


# Pixel Coordinates for Obtaining 3D Body Measurements from 2D Images

Nefise Gönül Şengöz<sup>1</sup>  0000-0001-8688-1141

Fatih Zeybek<sup>2</sup>  0000-0002-1866-197X

<sup>1</sup> Uşak University / Faculty of Engineering / Textile Engineering Department, Uşak, Türkiye

<sup>2</sup> Uşak University / Institute of Science and Technology / Textile Engineering Department PhD. Student, Uşak, Türkiye

<sup>2</sup> Isparta University of Applied Science / Yalvaç Technical Sciences Vocational School / Clothing Production Technology Program, Isparta, Türkiye

**Corresponding Author:** Nefise Gönül Şengöz, nefisegonul.sengoz@usak.edu.tr

## ABSTRACT

In this research, a new method developed with pixel coordinates is presented to obtain 3D body measurements from 2D images, to eliminate the need of the body to take measurements and to solve unfit problem in e-shopping. Front and side photographs are processed with new developed softwares PixelList1.0 and PyNGF-2 for verification. The sharp silhouettes, presented in authors' another publication, are benefited with algorithms to reach pixel coordinates of feature points. Number of pixels in between feature points are saved, absolute values of differences are calculated consecutively, and 3D body measurements in pixels are obtained with different mathematical models, circle, ellipse, and hippodrome circumference equations. A conversion coefficient is introduced and size of a pixel is calculated accurately, 0.2596 cm/pixel. 3D body measurements in centimeters are obtained by multiplying number of pixels by the size of one pixel. An overall accuracy rate of 91.585 % is concluded with the ellipse circumference equation precisely.

## 1. INTRODUCTION

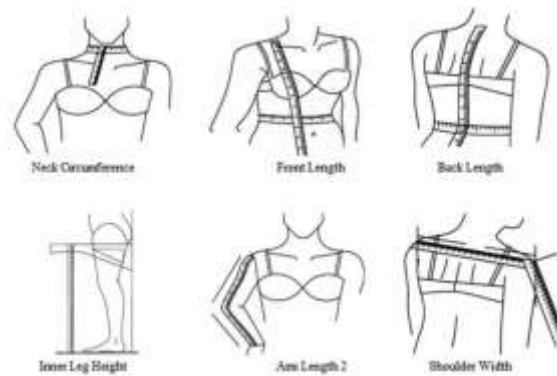
Parallel to the improvements in information technologies, internet usage is increasing day by day all over the world. Depending on this increasing internet usage, very many different fields of applications are developed and maybe the most benefited one is e-shopping. In the field of e-shopping, textiles, especially apparel, are a profound area in retail [1]. When an apparel is purchased via e-shopping, a consumer may be encountering some problems such as different measurements for the same size, absence of large size products, defects in the products either in fabrics or stitches, short sleeve lengths for tall people or vice versa, colors not matching with the order, and the most important of all is that the garment doesn't fit the person's own body, the fitting problem which is technically called unfit [2-4]. Therefore, body measurements are one of the most important data in apparel production. When the tailor sews a garment, the tailor takes body measurements from the person's body manually and the product fits the person's body finally. When garments are produced in the ready-wear industry, contrarily, it is unknown to whom the product will be sold, so body measurements are generalized to produce a garment,

international body sizing are generated, and apparel is mass produced. In this case, the unfit problem of apparel is encountered.

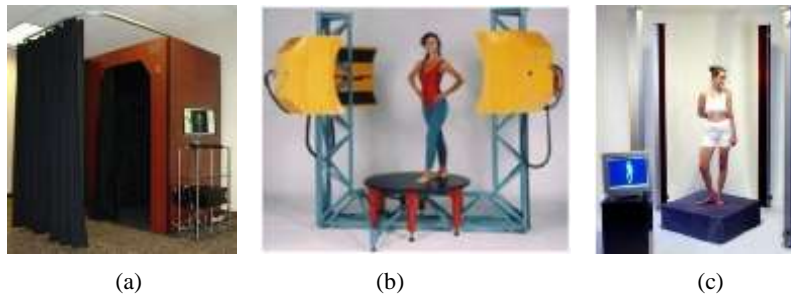
In the traditional way of obtaining body measurements manually, human body and a non-stretchable tape measure are used. Body measurements are taken according to the ISO-8559-Size designation of clothes Standard. In Figure 1 some examples of methods of taking body measurements manually are demonstrated [2-5]. With the rapid improvement of technology, body scanning technologies are developed to obtain body measurements quickly, easily and more precisely, also the objective to get over the unfit problem, but as mentioned above, the generalized body sizes are still limiting the body scanning technologies.

The presence of the body scanning systems are TC<sup>2</sup> 3D Body Scanner, Cyberware, Polyworks, Anthroscan, Vitus, etc. (Figure 2). These systems need the human body and take cross-sectional images from different areas by scanning the body from top to bottom, examine the body in terms of cross-sectional shape, slice area, and volume [6].

**To cite this article:** Şengöz N, Zeybek F. 2024. Pixel Coordinates for Obtaining 3D Body Measurements from 2D Images. *Tekstil ve Konfeksiyon*, 34(2), 127-146.



**Figure 1.** Demonstration of some methods of taking body measurements manually [2-5]



**Figure 2.** Examples of body scanning systems, a) TC<sup>2</sup> 3D Body Scanner, b) Cyberware, c) Vitus [6]

In the light of these informations, the objective of this research is to develop a method where the need for human body to take body measurements is eliminated, but instead where 2D photographs from front and side are used to obtain 3D body measurements, and where the unfit problem is solved, by experimenting with different mathematical models. The main logic here is to use the two photographs taken from the front and side, to acquire their sharp silhouettes, to reach the measurement's feature points in pixel values from the 2D images, to convert them to 3D body measurements mathematically, and to eliminate the usage of the human body to obtain body measurements either manually or by body scanners.

In related literature, there are studies on extracting personalized body measurements from 2D images from the front and side by applying super elliptic curves, B-spline curves and body cross section curves to obtain measurements such as waist circumference and chest circumference or by some estimation models for body measurements that cannot be obtained directly from these 2D images, where establishing a neck circumference size estimation model and top view of the created neck circumference measurements are seen in Figure 3 and 4, respectively [7]; a 2.5D system which is a combination of 2D and 3D measurements, reaching the chest circumference by comparing the measurements obtained from the 2D images and the elliptical measurements obtained from the virtual mannequin [8]; examining the simulation systems in garment design and body sizing, and explaining that they can be used for cross-sectional areas of body measurements

with B-spline curve approaches to obtain body measurements where the measurement of chest circumference and B-spline curves top view drawn with different number of control points are seen in Figure 5 and 6, respectively [9]; developing a software to extract body measurements from a 3D body scanner where a representation of it is seen in Figure 7 [10]; proposing an image-based system for taking anthropometric measurements from 2D images from the front, side and back images, obtaining the linear measurements from 2D images and the circumferential measurements via mathematical formulas where the estimation of the neck circumference using an ellipse is seen in Figure 8 [11]; a system consisting of two cameras to capture the front and side images and a software, where the marking of the body measurements' locations are seen in Figure 9 [12]; conducting the fit and the virtual fit tests for online shopping after the body measurements are obtained via 3D body scanner [13]; presenting a method for detecting the feature points in the silhouette of the human body from the front and side images using Freeman's chain code algorithm method (Figure 10) [14]; defining the feature points with an efficient shape coding algorithm, and evaluating the differences between the coding sequences where the extraction of feature points for head is seen in Figure 11, ankle in Figure 12 and 25 and 16 key feature points for the front and side 2D images in Figure 13 and 14, respectively [15]; and modelling the human body by developing an automatic land marking algorithm with anthropometric measurements for detection of neck, chest, waist, and hip circumferences (Figure 15) [16].

Another important literature [2,3] on this subject is initiating a study to obtain 3D body measurements from 2D images to eliminate the need for human body when taking body measurements manually or by body scanners and to explore a solution to the problem of unfit of garments, which often occurs in e-shopping. The photographs of 500 female participants from front and side rotated 90°, between ages 18-25, all volunteers, between weights 43-85 kg, wearing tight clothes, from 3 m distance, from neck to knees, arms and legs slightly open, using a camera that focuses on the waist and parallel to the ground, the camera being digital Canon EOS 7D and Fujifilm FinePix S2980 brand, were taken. Some examples are given in Figure 16.

Different body measurements up to 21 (Horizontal : neck, shoulder, biceps, chest, waist, belly, hip, thigh-right and thigh-left circumferences, back neck girth, back width, shoulder width; and Vertical : inner leg, outer leg, inner arm, front, back, side lengths, arm length from neck, arm length from shoulder, chest fall) were manually measured according to ISO-8559 standards using a non-stretchable tape measure, and the age, height and weight of the same person were also recorded. In the research, the descriptive statistics of the obtained data were calculated, and the relationships between height and weight were examined with regression analyses [2,3].



Figure 3. Establishing a neck circumference size estimation model [7]

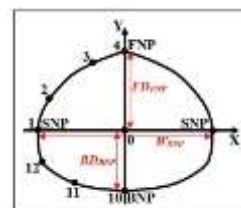


Figure 4. Top view of created neck easurement [7]

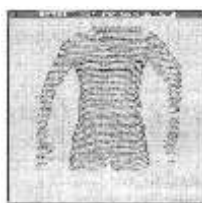


Figure 5. Cross-sectional areas of body measurements [9]

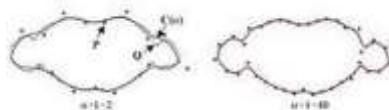


Figure 6. B-Spline curve approaches [9]

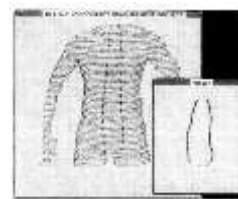


Figure 7. Developing software to extract body measurements [10]

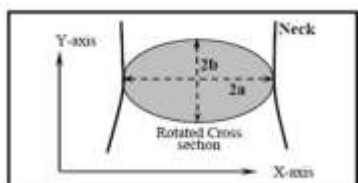


Figure 8. Extracting body size from a three-dimensional image [11]

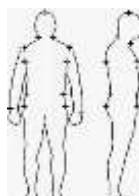


Figure 9. Marking the body measurements from the front and side pictures [12]

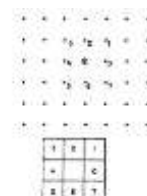


Figure 10. Freeman 7-way chain code [14]

