		Manual		Image 2D	
	Manual	Image 2D	Manual	Image 2D	5^{th}%ile	95^{th}%ile	5^{th}%ile	95^{th}%ile
Hand Length	178 ± 14	178 ± 14	45	45	155	201	155	201
Hand Breadth	98 ± 6	97 ± 7	22	21	88	108	85	109
Palm Length	97 ± 6	98 ± 6	22	20	87	107	88	108
Small Finger Length	61 ± 6	60 ± 6	20	23	51	71	50	70
Ring Finger Length	70 ± 7	70 ± 7	23	22	58	82	58	82
Middle Finger Length	76 ± 6	77 ± 7	25	27	66	86	65	89
Index Finger Length	70 ± 6	70 ± 5	25	21	60	80	62	78
Thumb Length	57 ± 5	58 ± 6	22	23	49	65	48	68
Distal Phalanx of Small Finger	23 ± 2	23 ± 2	9	9	20	26	20	26
Middle Phalanx of Small Finger	17 ± 3	16 ± 3	12	13	12	22	11	21
Proximal Phalanx of Small Finger	19 ± 4	18 ± 4	11	14	12	26	11	25
Distal Phalanx of Ring Finger	26 ± 3	26 ± 2	10	9	21	31	23	29
Middle Phalanx of Ring Finger	23 ± 2	22 ± 2	9	9	20	26	19	25
Proximal Phalanx of Ring Finger	23 ± 4	23 ± 4	16	17	16	30	16	30
Distal Phalanx of Middle Finger	26 ± 2	25 ± 2	8	10	23	29	22	28
Middle Phalanx of Middle Finger	25 ± 2	24 ± 2	8	8	22	28	21	27
Proximal Phalanx of Middle Finger	26 ± 3	25 ± 3	11	12	21	31	20	30
Distal Phalanx of Index Finger	24 ± 2	24 ± 2	6	7	21	27	21	27
Middle Phalanx of Index Finger	22 ± 2	22 ± 3	10	13	19	25	17	27
Proximal Phalanx of Index Finger	23 ± 3	22 ± 3	11	12	18	28	17	27
Distal Phalanx of Thumb	32 ± 3	32 ± 3	10	11	27	37	27	37
Proximal Phalanx of Thumb	29 ± 4	28 ± 4	16	14	22	36	21	35
All measurements are in mm; SD: standard deviation								

Table 2: Descriptive statistics of hand anthropometric data measured by manual and image 2D methods.

Parameters	Mean ± SD		t-Value	p-Value
	Manual	Image 2D		
Hand Length	178 ±14	178±14	-0.08	0.937
Hand Breadth	98 ± 6	97 ± 7	-0.119	0.906
Palm Length	97 ± 6	98 ± 6	0.244	0.809
Small Finger Length	61 ± 6	60 ± 6	-0.219	0.828
Ring Finger Length	70 ± 7	70 ± 7	0.258	0.798
Middle Finger Length	76 ± 6	77 ± 7	0.145	0.885
Index Finger Length	70 ± 6	70 ± 5	-0.347	0.731
Thumb Length	57 ± 5	58 ± 6	0.288	0.775
Distal Phalanx of Small Finger	23 ± 2	23 ± 2	-0.267	0.791
Middle Phalanx of Small Finger	17 ± 3	16 ± 3	-0.824	0.415
Proximal Phalanx of Small Finger	19 ± 4	18 ± 4	-0.498	0.621
Distal Phalanx of Ring Finger	26 ± 3	26 ± 2	-0.256	0.799
Middle Phalanx of Ring Finger	23 ± 2	22 ± 2	-0.656	0.516
Proximal Phalanx of Ring Finger	23 ± 4	23 ± 4	-0.379	0.707
Distal Phalanx of Middle Finger	26 ± 2	25 ± 2	-1.164	0.252
Middle Phalanx of Middle Finger	25 ± 2	24 ± 2	-0.538	0.594
Proximal Phalanx of Middle Finger	26 ± 3	25 ± 3	-0.376	0.709
Distal Phalanx of Index Finger	24 ± 2	24 ± 2	-0.794	0.432
Middle Phalanx of Index Finger	22 ± 2	22 ± 3	-0.284	0.778
Proximal Phalanx of Index Finger	23 ± 3	22 ± 3	-0.158	0.876

Distal Phalanx of Thumb	32 ± 3	32 ± 3	-0.514	0.61
Proximal Phalanx of Thumb	29 ± 4	28 ± 4	-0.486	0.63

Table 3: Comparison of hand anthropometric data measured by manual and image 2D methods (values in millimeter).

measurement procedures have no significant difference. For example, the average value of hand length in both the methods was 178 ± 14 and 178 ± 14 mm while that handbreadth was 98 ± 6 and 97 ± 7 mm respectively.

Apart from t-test, it can also be perceived from the scatter plot (Figures 2 and 3) shows that the points were reasonably spread very close for each pair of data, and it can depicted that there was a strong linear relationship between two values.

