Adaptive Body Circumference Measurement Technique Using Ellipse Formula

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https://doi.org/10.15221/22.12

Abstract

In the present paper, ellipse-like approximations are considered with the aim of minimizing the difference between the results of direct and software measurements. The human body can only be approximately represented by elliptic cross sections, and these can vary for each individual. We show that better results are obtained by adapting the fit to the body shape based on a simple criterion. Based on this study, we have selected two mathematical models to estimate upper human body circumferences.

The result is a fully trained system that can choose the best ellipse equation according to the human body shape to calculate human body circumferences.

1. Introduction

Online shopping has become more popular in recent years. A well-known problem for online cloth retailers is the high return rate due to a poor fit.

Existing body measurement systems available on portable devices (such as smart phones or tablets) are not able to satisfy both consumers and retailers due to a lack of accuracy and robustness.

From previous research, a digital circumference anthropometric system was developed using only images (static views). Anthropometric dimension measurement based on images has attracted attention due to its high potential for ease of use, portability, and low cost [4]. However, there are several drawbacks in existing software solutions. There are significant errors between the direct (tape) measurement results and those based on software, especially for upper human body circumferences such as for the chest and waist. The problem emerges because there have not been a careful study of which mathematical models to use to better represent upper human body circumference anthropometric variables.

Here, we report on the advances made over the state-of-the-art to obtain accurate body dimensions by using different ellipse formulas according to the human body shape.

Early on, it was proposed in [8] that human body cross-sections can be approximated with ellipses, which has been since [6]. However, the accuracy thus far achieved is not sufficient for many real-life applications, with over a centimeter of an error on average.

We have studied several ways to evaluate elliptic fitting to find the most accurate way to perform efficient human upper body measurements, leading us to compare the following three equations:

$$P \approx 2 \times \Pi \times \frac{\sqrt{\left(dist_a^2\right) + \left(dist_b^2\right)}}{2}$$ **Equation 1**

$$P \approx \Pi\left[3(dist_a + dist_b) - \sqrt{(3dist_a + dist_b)(dist_a + 3dist_b)}\right]$$ **Equation 2**

$$P = 4\int_0^{\frac{\Pi}{2}} \sqrt{\left(dist_a^2 \cos^2 \Theta\right) + \left(dist_b^2 \sin^2 \Theta\right)} \quad (d\Theta)$$ **Equation 3**

Note: *$dist_a$ = Major Axes, $dist_b$ = Minor Axes*

Equation (3) was proposed by Xun Wang *et al.* [7] who developed an approach that can estimate anthropometric dimensions based on 2D images by extracting landmarks through a convolutional neural network and by building a general multi-ellipse model in which body shape information is added to obtain more accurate results. Their network is trained by front and side views marked with 14 landmarks, together with a heatmap generated by a Gaussian template. The network is based on resnet-v101 pre-trained on ImageNet. Their dataset consisted of 41 female and 46 male bodies.

Based on such a background, in this research, two ellipsoid models to estimate upper human body circumferences will be used.