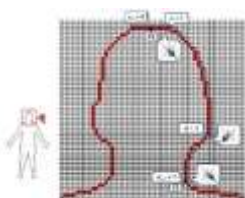


Figure 11. Extraction of feature points F1 and F2 for head size [15]

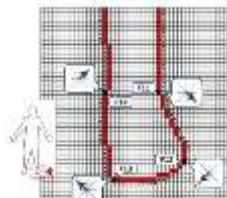


Figure 12. Measurement points between F11 and F14 for ankle [15]

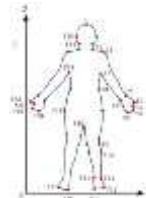


Figure 13. 25 key points from the front [15]

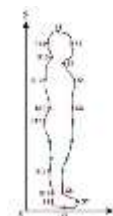


Figure 14. 16 key points from the side [15]



Figure 15. Modelling human body with automatic land marking algorithm, front and side [16]



**Figure 16.** Examples of photographs from front and side, (a) Person-1, (b) Person-13, (c) Person- 137, and (d) Person- 433 [2,3]

In the current research, the same photographs are used and the pixel coordinates for obtaining 3D body measurements from 2D images are processed with sharp silhouettes. In the second part of this manuscript, the material and method is introduced, and in the third part the results and discussion, where finding pixel coordinates for body measurements and marking body feature points are explained with the new developed softwares PixelList 1.0 and PyNGF-2 for verification, then, experimenting with different mathematical models to reach body measurements is explained with the circle, ellipse, and hippodrome circumference formulae, later, calculation of conversion coefficient “C” values, and comparison of the calculated measurements with the manually taken body measurements to reach the accuracy rates are accomplished. In the fourth part, the conclusion is presented.

## 2. MATERIAL AND METHOD

### 2.1 Material

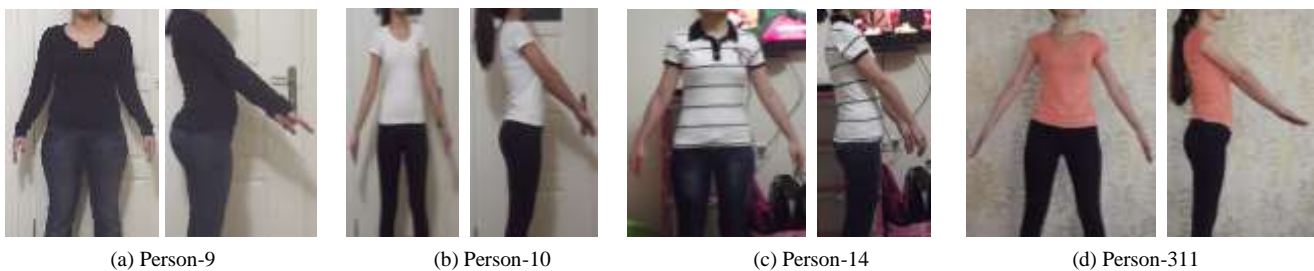
In this manuscript, pixel coordinates for obtaining 3D body measurements from 2D front and side images is presented. The material used in this research is mainly the front and side photographs of volunteers in Ref. [2,3]. As an example, the photographs from the front and side of Person-9, Person-10, Person-14, and Person-311 are given in Figure 17. Similarly, the same front and side photographs were benefited to acquire sharp silhouettes for obtaining 3D body measurements from 2D images in the authors’ another publication on obtaining sharp silhouettes [17], which essentially consists the first part of the current research.

In Ref. [2,3], 21 different body measurements were taken manually but in the current research, nine horizontal body measurements of the 21 are first chosen to develop a new method with pixel coordinates to obtain 3D body measurements from 2D images. The nine horizontal body

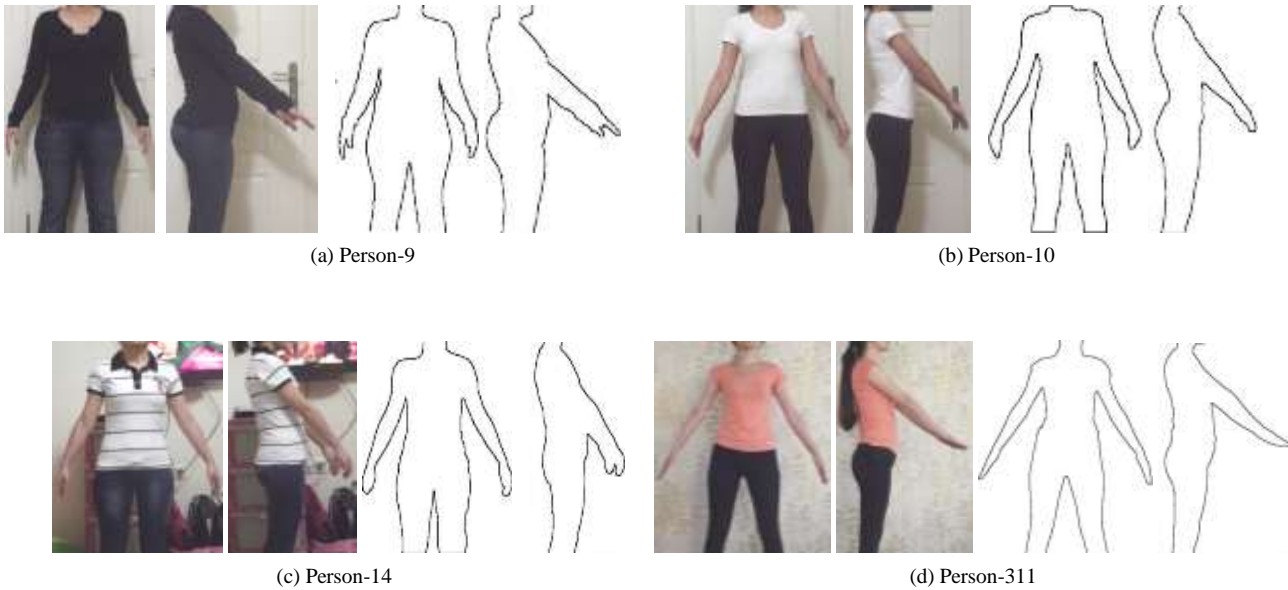
measurements are neck, shoulder, biceps, chest, waist, belly, hip, thigh-right, and thigh-left circumferences. The position of biceps required profound studies on it, they are explained in the last part of Section 3.1.1, and after this section, biceps measurement is eliminated in the scope of this manuscript but will be discussed in future work. This research is achieved with eight body measurements. Images of Person-10 are practiced in Sections 3.1 and 3.2, then with the information obtained, images of 30 more volunteers are included to calculate the conversion coefficient “C” values and the accuracy rates. Since there are circle, ellipse, and hippodrome equations, eight body measurements, and 30 volunteers, the calculation of “C” values and accuracy rates are realized with 720 values.

### 2.2 Method

Pixel coordinates for obtaining 3D body measurements from 2D front and side silhouettes is presented in this manuscript. In order to come to the stage of pixel coordinates, initially, sharp silhouettes have to be acquired from the 2D front and side silhouettes. The procedure to acquire sharp silhouettes which is presented in Ref. [17] was converting the color images to grayscale, thresholding and binary transformation with the new developed software named ImPrNGF-1.0, overcoming the problems encountered with other new developed software named PyNGF-1, background (noise) removal with Paint 3D (background cleaning), concluding the threshold value of 240 with another new developed software named ImPrNGF-2.0, applying edge detection algorithm (Sobel filter), and ultimately, attaining the negative image with the new developed software ImPrNGF-2.0. Perfect sharp silhouettes were achieved for obtaining 3D body measurements from 2D images. Examples of sharp silhouettes acquired from the front and side photographs of Person-9, Person-10, Person-14, and Person-311 are introduced in Figure 18 [17].



**Figure 17.** Additional examples of photographs from front and side, (a) Person-9, (b) Person-10, (c) Person-14, and (d) Person-311 [2,3]



**Figure 18.** Examples of sharp silhouettes acquired from front and side, (a) Person-9, (b) Person-10, (c) Person-14, (d) Person-311 [17]

In the present research, the pixel coordinates for the body measurements are investigated, the feature points are marked, and the number of pixels in between the marked feature points are determined with the new developed software in C# programming language which is named PixelList1.0. Then, another software is developed in Python programming language which is named PyNGF-2 for verification. Different mathematical models like circle, ellipse, and hippodrome circumference equations are experimented to reach 3D body measurements. A conversion coefficient is introduced and statistically analyzed to correlate the body measurements taken manually in centimeters with the determined number of pixels. The eight body measurements of 30 volunteers are taken. Once the size of a pixel is calculated accurately then the 3D body measurements are obtained by multiplying the number of pixels by the size of one pixel. A comparison of the 3D body measurements obtained from 2D images in pixels turned into centimeters and the manually taken body measurements in centimeters is proceeded and an accuracy rate is calculated to see how precise the model is functioning.

The workflow chart of the process steps is considered as a summary in Figure 19. The scheme briefly follows: removing the Sobel edge for Person-10 front and side silhouettes, determining the silhouette [17], reaching the pixel coordinates with the new developed software PixelList1.0, and verifying the pixel coordinates with another new developed software PyNGF-2.

### 3. RESULTS AND DISCUSSION

Rather a compelling work to obtain a sharp silhouette of the body is conducted which lead the way to the consideration

of the body measurements from 2D images. A feature point indicates the starting point of a body measurement and its ending point on a 2D silhouette in the current research. Since a front and a side silhouettes exist, at the same horizontal location, the number of pixels between the starting point of a body measurement and the ending of that measurement can be counted. That special body measurement was already taken manually, this gives the opportunity to correlate the number of pixel from the front and side silhouettes with the measurements in centimeters. By following this logic, the research within this scope will be explained in the following sections.

#### 3.1 Finding Pixel Coordinates for Body Measurements and Marking Body Feature Points

##### 3.1.1 Determining Pixel Coordinates for Body Measurements with PixelList 1.0

To start with, a new software is developed using Microsoft Visual Studio in C# programming language, named PixelList 1.0 and its interface is presented in Figure 20. On this interface, the “PictureBox”, “ListBox”, “TextBox”, “Label”, and “Button” items, and “OpenFileDialog” and “SaveFileDialog” objects are added. “PictureBox” item and “OpenFileDialog” object are used to withdraw the image file to be processed and to display it, respectively, “ListBox” item lists the pixel coordinates of the silhouette line, starts reading from left top, moves horizontal, when it notices a black pixel of the silhouette line it records its coordinates until the end of horizontal movement, then moves one pixel below on the vertical axis and again moves horizontal from left to right and the list continues until the end of vertical movement. The coordinate list varies between 4900 to 8500 according to the shape of the body silhouette.