Correlation between manual measurement and 2D image software measurement

Apart from t-test, Table 4 shows the correlation analysis between various measured hand dimensions by the two methods. The correlation coefficient measures the robustness of the relationship between two variables. The value of the correlation coefficient ranges from -1 to +1, which gives the strength of the relationship, whether the relationship has negative or positive. It was found that all the measure value were in ranged from 0.902 to 0.993, which means that the measured value by the two methods was close to 1. If the coefficient of two variables was found zero, it signifies there was no linear relationship between them.

The coefficient relationship between the difference of hand length and palm length against their mean with 95% limits of agreement (broken lines) was shown in (Figures 4 and 5). It was found that some value moves in a positive direction which shows positive correlation while some value moves in opposite direction showing a negative correlation. The measured value differs from mean by –1.96 to +1.96 mm, which means that measured value was found in the range of equal proportion.

Measurement of time taken by manual and 2D image methods

The new approach was used based on 2D image for obtaining accurate hand anthropometric datasets with minimal user interaction. Independent of the participant involvement of hand measurement was more preferable. Moreover, the average time taken of manual

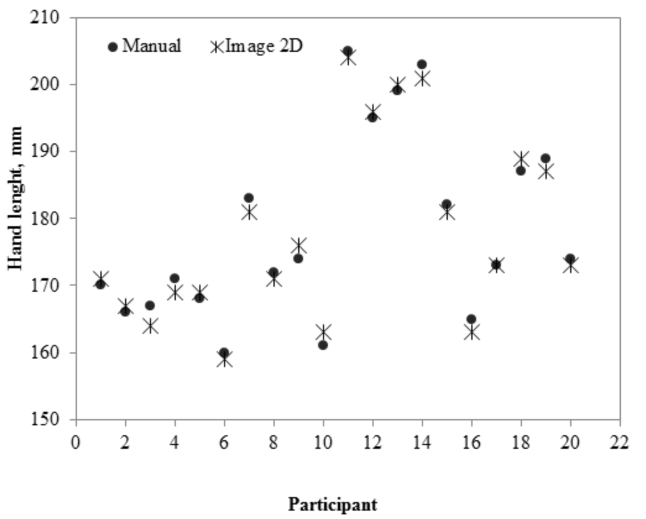

Figure 2: Scatter plot for measurements of hand length by manual and Image 2D scaling methods.

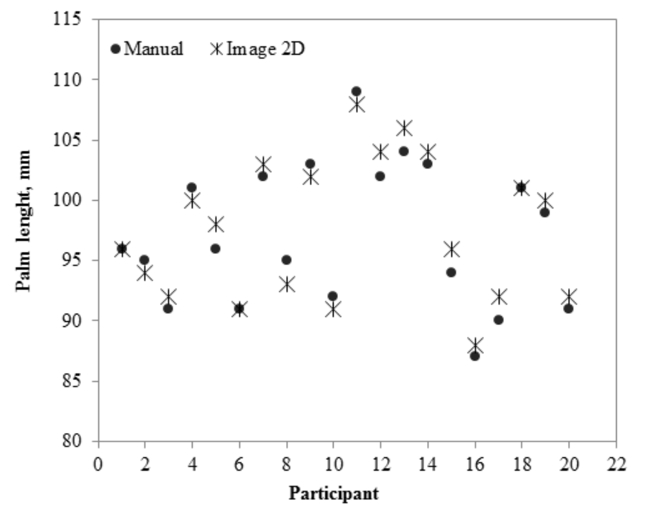

Figure 3: Scatter plot for measurements of palm length by manual and Image 2D scaling methods.

Sl. No.	Variable	Correlation	Significant
1	Hand Length	0.993	P<0.0001
2	Hand Breadth	0.950	P<0.0001
3	Palm Length	0.976	P<0.0001
4	Small Finger Length	0.941	P<0.0001
5	Ring Finger Length	0.966	P<0.0001
6	Middle Finger Length	0.956	P<0.0001
7	Index Finger Length	0.966	P<0.0001
8	Thumb Length	0.952	P<0.0001
9	Distal Phalanx of Small Finger	0.920	P<0.0001
10	Middle Phalanx of Small Finger	0.943	P<0.0001
11	Proximal Phalanx of Small Finger	0.963	P<0.0001
12	Distal Phalanx of Ring Finger	0.918	P<0.0001
13	Middle Phalanx of Ring Finger	0.916	P<0.0001
14	Proximal Phalanx of Ring Finger	0.967	P<0.0001
15	Distal Phalanx of Middle Finger	0.907	P<0.0001
16	Middle Phalanx of Middle Finger	0.915	P<0.0001
17	Proximal Phalanx of Middle Finger	0.933	P<0.0001
18	Distal Phalanx of Index Finger	0.902	P<0.0001
19	Middle Phalanx of Index Finger	0.946	P<0.0001
20	Proximal Phalanx of Index Finger	0.920	P<0.0001
21	Distal Phalanx of Thumb	0.914	P<0.0001
22	Proximal Phalanx of Thumb	0.950	P<0.0001

Table 4: Level of correlation between measured dimensions in the two methods.

measurement and software-based measurement shown close agreement (average <2% difference). The average time taken during measurement by both methods were calculated and plotted within the 99% confidence level (Figure 6). In paired two test of the average value (t=449; p=0.663), which indicates that the two values were not differ significantly.