2. Related Work

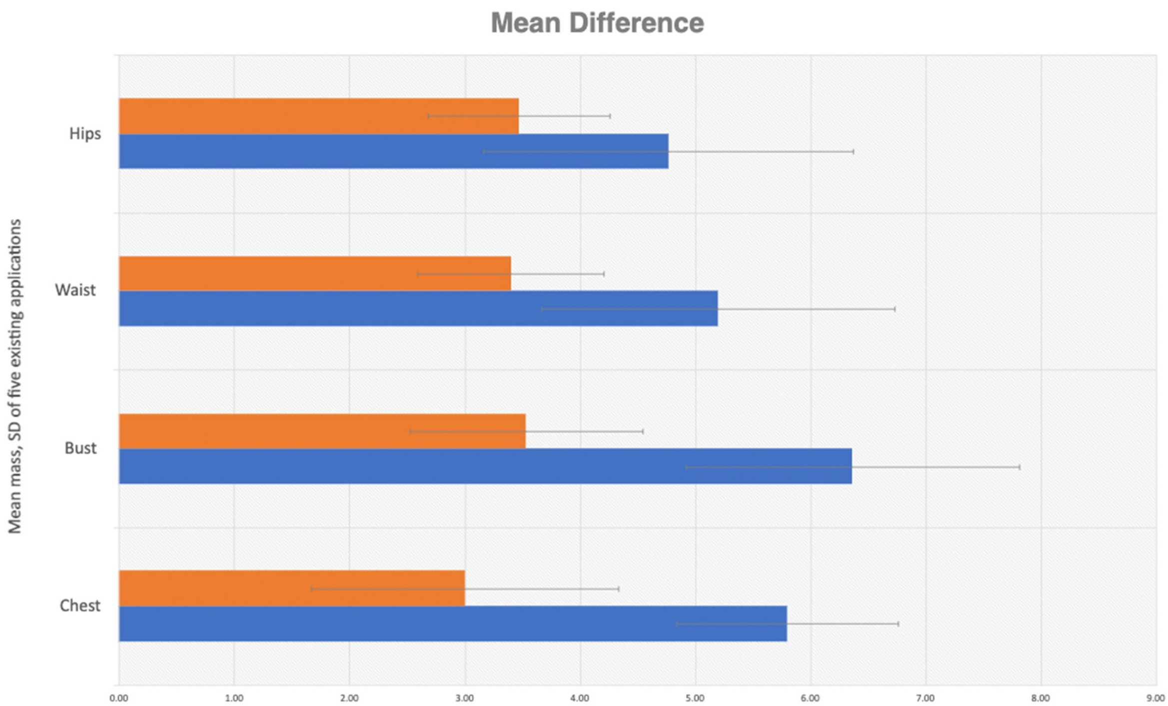
2.1. Subjects and Data

Our data was obtained from 55 participants. All the subjects self-identified as female, aged between 18 and 45 years old. According to different surveys, women are willing to buy more clothes than men, which is a main reason why we have decided to limit the participants to this group. Furthermore, the young generation is more willing to use new technologies to find their garment fit. Also, on the basis of research and experiments we have conducted, the average error of different existing software applications is higher for women than for men (figure 1). This is due to the greater variations in shape, observed for the female body.

We have captured 2D images from each participant based on the following four scenarios:

1. with a plain background;
2. with a cluttered or textured background;
3. using a pair of different body postures (A-Pose and Relax Pose)
4. using different distances from the camera

With 55 participants, this has resulted in an initial dataset with 220 data points.



	Chest	Bust	Waist	Hips
Male	3.00	3.53	3.40	3.47
Female	5.80	6.37	5.20	4.77

Figure 1: displays mean difference (cm) and standard division of five existing applications in the store. This data is been taken from 15 (who self-identified) as female/male participants in the same conditions from five different applications that exist in the store

2.2. Selection of Measurements

As an initial further constraint, we have focused our research and development on the upper body parts. Our initial research shows that some of the most serious garment distortions occur in the areas of the chest, bust, and armpits. Our results reported here are focused on the traditional chest, bust, waist, and hips measurements, this for comparison with other published works, and for validation of our method.

We have followed the standard procedure as proposed in ISO 8559-1 [1] ISO 8559-2 [2] and ISO 8559-3 [3], for obtaining our tape measurements (as ground truth references), in order to reduce the likeliness of introducing human errors.

2.3. Equipment and Software

For measuring the upper human body circumferences, tools like measuring tape will be used. After that for processing the data, several software, as well as Microsoft Excel 2021 and SPSS, have been used.

2.4. Data Collection

The data is obtained by a procedure consisting of a few steps. The first step is to collect the participant's actual upper body measurements with a tape. The next step is to take several images (front and side view) in different scenarios as mentioned in subsection 2.1. Afterward, we are inputting the 2D images into the software, and the software is grouping each section of the body into different ellipse formulas by calculating the semi-major and minor axes. We applied separately each ellipse equation (section 1) to estimate the upper human body measurements of each participant for each ellipse equation. Finally, the circumference results are compared with the tape measurements to find out the accuracy level of each model per scenario.

2.5. Elliptical Mathematical Models

We use linear regression to set variables. Variable 'x_1' which is determined from half of the chest or waist length (semi-major axes) and variable 'x_2' which is determined from half of the chest or waist breadth as the independent variables (semi-minor axes). Also, variable 'x_3' is determined from the chest or waist length, and variable (major axes) 'x_4' is determined from the chest or waist breadth (minor axes). Variables x_1, x_2, x_3 and x_4 were obtained from two images that we collected earlier from each participant and thereafter added to the software that we have developed to estimate each variable [5]. Illustrations about the variables are shown in figure 2.