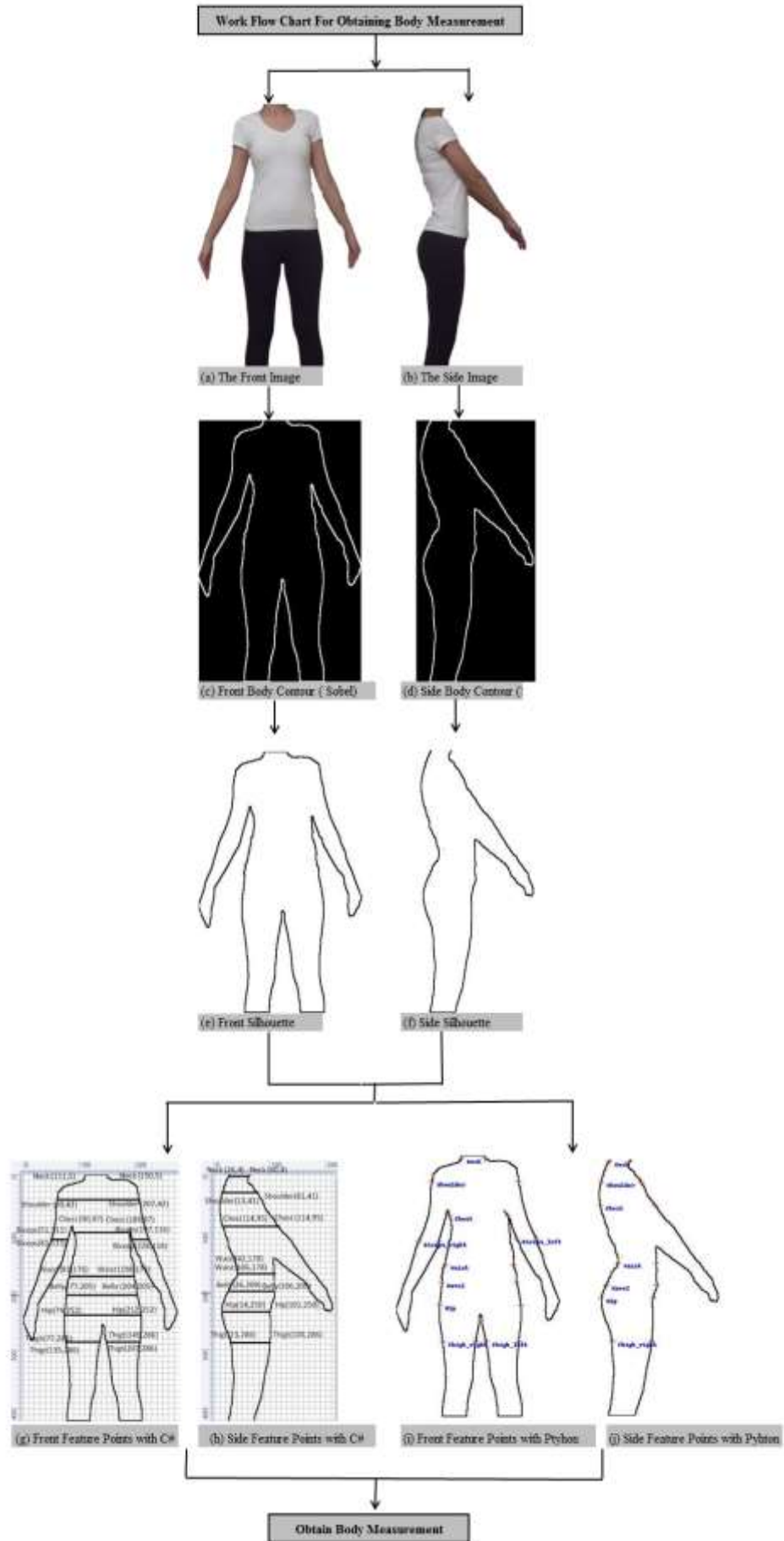


Figure 19. Workflow chart of obtaining body measurements

The coordinates are first obtained in parentheses and a slash in between the horizontal and vertical pixel coordinates like (150/37). Since the aim is to subtract these coordinate values, the necessary amendments are done on the software and they are listed as 150 37 separately. "SaveFileDialog" object saves the list of the pixel coordinates. An example of the pixel coordinates obtained with the new developed software PixelList 1.0 for Person-10 front silhouette is given in Figure 21. Then, the obtained pixel coordinates are saved as a text file seen in Figure 22 with the new developed software PixelList 1.0. Later, the text file is exported to an excel file and saved in two different columns. The transfer of the pixel coordinates to excel file from the text file is given in Figure 23.

For Person-10 front silhouette, a total of 4959 lines of pixel coordinates is listed in the excel file. Now a subtraction such as the value in the line underneath minus the value in the line above for all the values in all the 4959 lines is conducted and the results gives the number of pixels between the beginning of a feature point and at its ending. If a result is 0 or 1, this means the measurement is still continuing, not the end of that feature point is reached yet,

and if a result is 42, 83, 108, etc. this means it is the number of pixels of that body measurement between the feature points.

In the excel file, the subtraction command is given as the value in cell B2 is subtracted from the value in cell B3 and their difference is recorded in a separate column aside in cell D2. This is for the horizontal measurements. The same is also conducted for the vertical measurements where C2 is subtracted from C3 and the difference recorded in E2, even they will be considered in a different research. Both the D2 and E2 column is noted in Figure 24. All of the pixel coordinate differences in the rows below and above are obtained by subtraction, even 4950 lines or longer. By examining the side silhouette of the same person with the new developed software PixelList 1.0, the number of pixels for a special body measurement at the feature point is obtained. Now the number of pixels from the front and side are in hand, work will be done to obtain their circumferences, and since the manual measurements already exist in centimeters, there will be the opportunity to compare them and verify the model developed.

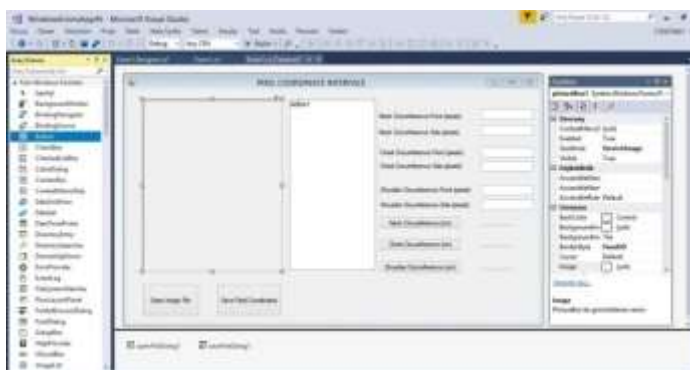


Figure 20. Interface of the new developed software PixelList 1.0

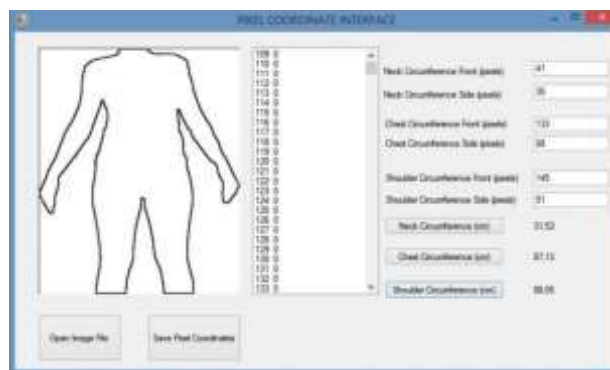


Figure 21. Pixel coordinates obtained with the new developed software PixelList 1.0 for Person-10 front silhouette

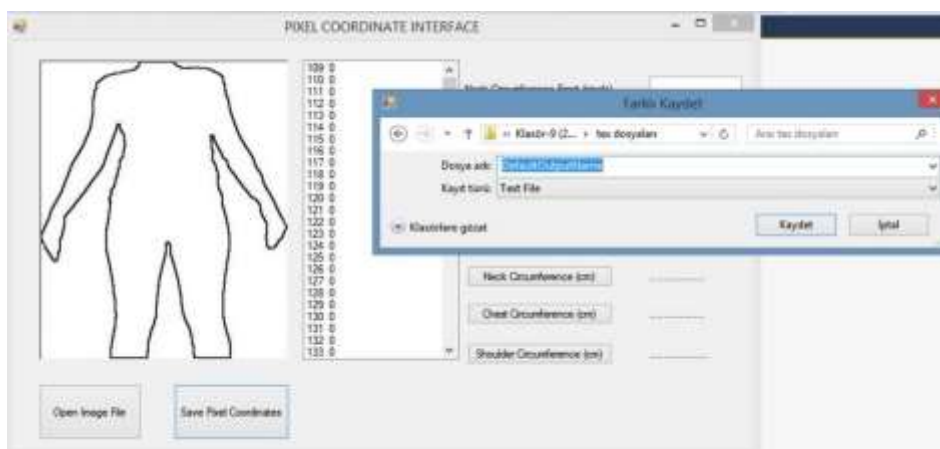


Figure 22. Pixel coordinates saved as text file with the new developed software PixelList 1.0

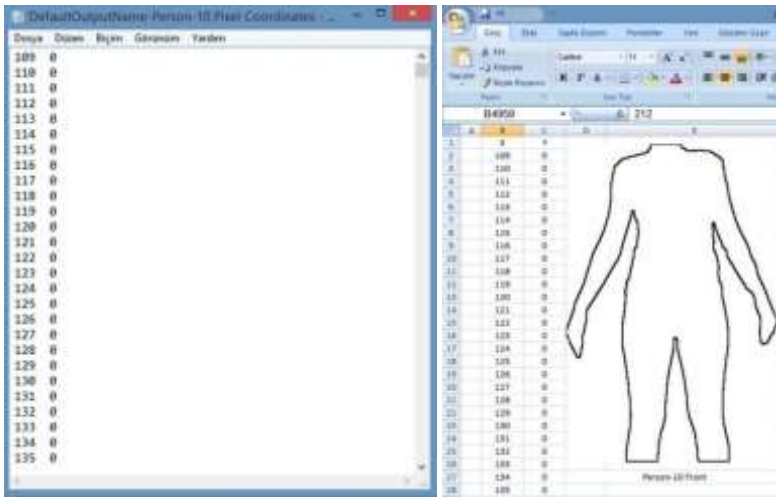


Figure 23. Pixel coordinates in text file and transferred to excel file

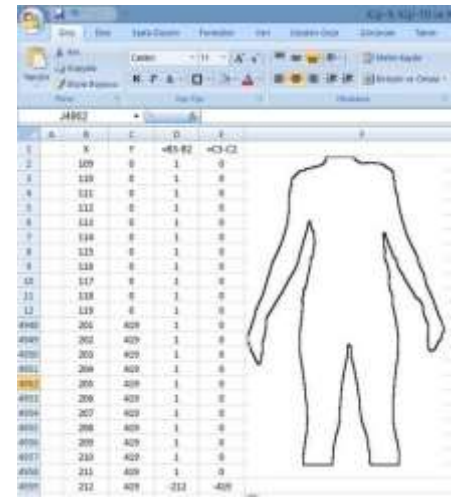


Figure 24. Subtracting and saving of pixel coordinates in excel file

To outline the procedure explained above, an example is given in Figure 25 where the right and left thigh measurements and their locations are explained for Person-10 front silhouette. The procedure steps followed are described in detail below:

