3D Beden Ölçülerinin 2D Görüntülerden Elde Edilmesi için Net Silüetler

Nefise Gönül ŞENGÖZ [1] (ID) Fatih ZEYBEK [2] (ID)

[1] Uşak University, Faculty of Engineering, Textile Engineering Department, Uşak, Türkiye,
nefisegonul.sengoz@usak.edu.tr *(Sorumlu Yazar/ Corresponding Author)*
[2] Uşak University, Institute of Science and Technology, Textile Engineering Department PhD Student, Uşak, Türkiye
[2] Isparta University of Applied Sciences, Yalvaç Technical Sciences Vocational School, Clothing Production
Technology Program, Isparta, Türkiye

Makale Bilgileri	ÖZ
	3D beden ölçülerinin 2D görüntülerden elde etmek için net silüetler gerekmektedir. Yazarların 3D beden ölçülerini elde etmek için 2D görüntülerden piksel koordinatları ile yeni bir yöntem geliştirdikleri devam eden araştırmalarında el ile ve beden tarayıcıları ile yaygın olan beden ölçüsü almak için bedene ihtiyaç duyulmayacağı için ve giysilerin e-alışverişler ile artması ile ortaya çıkan bedene oturmama probleminin çözülmesi amaçlandığı için, ilk adım, önden ve yandan çekilmiş fotoğraflardan net beden silüetlerinin elde edilmesidir. Bu makalenin amacı, net beden silüetlerinin elde edilmesi için, yeni geliştirilen ve ImPrNGF-1.0 ve ImPrNGF-2.0 adları verilen görüntü işleme programları ve yine yeni geliştirilen ve Python programlama dilindeki PyNGF-1 adı verilen programın geliştirilmesinde yapılan araştırmaların sunulmasıdır. Geliştirilen bu üç yeni programlarda izlenen işlem basamakları, önden ve yandan görüntülerde renkli görüntüyü gri tona dönüştürerek bir beden silüeti elde etmek, eşik değerleri ve ikili dönüşüm, farklı eşik değeri algoritmalarının uygulanması ile karşılaşılan problemlerin tanımlanması, Paint 3D programı ile arka planın kaldırılması (arka planın temizlenmesi) (gürültünün azaltılması), kenar algılama algoritmasını çalıştırılması (Sobel filtresi) ve elde edilen görüntünün negatifinin alınmasıdır. Böylece net beden silüetlerinin elde edilmesi başarılmıştır ve 3D beden ölçülerinin 2D görüntülerden elde edilmesi amacı için kullanılması mümkün olmaktadır.

Sharp Silhouettes for Obtaining 3D Body Measurements from 2D Images

Article Info	ABSTRACT
	Sharp silhouettes are needed for obtaining 3D body measurements from 2D images. Since the main goal in the authors' continuing research where a new method with pixel coordinates is developed to obtain 3D body measurements from 2D images, eliminating the need for human body common in manually and body scanning techniques, and solving the unfit problem aroused with increasing e-shopping of garments, the first step is to receive sharp body silhouettes derived from photographs taken from the front and side. The objective of current manuscript is to present the research done to obtain sharp body silhouettes by, first, developing new image processing programs named ImPrNGF-1.0 and ImPrNGF-2.0, then developing another new program in Python programming language named PyNGF-1. The procedures followed in these new developed three programs are obtaining the body silhouettes from the front and side images by converting color image to grayscale, thresholding and binary transformation, indicating the problems encountered by applying different threshold value algorithms, background (noise) removal with Paint 3D program (background cleaning), running edge detection algorithm (Sobel filter), and attaining the negative image which is finally the sharp silhouette achieved for obtaining 3D body measurements from 2D images.

INTRODUCTION

Internet is widespread all over the world and is used intensely leading to e-shopping being preferred more and more every day via online stores. Considering Türkiye, the rate of internet usage is increasing significantly in due time, being 45.0% of the households in 2011 and up to 92.0% in 2021. On the other hand, the rate of internet usage among individuals aged 16-74 was 42.9% in 2011 and increased to 82.6% in 2021 (Figure 1). The proportion of same individuals who purchased goods or services over the internet was 8.4% in 2011 and it increased significantly to 44.3% in 2021 (Figure 2). Among people using internet for shopping, 70.7% of individuals purchased apparel, shoes and accessories in the first three months of 2021. Internet shopping is expected to increase further in the coming years [1].
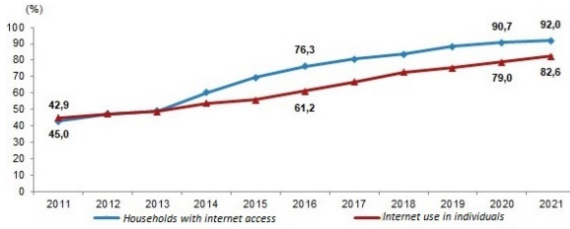