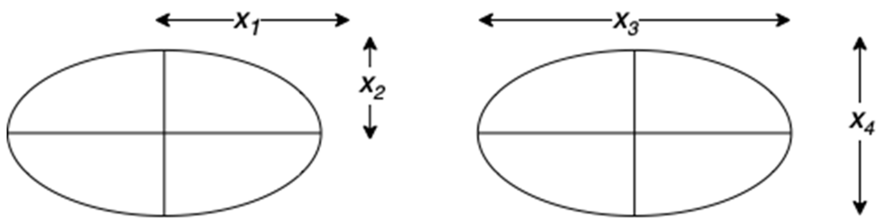


Figure 2: Display of independent Variables in the first and second model

Where,

x_1 = half of the chest or waist length

x_2 = half of the chest or waist breadth

x_3 = chest or waist length

x_4 = chest or waist breadth

The real circumferences of human subjects are only approximately elliptical (figure 3). The challenge is to find a best fit. Unlike for a circle, there is no simple direct formula (without an integral) for calculating the circumference of an ellipse. The differences between each shape can affect the final estimation, according to our data collection. This brought us attention to investigate and better understand how to resolve this issue according to our collected data insection 3. We decided to use more than one ellipse equation to estimate the human body circumference according to the body shape to minimize the difference with ground truth measurements. As can be seen figure 3, the ellipse shape can become more circular (top row) or, at another extreme, can become squashed (bottom row).

3. Results and Discussion

This section describes the datasets and shows the accuracy (results) of each ellipse equation and also compares our training software with the direct measurements.

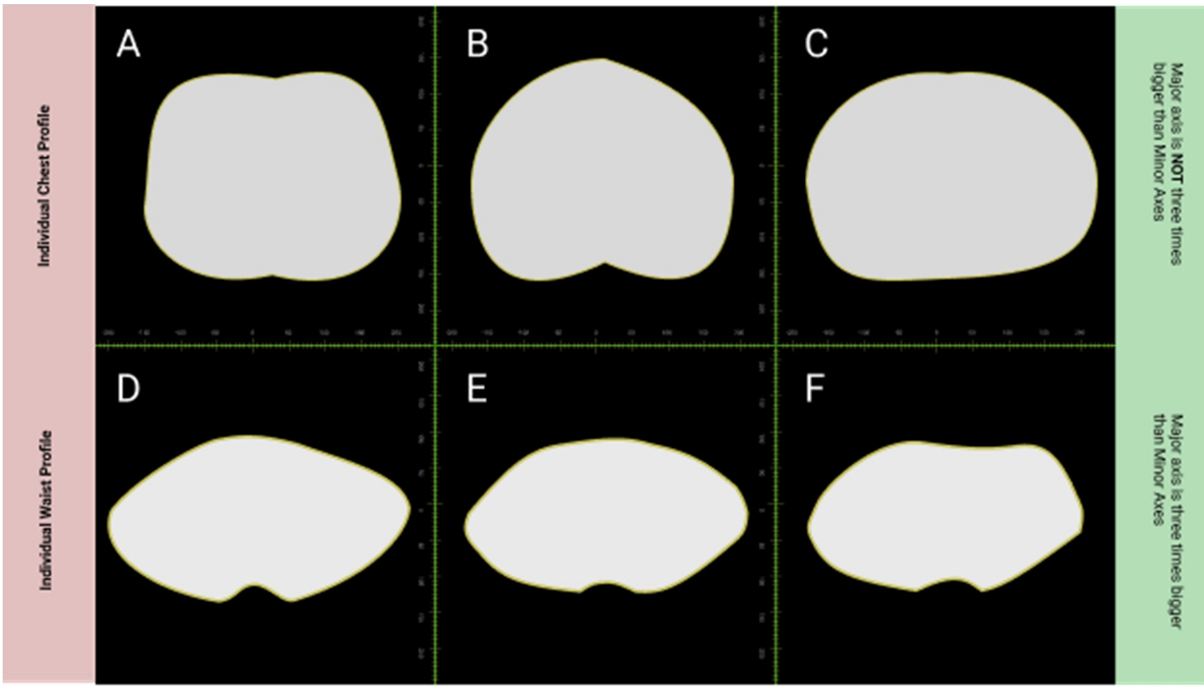


Figure 3: display of independent Variables in the first and second model

3.1. Datasets

The quantitative data for the 55 female participants were analyzed by using a descriptive statistics, an ANOVA single factor, and a t-test with two samples assuming equal variances.