#### Right Thigh

- \* Point A possesses the pixel coordinates (77,286).
- \* 77 is the value in Cell B3678 and 286 is the value in Cell C3678.
- \* What we understand from Point A is that the right thigh measurement starts from 77 pixels from the horizontal (left) and 286 pixels from the vertical (top) of the front silhouette.
- \* Point B possesses the pixel coordinates (135,286).
- \* 135 is the value in Cell B3679 and 286 is the value in Cell C3679.
- \* What we understand from Point B is that the right thigh measurement ends at 135 pixels from the horizontal (left) and 286 pixels from the vertical (top) of the front silhouette.
- \* The horizontal pixel difference for the right thigh is then  $135 - 77 = 58$  pixels.

#### Left Thigh

- \* Point C possesses the pixel coordinates (149,286).
- \* 149 is the value in Cell B3684 and 286 is the value in Cell C3684, where the left thigh measurement starts from 149 pixels from the horizontal (left) and 286 pixels from the vertical (top) of the silhouette.

- \* Point D has the pixel coordinates (207,286).
- \* 207 is the value in Cell B3685 and 286 is the value in Cell C3685, where the left thigh measurement ends at 207 pixels from the horizontal (left) and 286 pixels from the vertical (top) of the silhouette.
- \* The horizontal pixel difference for the left thigh is then  $207 - 149 = 58$  pixels.

The same procedure followed for obtaining the number of pixels for right and left thighs is successfully applied to the other horizontal body measurements considered in this research, which are the neck, shoulder, chest, belly, waist, and hip. Figure 26 demonstrates the starting and ending pixel coordinates and their locations obtained for Person-10 front and side sharp silhouettes with the new developed software PixelList 1.0. The list of the starting and ending pixel coordinates and the number of pixels in between the feature points obtained by subtracting processes for Person-10 front and side silhouettes is provided in Table 1

In the succeeding sections of this manuscript, the handling of E and J columns will be described.

In Table 1, biceps is not included because this measurement needed some more investigation on it and the studies done will be explained below. In Figure 26, it is noted the pixel coordinates of the right biceps start at (51,111) and end at (81,111) and the pixel coordinates of the left biceps start at (197,116) and end at (228,116). As described in the subtracting process the horizontal difference in number of pixels is 30 for the right biceps and 31 for the left biceps. At this point, attention has to be paid that this is the horizontal number of pixels, however, the arms are slightly open, this number of pixels obtained in this case is larger than the real number of pixels. There is a must to calculate the number of pixels perpendicular to the arm side, so the work done is explained in detail below..



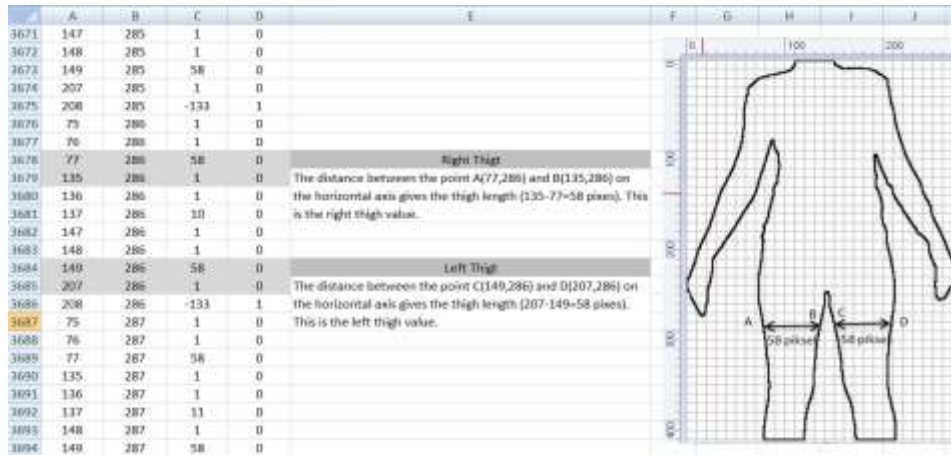


Figure 25. Right and left thigh measurements and locations for Person-10 front silhouette

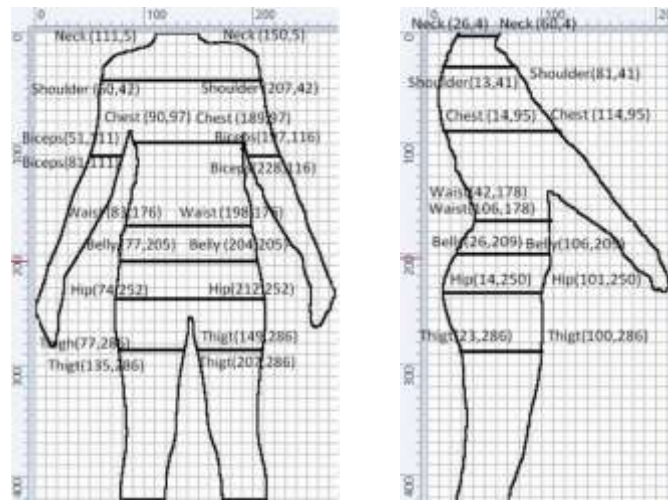


Figure 26. Starting and ending pixel coordinates and locations for Person-10 front and side silhouettes with the new developed software PixelList 1.0

Table 1. List of starting and ending pixel coordinates and number of pixels in between the feature points obtained by subtracting process for Person-10 front and side silhouettes, except biceps

Pixel Study	Front				Difference (Number of pixels)	Side				Difference (Number of pixels)
	Coordinate Starting Right		Coordinate Ending Left			Coordinate Starting Back		Coordinate Ending Front		
Column Name	A	B	C	D	E	F	G	H	I	J
Location	Horizontal	Vertical	Horizontal	Vertical	(C - A)	Horizontal	Vertical	Horizontal	Vertical	(H - F)
Neck	111	5	150	5	39	26	4	60	4	34
Shoulder	60	42	207	42	147	13	41	81	41	68
Chest	90	97	189	97	99	14	95	114	95	100
Waist	83	176	198	176	115	42	178	106	178	64
Belly	77	205	204	205	127	26	209	106	209	80
Hip	74	252	212	252	138	14	250	101	250	87
Thigh-Right	77	286	135	286	58	23	286	100	286	77
Thigh-Left	149	286	207	286	58	None	None	None	None	None

The main logic here is the consideration of the horizontal number of pixels as the hypotenuse of a right angle. To support this consideration, the mathematical model is defined to calculate the distance between two points A and B where  $|AB|$  is meant to be the hypotenuse. The points A  $(x_1, y_1)$  and B  $(x_2, y_2)$  on a coordinate plane are shown in Figure 27 and the equation to calculate the distance

between them is given in Equation 1 [18]. The number of pixels between the points B and C in Figure 28 will then be calculated with Equation 1. In this case GeoGebra is taken advantage of [19].

$$|AB| = \sqrt{(x^2 - x^1)^2 + (y^2 - y^1)^2} \quad (1)$$

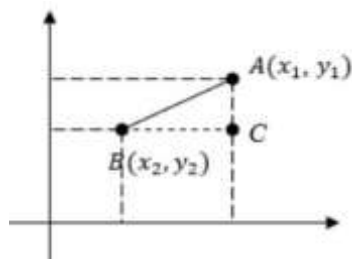


Figure 27. Points A and B on a coordinate plane to calculate the distance between them

GeoGebra is a dynamic mathematics software that combines geometry, algebra, and analysis [19]. With GeoGebra, the number of pixels perpendicular to the arm side, represented with points B and C in Figure 28, is reached. Another advantage of GeoGebra is that it can mark the points on the silhouette line of a silhouette and it is additionally shown in Figure 29 for Person-10 front and side silhouettes. In the same figure the illustrative horizontal reading of the biceps and the perpendicular drawing on the arm sides can also be seen.

Taking a closer look at Figure 28, marking Point A at the outer side of the arm with pixel coordinates (51,111) and Point B at the inner side of the arm with pixel coordinates (81,111) can clearly be seen connected horizontally, the number of pixels being 30. Two imaginary parallel lines are drawn including the biceps region of the arm and consequently a perpendicular line intersecting Point B is drawn, leading to Point C appearing where the perpendicular line intersects the outer side of the arm. The pixel coordinates of Point C are (53.1, 118.66) as obtained from the GeoGebra. Now the desired number of pixels in the line segment |BC| can be calculated from Equation 1 which comes out to be 28.93 pixels.

$$|BC| = \sqrt{(81 - 53,1)^2 + (118,66 - 111)^2}$$

$$|BC| = \sqrt{(27,9)^2 + (7,66)^2}$$

$$|BC| = 28,93 \text{ pixels}$$

Since the calculated biceps size is 28.93 pixels perpendicular and was 30 pixels from the pixel coordinates horizontal, the difference is  $30 - 28.93 = 1.07$  pixels which makes 3.567 % deviation. This difference may be higher according to the horizontal position of the arm. Some profound work will be carried on to determine up to which pixel difference or angle of the arm horizontal position will give a reliably negligible result and after then the pixel value perpendicular to the arm will be calculated with the distance equation (Equation 1) for large differences for further research.

In the later sections of this research, biceps measurement will not be included because of the problem encountered which requires profound work that may be the subject of another manuscript.