Conclusion

The measurements of hand dimensions are very useful in

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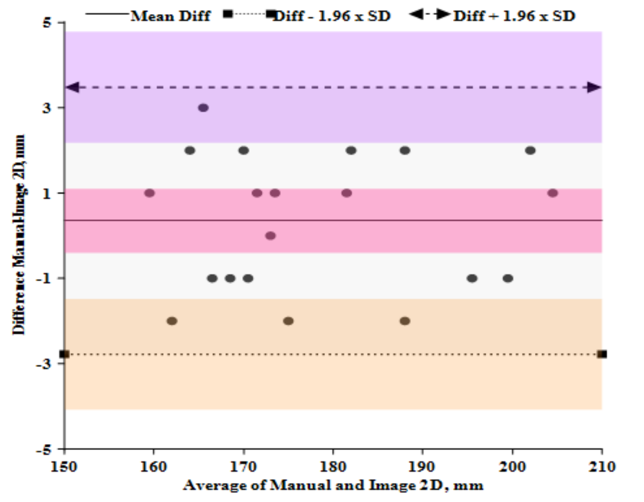

Figure 4: Difference against mean plot for measurements of hand length by manual and Image 2D scaling methods with 95% limits of agreement (broken lines).

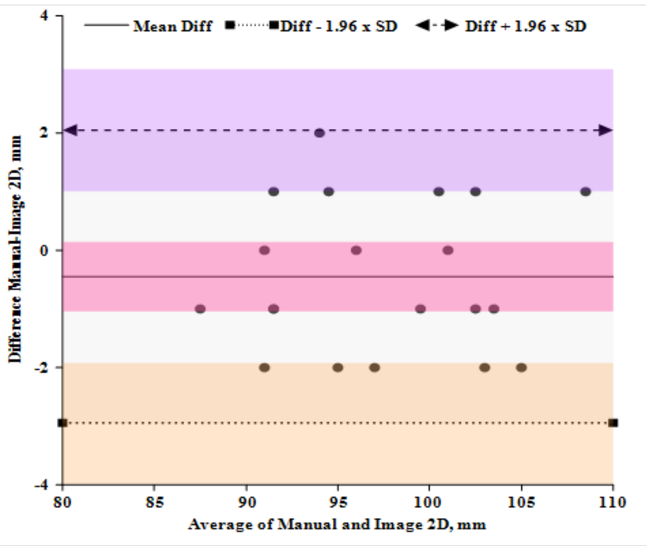

Figure 5: Difference against mean plot for measurements of palm length by manual and Image 2D scaling methods with 95% limits of agreement (broken lines).

improving the ergonomic design of tools, workstations, and aids for disabled people, which are the keys that influence the development of industrial activities and the productivity of any organizations. Manual anthropometry is a simple, low cost, time-consuming method but it needs the cooperation of the individual who is being tested. Hence, the alternative one could be beneficial in indirect anthropometry. Since used of image 2D methods because of non-involvement of participants and non-contact with measuring tools people were more willing to co-operate.

The results of the present study validate the use of the direct and indirect measurements. Both the measurement methods like manual and image 2D showed a strong correlation with each other. Further, the dimensions obtained under the two modes of measurement were found to be linear, and the statistical analyses also showed that Image

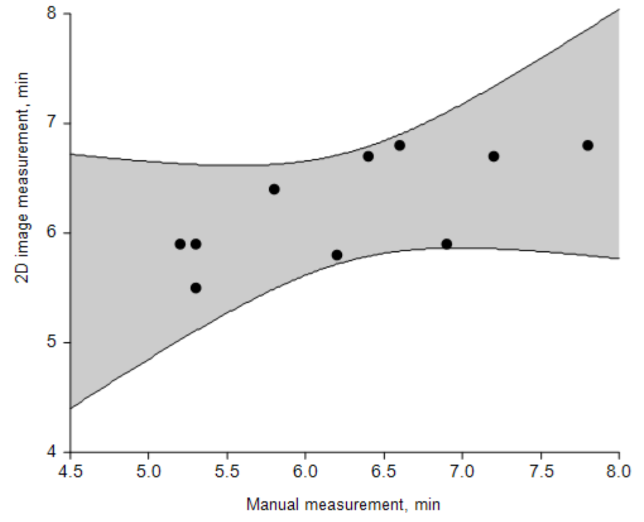

Figure 6: Time take by manual and image 2D measurement at 99% confident level.

2D method could be used instead of a manual mode. However, the time required by both the means does not have a significantly different. The 2D image process have better advantages as there is no direct involvement of participant during measurement which would reduce workforce, cost, and energy.

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