Data description is been used in all stages of our data collection. ANOVA test is been used to compare Equations 1, Equations 2 and Equations 3 for the reliability of measured data. And finally, we have used a t-test: two-sample assuming equal variances to compare our software with the actual tape measurements to make sure that we were able to improve the state-of-the-art in terms of accuracy. The quantitative data was reviewed and compared at every different stage, such as in terms of accuracy and reliability of each method and technique.

3.2. Results

The following tables report on the mean, median, minimum and maximum differences as well as the standard deviation according to different body shape.

Table 1: Summary of the differences between our software and tape-measured data for the 55 participants (220 cases in total) included in this study. Each participant performed at least 3 case studies (clothing that has creases, plain/cluttered background, different body posture, variety of lighting conditions and different distance from the camera point of view). The best, worst, mean (ABS) and standard deviation of the accuracy of all the three different ellipse equations on female body torso for comparison with the tape measurements.

Body Type	**Chest**	**Bust**	**Waist**	**Hips**
Mean Differences (cm)	0.809	0.734	0.921	0.765
Median Differences (cm)	0.784	0.725	0.799	0.765
Max Differences (cm)	1.884	1.557	3.009	3.022
Min Differences (cm)	0.026	0.002	0.017	0.015
Standard Deviation (cm)	0.381	0.323	0.486	0.520

Equations 1

Body Type	**Chest**	**Bust**	**Waist**	**Hips**
Mean Differences (cm)	0.622	0.747	0.700	0.799
Median Differences (cm)	0.655	0.765	0.696	0.698
Max Differences (cm)	1.734	2.209	1.765	3.398
Min Differences (cm)	0.068	0.018	0.054	0.036
Standard Deviation (cm)	0.324	0.418	0.312	0.611

Equations 2

Body Type	**Chest**	**Bust**	**Waist**	**Hips**
Mean Differences (cm)	0.617	0.746	0.698	0.801
Median Differences (cm)	0.655	0.775	0.690	0.694
Max Differences (cm)	1.733	2.203	1.754	3.398
Min Differences (cm)	0.072	0.023	0.048	0.030
Standard Deviation (cm)	0.327	0.416	0.312	0.614

Equations 3

The ANOVA test is used to see if there is a statistically significant difference between the ellipse formulas by testing for differences in the mean. Based on our collected data from the participants, and by best fitting the human body shape (horizontal slices) by ellipses, we observed that for elliptic profiles such that their major axis were not more than 3 times longer than their minor axis, the stress level of Formula B and C (M= 1.03, SD = 0.46, n = 96) was hypothesized to be greater than the stress level of Formula A (M = 0.48, SD = 0.27, \ n = 96). This difference proved extremely significant: t(285) = -10.06, \ p =1.00281537709417E-21 (1 tail).