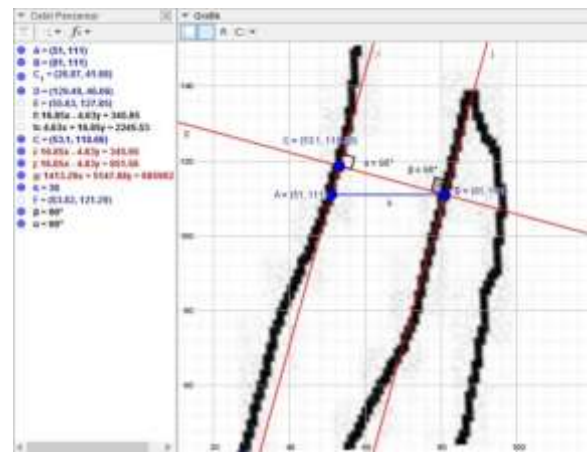


Figure 28. Drawing of number of pixel calculation of biceps measurement for Person-10 with GeoGebra [19]

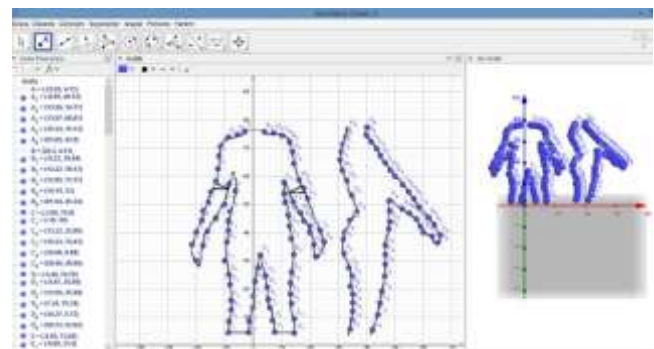


Figure 29. Marking the points on the silhouette line of Person-10 front and side silhouettes with GeoGebra [19]

### 3.1.2 Determining Pixel Coordinates for Body Measurements Feature Points with PyNGF-2

Even the pixel coordinates are successfully acquired with the new developed software PixelList 1.0, they also need to be verified with another computer software to prove functioning right. In this case another new software in Python programming language named PyNGF-2 is used, which included Python Imaging Library, Pillow, OpenCV, Python, Matplotlib and Xlsxwriter libraries. The new developed software PyNGF-2 constitutes of “settings.py” (Figure 30), “body\_region.py” (Figure 31), and “run.py” files (Figure 32). In the “setting.py” file, the ranges of pixel coordinates of all body measurements in the horizontal and vertical directions are defined. In the “body\_region.py” file, the names of the body measurements and the minimum (exp. waist) or the maximum (exp. hip) decision of that measurement in the “settings.py” region definition is defined. The “run.py” file runs PyNGF-2 software from the terminal.

For determining the feature points, the new developed software PyNGF-2 demands the horizontal and vertical regions to be defined in pixel coordinates, in order for it to find the maximum or the minimum horizontal distance in number of pixels in-between. For example, in Figure 33, an enlarged front neck drawing is represented. The

horizontally defined region is in between 100 and 200 pixels, and the vertically defined region is in between 5 and 10 pixels. Similarly, in Figure 34, an enlarged side neck drawing is represented. The horizontally defined region is in between 11 and 80 pixels, and the vertically defined region is in between 0 and 20 pixels. When the “run.py“ is run then PyNGF-2 finds the pixel coordinates for the beginning and ending points of the minimum horizontal distance of the feature point, front and side neck in this case. This pixel coordinates of the beginning and ending points of the minimum horizontal distance is in-between the defined horizontal and vertical regions. Similarly, in a different case, the pixel coordinates of the beginning and ending points of the maximum horizontal distance can be found with “run.py”.

The horizontal and vertical regions for neck, shoulder, chest, waist, belly, hip, thigh-right, and thigh-left are defined in the new developed software PyNGF-2 for Person-10 front and side body silhouettes. The list for the pixel coordinates of these horizontal body measurements are provided in Table 2. The “Regarding” column in Table 2 is whether that horizontal body measurement will be assessed as the minimum or the maximum distance in between the beginning and ending coordinates.

Consequently, PyNGF-2 is run with the “run.py“ and it gives the list of the beginning and ending pixel coordinates of the feature points either minimum or maximum, also marking their locations on the front and side body silhouette as seen in Figure 35.

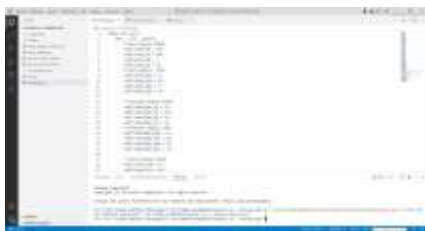


Figure 30. “settings.py” file in new developed software PyNGF-2



Figure 31. “body\_region.py” file in new developed software PyNGF-2



Figure 32. “run.py” file in new developed software PyNGF-2

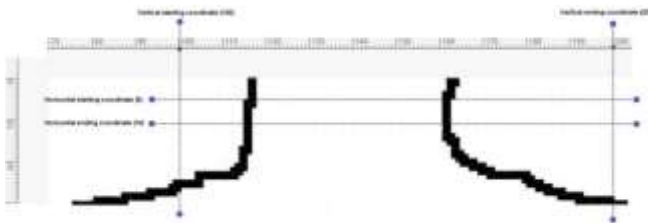


Figure 33. Enlarged front neck drawing for definition of horizontal and vertical regions

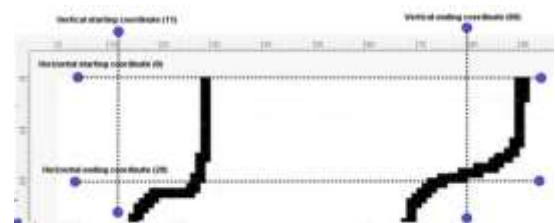


Figure 34. Enlarged side neck drawing for definition of horizontal and vertical regions

Table 2. Defined pixel coordinates of horizontal and vertical regions for horizontal body measurements in new developed software PyNGF-2 for Person-10 front and side body silhouettes

Horizontal Body Measurement	Regarding	Front				Side			
		Horizontal (x)		Vertical (y)		Horizontal (x)		Vertical (y)	
		Defined beginning pixel coordinates	Defined ending pixel coordinates	Defined beginning pixel coordinates	Defined ending pixel coordinates	Defined beginning pixel coordinates	Defined ending pixel coordinates	Defined beginning pixel coordinates	Defined ending pixel coordinates
Neck	Minimum	100	200	5	10	11	80	0	20
Shoulder	Maximum	60	239	30	44	11	82	30	42
Chest	Maximum	55	219	97	110	1	118	61	97
Waist	Minimum	72	217	176	182	20	136	175	180
Belly	Minimum	64	240	200	210	22	129	148	210
Hip	Maximum	56	248	248	260	9	129	250	260
Thigh Right	Maximum	50	135	286	320	20	128	286	320
Thigh Left	Maximum	140	220	286	320	20	128	286	320

Person 10. Front Pixel Coordinates		
Regions	Beginning Coordinate (x <sub>0</sub> , y <sub>0</sub> )	Ending Coordinate (x <sub>1</sub> , y <sub>1</sub> )
Neck	(111, 5)	(150, 5)
Shoulder	(60, 42)	(207, 42)
Chest	(90, 97)	(189, 97)
Biceps_right	(51, 111)	(81, 111)
Biceps_left	(197, 116)	(228, 116)
Waist	(83, 176)	(198, 176)
Belly	(77, 205)	(204, 205)
Hip	(74, 252)	(212, 252)
Thigh_right	(77, 286)	(135, 286)
Thigh_left	(149, 286)	(207, 286)

Person 10. Side Pixel Coordinates		
Regions	Beginning Coordinate (x <sub>0</sub> , y <sub>0</sub> )	Ending Coordinate (x <sub>1</sub> , y <sub>1</sub> )
Neck	(26, 4)	(60, 4)
Shoulder	(13, 41)	(81, 41)
Chest	(14, 95)	(114, 95)
Biceps_right	None	None
Biceps_left	None	None
Waist	(42, 178)	(106, 178)
Belly	(26, 209)	(106, 209)
Hip	(14, 250)	(101, 250)
Thigh_right	(23, 286)	(100, 286)
Thigh_left	None	None

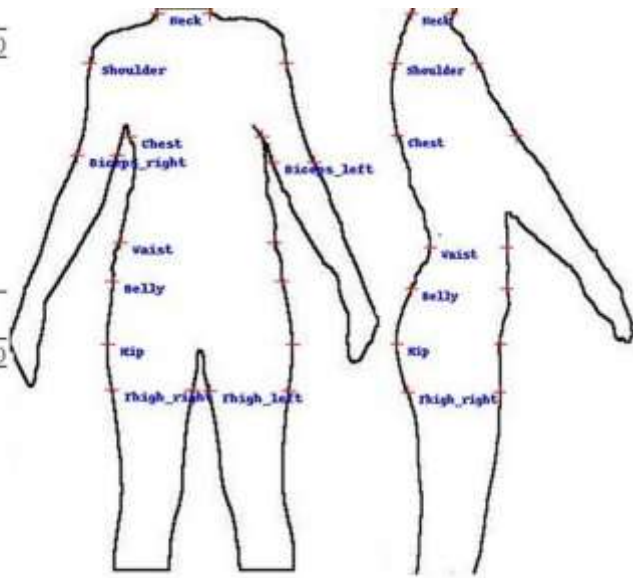


Figure 35. List of the beginning and ending pixel coordinates of feature points and locations for Person-10 front and side body silhouettes obtained from ne developed software PyNGF-2

### 3.2 Experimenting with Different Mathematical Models to Reach Body Measurements

In this section, it is experimented with different mathematical models to obtain 3D measurements from 2D measurements to reach the closest to the manually taken body measurements. To start with, the manual body measurements and the pixel coordinates (and their differences) of feature points for Person-10 front and side silhouettes obtained from both of the new developed softwares PixelList1.0 and PyNGF-2, which are the same, are presented in Table 3. In the table, the manual body measurements are in centimeters and the front and the side “Horizontal Difference Pixel” columns in Table 3 are the differences of the beginning and ending horizontal pixel coordinates, and their absolute values are written in these columns. For example, the neck measurement is calculated

according to pixel coordinates beginning at (x<sub>1</sub>=111, y<sub>1</sub>=5) and ending at (x<sub>2</sub>=150, y<sub>2</sub>=5), where the absolute value of the difference |x<sub>1</sub>-x<sub>2</sub>|=|111-150|=39 pixels, giving the horizontal distance front. Similarly, for the side, the neck measurement is calculated according to pixel coordinates beginning at (x<sub>1</sub>=26, y<sub>1</sub>=4) and ending at (x<sub>2</sub>=60, y<sub>2</sub>=4), where the absolute value of the difference |x<sub>1</sub>-x<sub>2</sub>|=|26-60|=34 pixels, giving the horizontal distance side. For the vertical pixel coordinates, the same sequence can be followed but since they are at the same vertical coordinate, the difference will be zero, so they are not included in Table 3. The same sequence of taking the differences is done for every neck, shoulder, chest, waist, belly, hip, thigh-right, and thigh-left horizontal body measurement and the results are presented in Table 3.