Figure 1. *Internet use in households and individuals with internet access between 2011-2021 [1]*
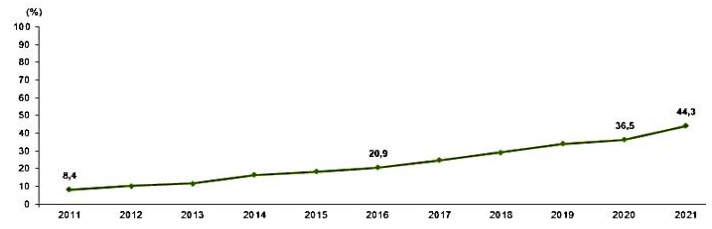

Figure 2. *Individuals aged 16-74 who purchased goods or services over internet 2011-2021 [1]*

There are many problems consumers face while e-shopping garments such as there are different measurements of the same size, lack of large size products, faulty products in fabric or sewing, short arm lengths for tall people or vice versa, unsuitable colors for the chosen ones, and the most important of all is that the clothes bought do not fit the person's own body, the unfit problem. It is aimed in our research to solve the unfit problem by obtaining 3D body measurements from 2D body measurements where the body measurements of the consumer will be determined by using the two-dimensional front and side images of the consumer, and it will be ensured that the clothes they buy will fit their body perfectly, besides, the need for the body to take body measurements will be eliminated. While working, the need to obtain sharp silhouettes from 2D images aroused. In this manuscript the intensive research of the reference studies conducted to obtain sharp body silhouettes is presented.

Body measurements are one of the most important data in apparel making. When done in tailor sense, the tailor takes body measurements from our body by hand and the product fits us when sewn. The case leading to the unfit problem is the improvement of ready-wear industry because when production is done massively it is unknown to whom the product will be sold, so body measurements needed to be generalized. Expressions like S, M, L or 36, 38, 40, etc. are developed and these didn't fit everyone's body, arousing the unfit problem. In the traditional way of obtaining body measurements manually, the human body and a non-stretchable tape measure are used. In Figure 3, some examples of the definitions of body measurements and the way they are taken are given [2, 3], they are standardized by ISO-8559. 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 as mentioned above the generalized sizes are still limiting them. Some examples of body scanning systems are TC^2 3D Body Scanner, Cyberware, Polyworks, Anthroscan, Vitus, etc. (Figure 4). These systems take cross-sectional images from different areas by scanning the body from top to bottom, allowing examining the body in terms of cross-sectional shape, slice area and volume [4]. 3D body scanning systems offer solutions to problems especially in the apparel industry. With the improvement of 3D body scanner technologies, time saving and flexibility in the processes of clothing production such as resequencing and sizing of the garment have been achieved. Another benefit can be named as to be able to dress clothes on 3D models and show virtually how the clothes look on the model

[5]. Besides, a calibrated Kinect sensor was also used to obtain widths at different positions like shoulder width, bust width, arm open width, total height and hand up height. These measurements were obtained with accuracies of 98.46% to 99.6%, when compared with the results of sensor and the actual body measurements. It was suggested that this kind of a depth image sensor can be used as an alternative way to measure body measurements [6]. Additionally, virtual fitness tests were performed for online shopping after body measurements were taken with a 3D body scanner [7]. These body scanners still need the human body to obtain the body measurements, whereas in our research, the need for the human body will be eliminated because the front and side images will be used and the unfit problem will be solved.
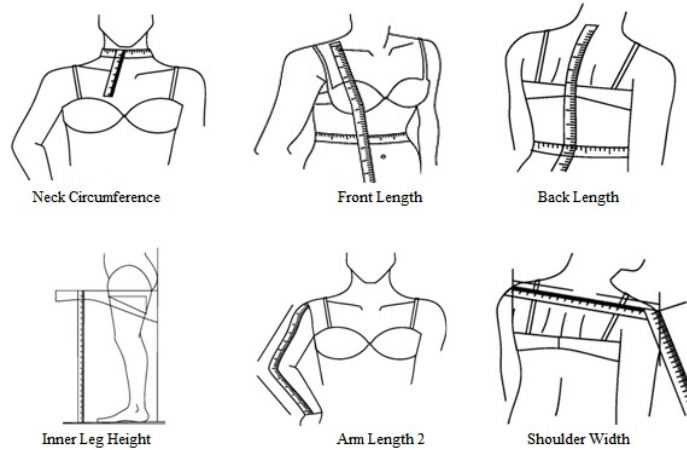