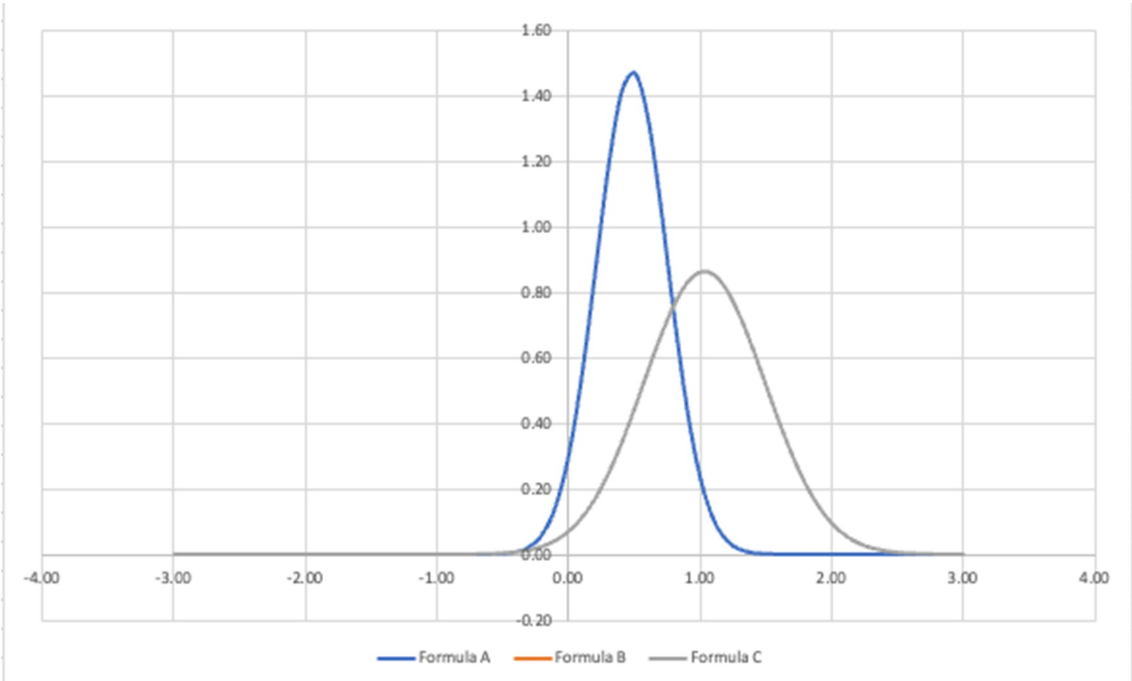


Figure 4: displays the stress level of each formula in the bell curve Note: Formula B and C provide almost the same results that is why in the curve shows only one colour

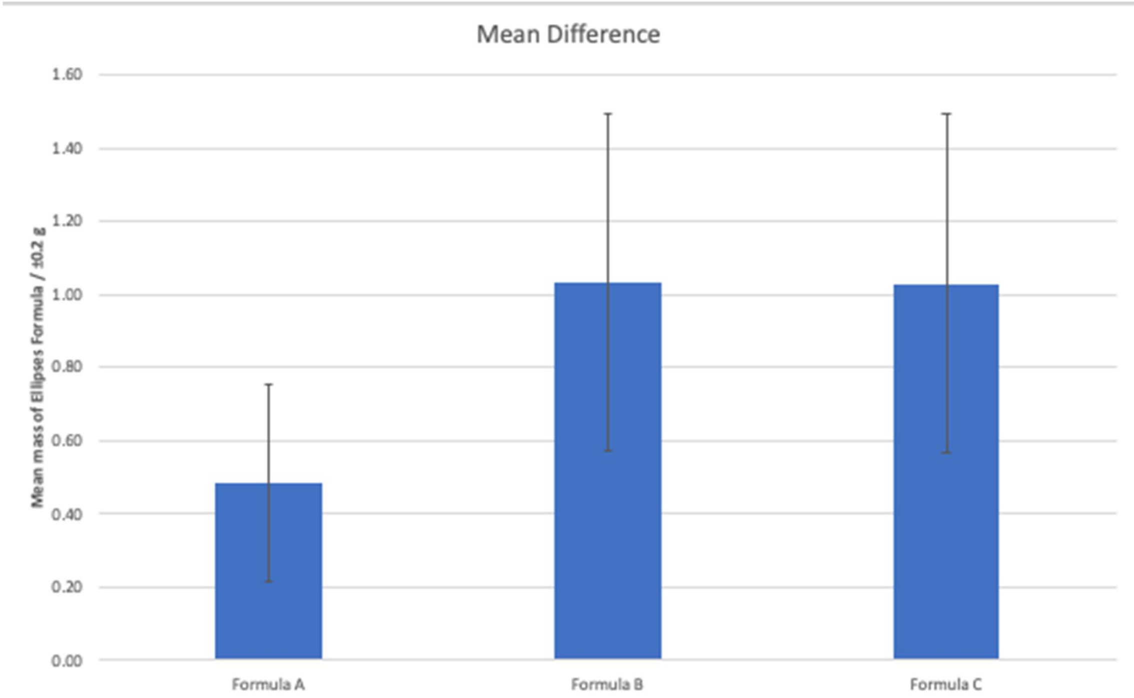


Figure 5: displays the mean difference as well as the standard deviation for each formula – comparison of chest, bust, waist hips circumference between direct (tape) measurements and our software

On the other hand, for body shape such that the major axis is 3 times (or more) longer than the minor one, the stress level of Formula A (M = 1.06, SD = 0.38, n = 124) was hypothesized to be greater than the stress level of Formula B and C (M = 0.48, SD = 0.21, n= 124). This difference was again extremely significant: t(369) = 14.1, *p* =4.69746108928603E-56 (1 tail). Please refer to the bell curve below to see the data in more detail.