Table 3. Manual body measurements and the same pixel coordinates (and their differences) of feature points for Person-10 front and side silhouettes obtained from both of the new developed softwares PixelList1.0 and PyNGF-2

Body Measurements	Manual Measurement and 2D Measurement (Person-10)				2D coordinates Side (pixels)		
	Manuel Measurement (cm)	Beginning coordinates (x <sub>1</sub> ,y <sub>1</sub> )	Ending coordinates (x <sub>2</sub> ,y <sub>2</sub> )	Horizontal difference pixel  x <sub>1</sub> -x <sub>2</sub>	Beginning coordinates (x <sub>1</sub> ,y <sub>1</sub> )	Ending coordinates (x <sub>2</sub> ,y <sub>2</sub> )	Horizontal difference pixel  x <sub>1</sub> -x <sub>2</sub>
Neck Circumference	31,5	111, 5	150, 5	39	26, 4	60, 4	34
Shoulder Circumference	88	60, 42	207, 42	147	13, 41	81, 41	68
Chest Circumference	87	90, 96	191, 96	101	15, 94	114, 94	99
Waist Circumference	71	83, 176	198, 176	115	41, 177	106, 177	65
Belly Circumference	78	77, 205	204, 205	127	26, 209	106, 209	80
Hip Circumference	93	74, 245	211, 245	137	14, 250	101, 250	87
Thigh right Circumference	55	77, 286	137, 286	60	23, 285	100, 285	77
Thigt left Circumference	55	149, 286	209, 286	60	23, 285	100, 285	77

The manual body measurements, the front number of pixels values and the side number of pixels values are all obtained now. The next step is to determine accurately which circumference formula, circle, ellipse, or hippodrome, will be used to obtain results as close to the manual body measurements because acquisition of the appropriate circumference formula is very important for the accurate calculation of the circumferential 3D body measurements. Neck circumference of Person-10 is chosen as an example and the calculations are explained in detail using the three formulas below:

### 3.2.1 Calculation with Circle Circumference Formula

The circumference equation of a circle is given in Equation 2. From the information in Table 3, the diameter of neck is 39 pixels in the front silhouette and 34 pixels in the side

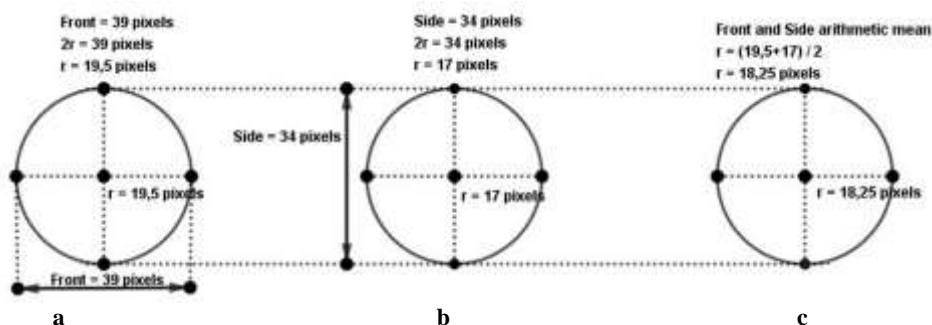
Circle Circumference =  $2\pi r$

$$a = \frac{\text{Front}}{2} = \frac{39}{2} = 19,5 \text{ pixels} \quad \text{and} \quad b = \frac{\text{Side}}{2} = \frac{34}{2} = 17 \text{ pixels}$$

$$r = \frac{(a + b)}{2} = \frac{19,5 + 17}{2} = 18,25 \text{ pixels}$$

$$\text{Neck Circumference} = 2\pi r = 2 \cdot \pi \cdot (18,25) = 114,668 \text{ pixel}$$

(2)



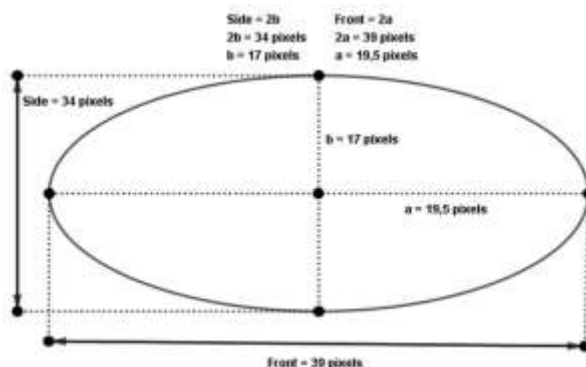
**Figure 36.** Neck circumference calculation with a circle formula, a) Radius calculation in front silhouette, b) Radius calculation in side silhouette, c) Radius calculation from the arithmetic mean of front and side silhouettes

$$\text{Ellipse Circumference} = \pi [(3a + 3b) - \sqrt{(a + 3b)(3a + b)}]$$

(3)

$$\text{Neck Circumference} = \pi [(3 \cdot (19,5) + 3(17)) - \sqrt{(19,5 + 3 \cdot (17))(3 \cdot (19,5) + 17)}]$$

$$\text{Neck Circumference} = 114,803 \text{ pixel}$$



**Figure 37.** Neck circumference calculation with an ellipse formula

silhouette. However, the circle circumference equation involves only one diameter. So, the arithmetic mean of the front and side silhouettes' diameters is calculated and the radius is found, as seen below and in Figure 36. The neck circumference is calculated as 114,668 pixels.

### 3.2.2 Calculation with Ellipse Circumference Formula

The circumference equation of an ellipse is given in Equation 3 where the major (2a) and minor (2b) diameters are indicated. From the information in Table 3, the major diameter of the neck is 39 pixels in the front silhouette and the minor 34 pixels in the side, so, "a" is 19,5 pixels and "b" is 17 pixels. By applying Equation 3, neck circumference is calculated as 114,803 pixels, as seen below and in Figure 37.

### 3.2.3 Calculation with Hippodrome Circumference Formula

The circumference equation of a hippodrome is as in Equation 4 where there are two semicircles of the same radius on the right and left sides of the hippodrome and two straight lines above and below connecting them, as seen in Figure 38. From the information in Table 3, looking at the side silhouette, the diameter of the semicircles is 34 pixels, radius being 17 pixels, and similarly, looking at the front silhouette, the distance between the beginning and ending points is 39 pixels, which constitutes of the radii of the two semicircles and the gap (x) in between which can be written as  $x+2r=39$ . "x" is calculated as  $(39-2(17))=5$  pixels which is the gap in between the semicircles and connected with two straight lines above and below. Using these values and Equation 4, neck circumference is calculated as 116,814 pixels.

$$\text{Hippodrome Circumference} = 2\pi r + 2(\text{Front} - \text{Side}) \quad (4)$$

$$r = \frac{\text{Side}}{2} = \frac{34}{2} = 17 \text{ pixels}$$

$$x = \text{Front} - \text{Side} = 39 - 34 = 5 \text{ pixels}$$

$$\text{Neck Circumference} = 2\pi r + 2x = 2 \cdot \pi \cdot 17 + 2 \cdot 5 = 116,814 \text{ pixels}$$

Putting together, the different circumference formulas, circle results 114,668 pixels, ellipse 114,803 pixels, and hippodrome 116,814 pixels for the neck circumference. The remaining seven horizontal body circumferences for Person-10 are also calculated with the three different formulas and results in number of pixels are presented in Table 4. Chest circumference results in the table are very close to each other and some results are even the same for each circumference equation. The other horizontal body measurements have differences ranging between 2-34 pixels.

### 3.3 Calculation of conversion coefficient "C" values

Momentarily there is a demand to resolve how much is a pixel in centimeters. A conversion coefficient named "C" is determined, which is simply in the unit of cm/pixel. "C"

conversion coefficient is the division of the manual horizontal body measurement circumference in centimeters to the number of pixels obtained from the three different circumference formulae. Examples of background removed images and silhouettes for Person-9, Person-10, Person-14, and Person-311 in Figures 39-42, respectively, are given.

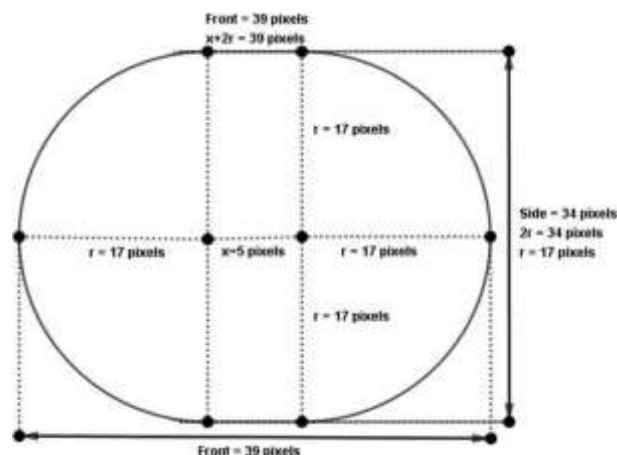


Figure 38. Calculation with a hippodrome formula (Neck example)

In Table 5, the results of each eight horizontal body measurement calculated for Person-9 with circle, ellipse and hippodrome equations is presented, including the manually taken measurement of the same studied one. The calculation results are first given in pixel unit, then divided by the manual measurement to reach "C" values in cm/pixel unit.

29 more volunteers front and side images are chosen to reach the total of 30. In order to chose random volunteers numbered in our SPSS folder, Random Sample command is run and the images of those volunteers are processed for the calculation of "C" values and accuracy rates. In Figure 43 the total 30 front silhouettes are presented, and in Figure 44, their side silhouettes.