Figure 3. *Method of taking body measurements by hand [2, 3]*

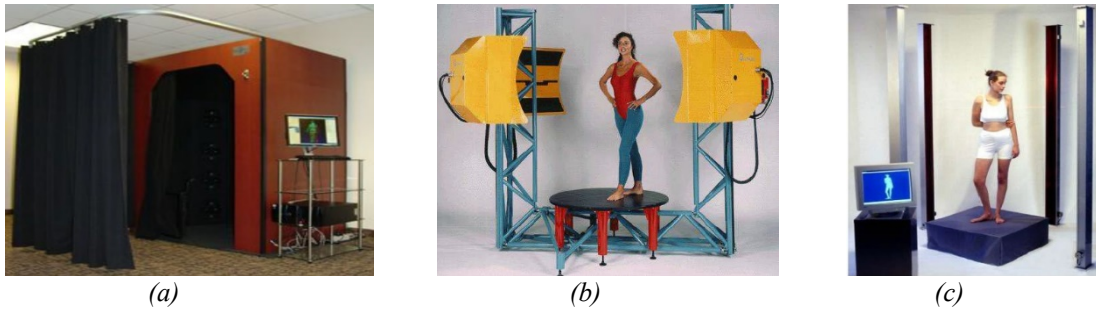*(a)*   *(b)*   *(c)*

Figure 4. *Examples of body scanning systems a) TC² 3D Body Scanner b) Cyberware c) Vitus [4]*

In literature, there are studies on investigating the suitability of standard body sizes, where standard size trousers provide a good fit especially in small size groups, while problems with large sizes, hence tailor-made production for people with large bodies and non-standard body shapes [8]; establishing a neck circumference size estimation model (Figure 5), top view of the created neck circumference measurements (Figure 6) [9]; acquiring the chest circumference by comparing the measurements obtained from the 2D images and the elliptical measurements obtained from the virtual mannequin [10]; 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, and developing software to extract body measurements from a 3D body scanner (Figure 7-9) [11,12].
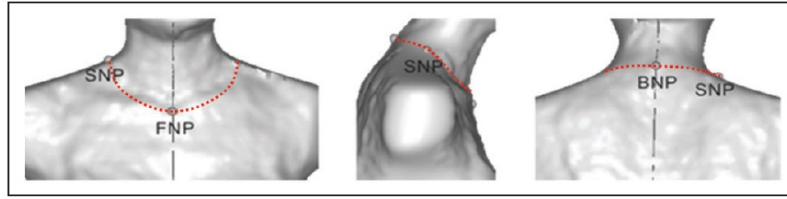
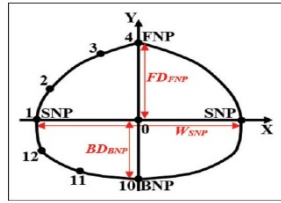**Figure 5.** *Establishing a neck circumference size estimation model [9]*

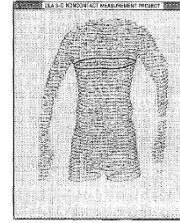**Figure 6.** *Top view of the created neck measurement [9]*

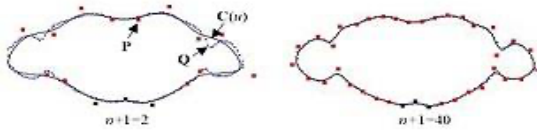**Figure 7.** *Cross-sectional areas of body measurements [11]*

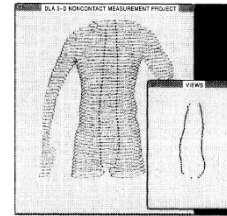**Figure 8.** *B-Spline curve approaches [11]*

Figure 9. *Developing software to extract body measurements [12]*

Another important literature on this subject is initiating a study to obtain 3D body measurements from 2D images to eliminate the need for body when taking body measurements by hand or body scanners and to seek a solution to the problem of not fitting of the garment to the body. The photographs of 500 female participants aged 18-25, all volunteers, weights 43-85 kg, wearing tight clothes, from 3 m distance, from front and side rotated 90^0, from neck and 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 of the photographs for Person-13, Person-137, and Person-433 are given in Figure 10. Different body measurements up to 20 were manually measured according to ISO-8559 standard using a non-stretchable tape measure, and the age, height and weight of the same person were recorded. In the mentioned research, the descriptive statistics of the obtained data were calculated, and the relationships between height and weight were examined with regression analyses [2, 13].