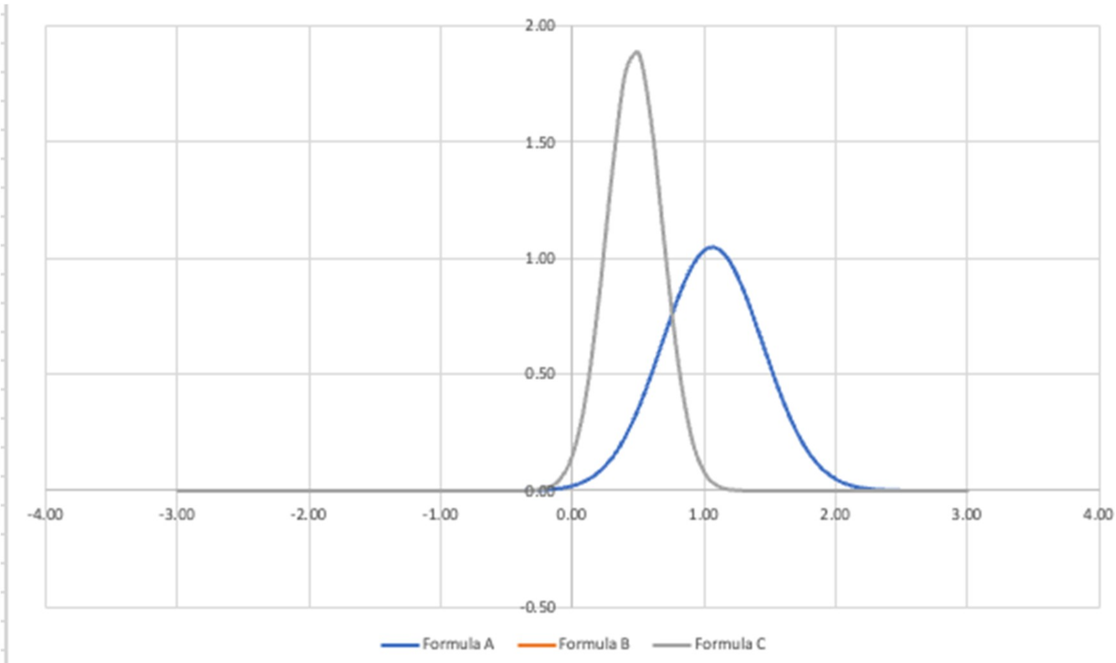


Figure 6: displays the stress level of each formula in the bell curve displays the stress level of each formula in the bell curve: Formula B and C provide almost the same results that is why in the curve shows only one colour

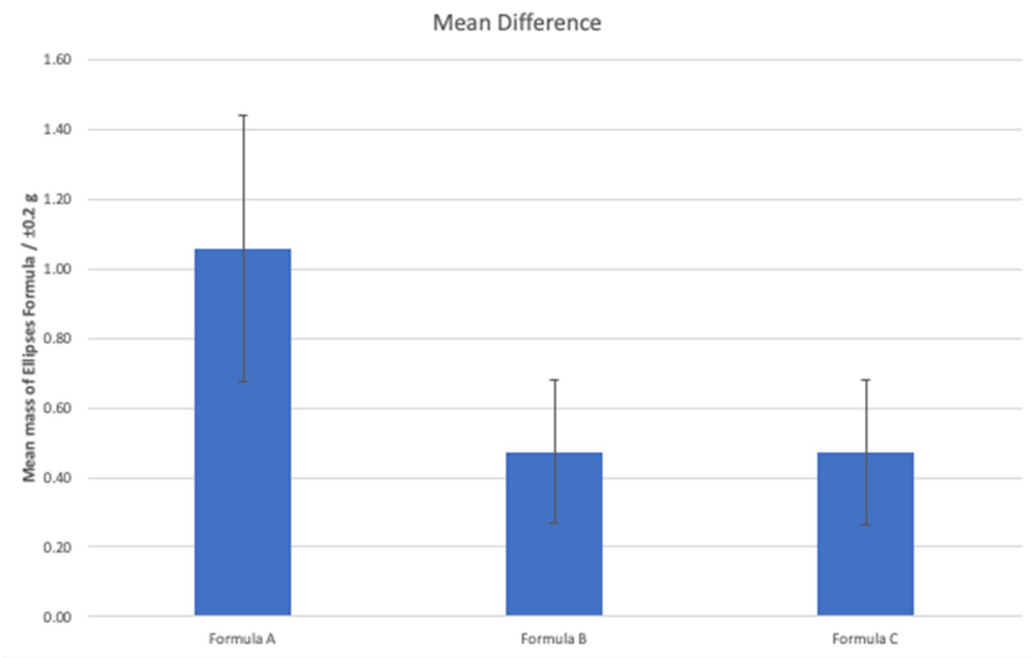


Figure 7: displays the mean difference as well as the standard deviation for each formula – comparison of chest, bust, waist hips circumference between direct (tape) measurements and our software