Table 4. Horizontal body measurement circumferences in number of pixels calculated with three different formulas for Person-10

Pixel values calculated from 3 different equations for Person-10			
Body Measurements	Circle	Ellipse	Hippodrome
Neck Circumference	114,668	114,803	116,814
Shoulder Circumference	337,721	349,218	371,628
Chest Circumference	314,159	314,167	315,017
Waist Circumference	282,743	288,224	304,203
Belly Circumference	325,155	329,359	345,327
Hip Circumference	351,858	356,255	373,318
Thigt Right Circumference	215,199	216,028	207,902
Thigt Left Circumference	215,199	216,028	207,902

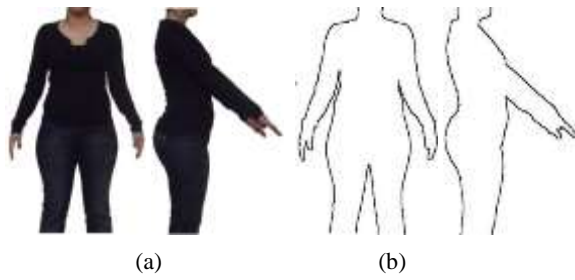


Figure 39. Person-9, a) Background removed image, b) Silhouette

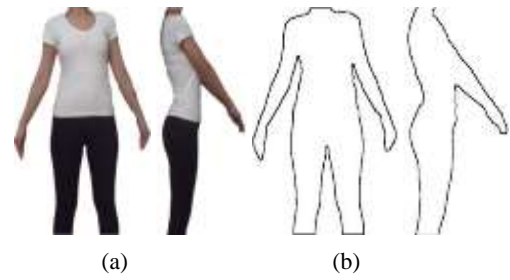


Figure 40. Person-10, a) Background removed image, b) Silhouette

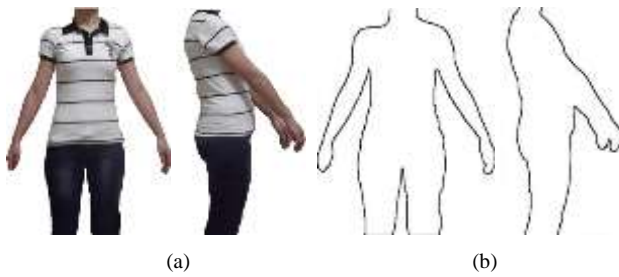


Figure 41. Person-14, a) Background removed image, b) Silhouette



Figure 42. Person-311, a) Background removed image, b) Silhouette

Table 5. Person-9 – Manual measurements, calculated circumference measurements and C values

Manual Measurement and 2D Measurement (Person-9)									
Body Measurement	Manuel Measurement (cm)	2D resulting measure Front (pixels)	2D resulting measure Side (pixels)	Circumference of the Circle (pixel)	Result Circle Equation "C" (cm/pixel)	Circumference of the Ellipse (pixel)	Result Ellipse Equation "C" (cm/pixel)	Circumference of the Hippodrom (pixel)	Result Hippodrome Equation "C" (cm/pixel)
Neck Circum.	30,8	43	46	139,801	0,220	139,840	0,220	138,513	0,222
Shoulder Circum.	88,0	153	69	348,716	0,252	361,312	0,244	384,770	0,229
Chest Circum.	88,0	109	110	344,004	0,256	344,006	0,256	343,575	0,256
Waist Circum.	76,0	128	97	353,429	0,215	355,108	0,214	366,734	0,207
Belly Circum.	86,5	145	113	405,265	0,213	406,825	0,213	419,000	0,206
Hip Circum.	105,0	157	112	422,544	0,248	425,505	0,247	441,858	0,238
Thigt Right Circum.	60,5	61	77	216,770	0,279	217,499	0,278	209,902	0,288
Thigt Left Circum.	60,5	58	77	212,057	0,285	213,109	0,284	203,902	0,297

For each 30 different front and side images, tables like Table 5 are prepared and stored in an excel file. There are totally 720 "C" values obtained because there are 3 different equations, 8 different body measurements, and 30 different front and side images. The "C" values are also entered into the IBM SPSS Statistics (v23) Package Program. The objective here is to determine a common "C" value to be used confidentially for each body measurement

[20]. In Table 6, the overall average "C" value, average "C" values and their standard deviations for each circle, ellipse, and hippodrome circumference equations are depicted for each horizontal body measurement studied in this research.

As depicted in Table 6, the overall average "C" value is 0.25865 cm/pixel, including every body measurement and every equation. Ranges can be listed as :



Figure 43. Total 30 front silhouettes



Figure 44. Total 30 side silhouettes



**Table 6.** Overall average “C” value, average “C” values and their standard deviations for each circle, ellipse, and hippodrome circumference equations

n = 30	Overall Average “C”	Average “C”	Circle Equation “C”		Ellipse Equation “C”		Hippodrome Equation “C”	
			Average “C”	S.D. “C”	Average “C”	S.D. “C”	Average “C”	S.D. “C”
Neck Circumference	0,25865	0,2601	0,2609	0,0273	0,2606	0,0273	0,2588	0,0272
Shoulder Circumference	0,25865	0,2788	0,2887	0,0304	0,2816	0,0294	0,2660	0,0277
Chest Circumference	0,25865	0,2716	0,2725	0,0266	0,2722	0,0265	0,2702	0,0257
Waist Circumference	0,25865	0,2401	0,2443	0,0191	0,2425	0,0187	0,2335	0,0176
Belly Circumference	0,25865	0,2250	0,2294	0,0222	0,2273	0,0218	0,2181	0,0205
Hip Circumference	0,25865	0,2577	0,2636	0,0241	0,2605	0,0235	0,2490	0,0222
Thigt right Circumference	0,25865	0,2682	0,2667	0,0251	0,2662	0,0251	0,2716	0,0258
Thigt left Circumference	0,25865	0,2680	0,2665	0,0254	0,2661	0,0254	0,2713	0,0262

	Range	
	Low	High
Average “C” value	0,225 belly circumference	0,2788 shoulder circumference
Circle equation average “C” value	0,2294 (0,0222) belly circumference	0,2887 (0,0304) shoulder circumference
Ellipse equation average “C” value	0,2273 (0,0218) belly circumference	0,2816 (0,0294) shoulder circumference
Hippodrome equation average “C” value	0,2181 (0,0205) belly circumference	0,2716 (0,0258) thigh-right circumference

It is important to point that the low values are for belly circumference and the high values are for shoulder circumference except hippodrome equation being thigh-right circumference. It is evaluated that this indicates the way the photograph is taken because it was focused on the belly, and the shoulders and the thighs are almost equal distance away from the belly.

In Table 7 the descriptive statistics for the total 720 “C” values and separately 240 “C” values obtained from each circle, ellipse, and hippodrome equation. Statistical analyses descriptive statistics, histograms, *t*-tests, ANOVA, and correlation are processed, and in the light of the information reached, it is concluded that applying the ellipse equation and its “C” value 0.2596 cm/pixel is appropriate to be used for the rest of the research. For example, as seen in Table 7, the “C” value of the ellipse equation is the closest to the total average of “C” values, standard error of mean is the least, the least mode is the

closest to its average, standard deviation is the least, and ranges is the least.

### 3.4 Accuracy Rates of Calculated 3D Horizontal Body Measurements

The 3D horizontal body measurements are calculated from the 2D front and side silhouettes in pixels accordingly with the acquisition of the ellipse equation and “C” value 0.2596 cm/pixel, for each 30 volunteer’s images. The calculated 3D body measurements and the manually taken horizontal body measurements are proportioned and their accuracy rates are attained. An example of the results is provided in Table 8 for Person-10, but also prepared for 30 of them.

In Table 9, the average accuracy rates and their standard deviations for ellipse circumference equation are depicted for each horizontal body measurement studied in this research.

**Table 7.** Descriptive statistics of both total “C” values and each different circumference equation

Descriptive Statistics					
		Total “C” value	Circle equation “C” value	Ellipse equation “C” value	Hippodrome equation “C” value
N	Valid	720	240	240	240
	Missing	0	480	480	480
Mean		,25865	,26156	,25960	,25479
Std. Error of Mean		,001119	,001938	,001894	,001962
Median		,25900	,26150	,26000	,25550
Mode		,265	,244 <sup>a</sup>	,256 <sup>a</sup>	,240 <sup>a</sup>
Std. Deviation		,030017	,030025	,029349	,030389
Variance		,001	,001	,001	,001
Skewness		,043	,113	,054	-,016
Std. Error of Skewness		,091	,157	,157	,157
Kurtosis		-,075	,069	-,039	-,269
Std. Error of Kurtosis		,182	,313	,313	,313
Range		,177	,167	,158	,164
Minimum		,174	,184	,182	,174
Maximum		,351	,351	,340	,338

a. Multiple modes exist. The smallest value is shown



**Table 8.** Calculation of 3D horizontal body measurements from 2D silhouettes in pixels and their accuracy rates for Person-10

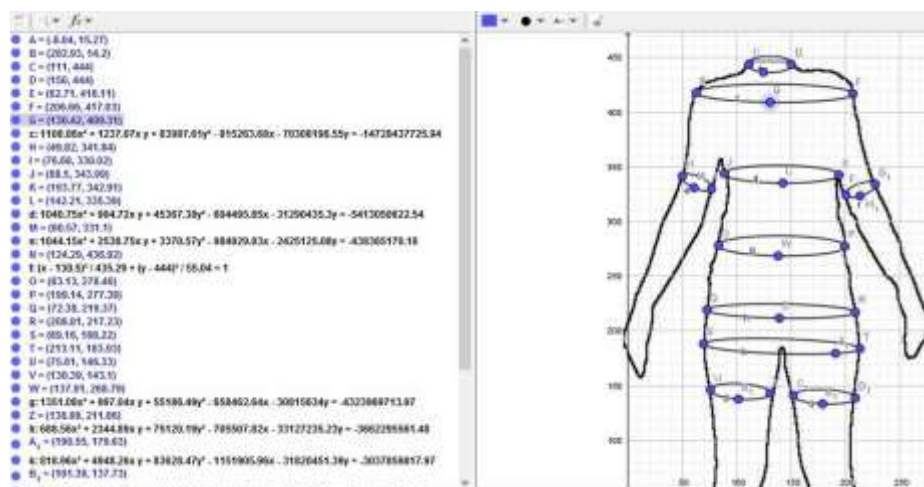
Manual measurements and calculated 3D measurements (Person-10)							
Body Measurement	Manuel Measurement (cm)	2D resulting measure Front (pixels)	2D resulting measure Side (pixels)	Accepted "C" (cm/pixel)	Circumference of the Ellipse (pixels)	3D Calculated Body Measurements (cm)	Accuracy rate (%)
Neck Circumference	31,5	39	34	0,2596	114,803	29,803	94,612
Shoulder Circumference	88,0	147	68	0,2596	349,218	90,657	97,069
Chest Circumference	87,0	101	99	0,2596	314,167	81,558	93,745
Waist Circumference	71,0	115	65	0,2596	288,224	74,823	94,891
Belly Circumference	78,0	137	87	0,2596	329,359	85,502	91,226
Hip Circumference	93,0	60	77	0,2596	356,255	92,484	99,445
Right Thigt Circumference	55,0	60	77	0,2596	216,028	56,081	98,073
Left Thigt Circumference	55,0	39	34	0,2596	216,028	56,081	98,073
Mean							95,892