These results show that as a function of variances in the body shape (horizontal slices), one formula is more accurate than others, this to minimize the difference error between direct measurement and a software solution. For body shapes with semi-major axes that are not more than 3 times longer than their semi-minor axes (in other words, the ellipses are not overly elongated), Equation 1 provides better accuracy, while for those with semi-major longer than 3 times that of their semi-minor axes (squashed ellipses), Equations 2 or 3 provide better results. Since, equations 2 and 3 provide almost the same accuracy, due to the complexity of equation 3, we have in practice relied only on the first two formulas.

Furthermore, the t-test is been used to compare the direct measurements and our developed software. By using two ellipse equations according to different body shapes (horizontal slices), we were able to minimise the mean (average) error to ±1cm, which is a good enough result for a number of real-life applications.

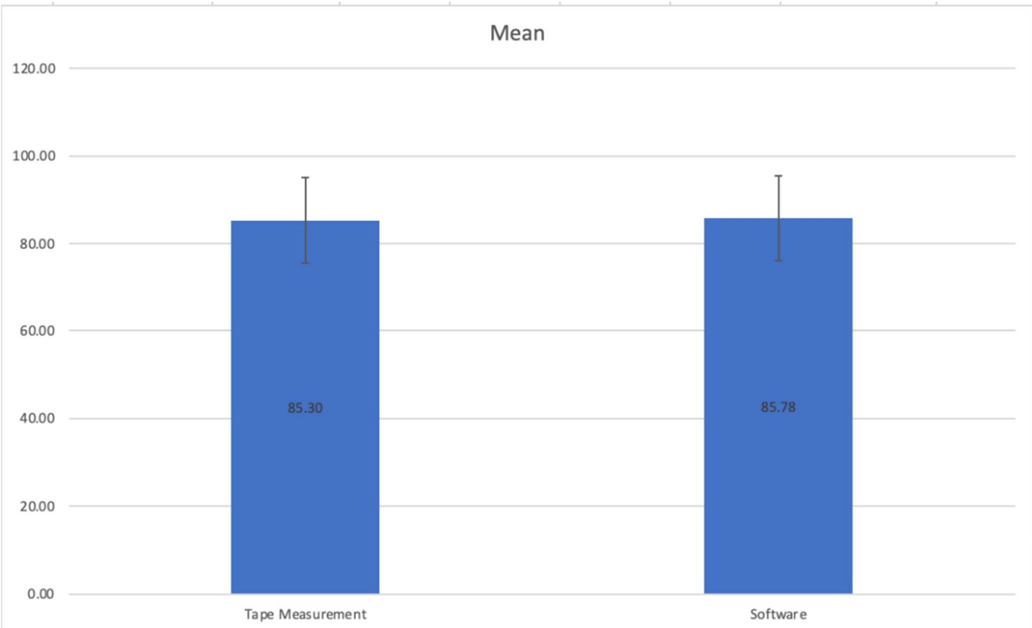


Figure 8: displays the mean difference as well as the standard deviation - comparison of chest, bust, waist hips circumference between direct (tape) measurements and our software e

4. Conclusion

An improved method of anthropometric measurements based on 2D images is proposed to obtain a sufficient level of accuracy for real-life applications, such that less than a centimeter of an error on average is expected. Two different ellipse equations are used based on variations of the body shape (horizontal slices) to measure human body circumferences.

With this method, we were able to improve the state-of-the-art in terms of accuracy to a maximum of ±1cm average difference (in comparison to the tape measurements methods) for 55 participants (who self-identified as female).

In future work, more images with more postures can be added to the training set to improve the stability and accuracy of body shape extractions. By expanding the number of test images, that is, using more human body images with different body shapes, the error of the multi-ellipse model can be reduced. In addition, the estimated measurements obtained in our experiment can also be used in garment customization, virtual fitting, 3D human modeling, and other related applications.

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