**Table 9.** Average accuracy rates and their standard deviations for ellipse circumference equation

n = 30	Average Accuracy Rate	Ellipse Equation Accuracy Rate	
		Average Accuracy Rate	S.D. Accuracy Rate
Neck Circumference	91,585	91,9608	5,5842
Shoulder Circumference	91,585	90,0846	6,3849
Chest Circumference	91,585	91,4983	5,1788
Waist Circumference	91,585	92,5595	6,2919
Belly Circumference	91,585	87,2962	7,9568
Hip Circumference	91,585	93,7104	5,5937
Thigt right Circumference	91,585	92,9292	5,4542
Thigt left Circumference	91,585	92,6384	5,1968

As depicted in Table 9, the average accuracy rate is 91.585%, including every body measurements. With a closer look, the average accuracy rate ranges between 87,2962% (7,9568%) for belly circumference – 93,7104% (5,5937%) for hip circumference. It is important to point that it is again the belly circumference for the lowest value, however, for the highest value it is the hip circumference.

Additionally, the ellipse formula is entered into GeoGebra and with the conversion coefficient “C” 0.2596 cm/pixel, the circumferences of the horizontal body measurements studied in this research are estimated for Person-10 front silhouette, where the results revealed to be the same. An example is given in Figure 45.



**Figure 45.** Elliptical circumference estimation of horizontal body measurements for Person-10 with GeoGebra

#### 4. CONCLUSION

In the field of e-shopping, textiles, especially apparel, found itself a good area of retail. When an apparel is purchased via e-shopping, a consumer may be encountering the unfit problem of the garment. Body measurements are one of the most important data in apparel making. With the rapid improvement of technology, body scanning technologies are developed to obtain body measurements quickly, easily, and more precisely, also aiming to get over the unfit problem, but the generalized sizes are still limiting them. Besides, manually or with these body scanners, human body is still needed to obtain body measurements. In the light of these information, it is thought of a method where the need for the body to take body measurements is eliminated, instead, to obtain 3D body measurements from 2D photographs from front and side is used. Consequently, made-to-fit apparel like tailor sense is realized, unfit problem in online-shopping is solved, leading to much more easier and extensive e-shopping, with less costs.

In this research, pixel coordinates for obtaining 3D body measurements from 2D front and side images is presented. Photographs from front and side are used to quickly and accurately obtain the 3D horizontal body measurements which are neck, shoulder, chest, waist, belly, hip, thigh-right, and thigh-left circumferences from 2D silhouettes. These feature points are marked, and the number of pixels in between the marked feature points are determined with the new developed softwares PixelList1.0 and PyNGF-2 for verification, both resulting the same number of pixels. Once the numbers of pixels are determined for 2D front and side silhouettes, they are experimented with different mathematical models to reach the 3D circumferential body measurements. In literature, the mathematical models for circle and ellipse circumference are used, unlike others, hippodrome circumference equation is introduced in this research, and all three, circle, ellipse, and hippodrome circumference equations are applied to reach the 3D body measurements for each eight horizontal body measurement studied. The results are in pixels but the manually taken body measurements are in centimeters, to convert pixels to the unit of centimeters, a conversion coefficient "C" is introduced which is the division of manually taken body measurement to the number of pixels, its unit becomes

cm/pixel . "C" is statistically analyzed, and is concluded that 0.2596 cm/pixel is an appropriate value to be used. On the other hand it is concluded that the ellipse circumference equation is the appropriate one to be used.

A comparison of the 3D body measurements obtained from 2D images in pixels converted to centimeters and the real manually taken body measurements in centimeters is proceeded and an accuracy rate is calculated to see the how precise the model is functioning. The overall accuracy rate average is 91.585 % which is concluded to be very strong. Statistical analysis proves that the work done in this research is operative for obtaining 3D body measurements from 2D images especially serving for e-shopping with measurement accuracy rate 91.585 % .

Furthermore, the advantages of this research are listed as follows:

- Extra cost-effective than 3D body scanning systems,
- Elimination of the need for person's body to take body measurements,
- Available for personalized body measurements,
- Solution to the unfit problem in online shopping.

Future work will be done with the rest of the available photographs [2,3], acquiring a sharp silhouette for determining the pixel coordinates, finding the body measurements feature points with PixelList 1.0, validating with PyNGF-2, a broader work for the conversion coefficient "C", with the ellipse circumference equation obtaining the 3D body measurements and comparing them with the manually taken body measurements. On the other hand, the conversion coefficient concluded 0.2596 cm/pixel in this research will be assessed if it reaches the correct manually taken body measurements in the rest of the photographs within the accuracy rate of 91.585 % . Vertical body measurements will also be considered. Biceps measurement will be calculated profoundly to determine the angle of the arms with the horizontal. In this research, only the ladies aged 18-25 are studied but in future work different age intervals will also be considered and compared, pointing to male gender, and behavior of the same research in different nations will also be investigated.

#### REFERENCES

1. Turkish Statistical Institute (TÜİK), (2021). [https://data.tuik.gov.tr/Bulten/Index?p=Hanehalki-Bilisim-Teknolojileri-\(BT\)-Kullanim-Arastirmasi-2021-37437](https://data.tuik.gov.tr/Bulten/Index?p=Hanehalki-Bilisim-Teknolojileri-(BT)-Kullanim-Arastirmasi-2021-37437)
2. Eren, R.C. and Güngör, A. (2013). "A Different Method for Reaching Body Measurements", Graduation Project, Uşak University, Faculty of Engineering, Department of Textile Engineering, Uşak, Supervisor: Doctoral Lecturer Nefise Gönül ŞENGÖZ (received support from TÜBİTAK 2209-A-2012-1), p.3-16.
3. Şengöz, N.G, Eren, R.C. and Güngör, A., 2017. "Development of a Method for Obtaining Body Measurements from Two-Dimensional Images", IITAS-2017 XIV. International Textile and Apparel Symposium, p.109-112, İzmir.
4. Sen Kılıc, A. & Öndogan, Z. (2016). Evaluating And Defining Body Measurements According To Anthropometric Measurement Technique For Lower Garment Pattern Preparation. *Tekstil ve Konfeksiyon*, 26(1), 109-116. <https://dergipark.org.tr/tr/pub/tekstilvekonfeksiyon/issue/23651/251944>

5. Bayraktar, F. (2007). "Setting the standardization for body size to be employed in the production of ready-made apparel for plus size women". Gazi University, Institute of Educational Sciences, Department of Clothing Industry and Fashion Design Education. PhD thesis, Ankara, p.63-75.
6. Eğri, Ş. (2011). "A Case Study on The Problems Encountered in Three-Dimensional Body Scanning Systems (Kardem and İma example)". Master's thesis, Ankara, p.44-58.
7. Gu, B., Liu, G. and Xu, B., (2017). "Individualizing Women's Suit Patterns Using Body Measurements From Two-dimensional Images", *Textile Research Journal*, Vol.87, Issue 6, p.669-681
8. Guerlain, Ph., Durand B., (2006). "Digitizing and Measuring of the Human Body for the Clothing Industry", *International Journal of Clothing Science and Technology*, Vol. 18 Issue: 3, p.151-165.
9. Öndoğan. Z., Pamuk, O., Topal, E. (2007). "Investigation of Simulation Systems in Clothing Design, Body Measurement and Clothing Marketing", *Tekstil ve Konfeksiyon* 4/2007, p.265-272.
10. Pargas, P.R., Staples, J.N., Davis, J.S. (1997). *Automatic Measurement Extraction for Apparel from a 3 Dimensional Body Scan*, Elsevier Science Limited, p. 157-172, USA.
11. Hung P.C., Channa P. Witana, and Ravindra S. Goonetilleke, (2004). "Anthropometric Measurements from Photo graphic Images", *Human Performance Laboratory, Department of Industrial Engineering and Engineering Management, Hong Kong University of Science and Technology, ClearWater Bay, Hong Kong. Work with Computing Systems 2004*. H.M. Khalid, M.G. Helander, A.W. Yeo (Editors) . Kuala Lumpur: DamaiSciences, p.764-769, Hong Kong.
12. Pierre M and Shi Y. (2000). "Performance of 2D Image-Based Anthropometric Measurement and Clothing Sizing System". *Applied Ergonomics*; 31: p.445-451.Toronto, Canada.
13. Apeageyi, P. (2010). "Application of 3D Body Scanning Technology to Human Measurement for Clothing Fit". *International Journal of Digital Content Technology and its Applications*, 4(7), 1-11.p.58-68 England, UK.
14. Lin, Y. L., Wang, M. J. (2011). "Automated Body Feature Extraction From 2D Images". *Expert Systems with Applications*, 38, p. 2585-2591.
15. Freeman, H., 1961. On The Encoding Of Arbitrary Geometric Configuration. *IRE Transactions on Electronics Computers*, 10, 264-268.
16. Kohlschütter, T. (2012). *Human Body Modelling by Development of the Automatic Land Marking Algorithm*. Technical Report No. DCSE/TR-2012-11.
17. Sengoz, N.G. & Zeybek, F. (2022). Sharp Silhouettes for Obtaining 3D Body Measurements from 2D Images. *Necmettin Erbakan University Journal of Science and Engineering*, 4 (2), 8-25. Retrieved from <https://dergipark.org.tr/tr/pub/neufmbd/issue/74887/1202121> DOI: 10.47112/neufmbd.2022.2 E-ISSN: 2667-7989
18. Şeker Ş, 2018, "Detection of Profile Size with Image Processing Method", M.Sc. Thesis, Karabük University Graduate School of Natural and Applied Sciences Department of Computer Engineering, Karabük, p.9-12.
19. GeoGebra, 2022. *Geometry algebra and analysis software*. <https://www.geogebra.org/graphing> (Date of Access: 01.05.2022).
20. Montgomery, D. C., (2013). "Introduction to Statistical Quality Control", 7th Edition, John Wiley & Sons, 754 p.