In this research, to reach the goal of obtaining 3D body measurements from 2D images, first a sharp silhouette of the front and side images is searched and presented here.

MATERIALS AND METHODS

Sharp silhouettes for obtaining 3D body measurements from 2D front and side images is presented in this manuscript. Sharp silhouettes are the initial step of the present research to obtain 3D body measurements from 2D front and side images, incidentally the attributing studies are exhibited here. The material used in this research is mainly the front and side photographs of females [2, 13]. They are necessarily benefited to acquire sharp silhouettes for obtaining 3D body measurements from 2D images. Some other examples of the photographs from the front and side for Person-10, Person-9, and Person-14 are given in Figure 11 [2, 13].

(a)   *(b)*

(c)   *(d)*

Figure 10. *Examples of photographs from front and side, a) Person-1, b) Person-13, c) Person-137, and d) Person- 433 [2,13].*

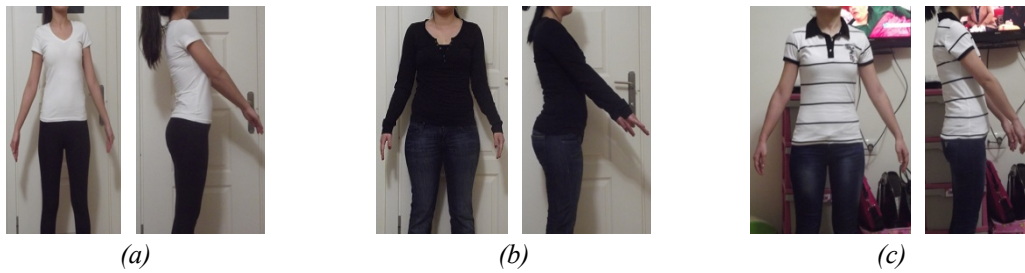*(a)*   *(b)*   *(c)*

Figure 11. *Examples of photographs from front and side, a) Person-10, b) Person-9, and c) Person-14 [2,13].*

In this research, in order to acquire sharp silhouettes for obtaining 3D body measurements from 2D front and side images, new image processing programs are developed. Two of them are the programs in Microsoft Visual Studio in C# programming language Windows Form Application and Visual Studio Code compiler in image processing which are named as ImPrNGF-1.0 and ImPrNGF-2.0, besides the OpenCV (Open Source Computer Vision) library is also taken advantage of. The third one is in Python programming language, which is named as PyNGF-1. The procedures followed in these new developed programs are obtaining the body silhouettes from the front and side images by converting color image to grayscale, then thresholding and binary transformation, indicating the problems encountered and how they are solved, later background (noise) removal with Paint 3D (background cleaning), running the edge detection algorithm (Sobel Filter), and finally attaining the negative image, they will be explained in detail in the next section. At the end, sharp silhouettes are successfully obtained for the purpose of obtaining 3D body measurements from 2D images.

RESULTS AND DISCUSSION

In this research, studies are conducted to acquire sharp silhouettes for obtaining 3D body measurements from 2D front and side images. Below are explained the intensive work carried out, the results, and discussion to reach this goal.

Obtaining Body Silhouettes with the New Developed Program ImPrNGF-1.0

The front and side images to obtain body silhouettes are colored as seen in Figure 10 and 11. It is first needed to transform the color images into grayscale images. Grayscaling needs further work to get only the outlines with thresholding and binary transformation to obtain body silhouettes. The structural design to convert the color images to grayscale and thresholding and binary transformation are explained in the following sections below:

Converting Color Image to Grayscale

In general, each pixel in a color image consists of three color components, which are red, green, and blue (RGB), and each component in a pixel is given a value between 0 and 255. If the RGB is (0, 0, 0) respectively, then the color is black, similarly, white when they are (255, 255, 255). The gray color has equal RGB values, where light gray is defined by (230,230,230), and dark gray (100,100,100), furthermore, a dark pink color is reached with (200, 20, 80). In Figure 12, examples of RGB values for dark pink and dark gray colors are given [14].

(a)   *(b)*

Figure 12. *Examples of RGB values, a) Dark pink (200, 20, 80); b) Dark gray (100, 100, 100) [14]*

When a color pixel is converted to grayscale, the arithmetic average of the RGB values is taken and the resultant value is assigned to all three RGB components [15]. The dark pink color in Figure 12a possesses RGB values (200, 20, 80), their average is given in Equation 1, which is 100, and this value is issued to each RGB component, outcoming as (100, 100, 100), indicating the final grayscale of the dark pink color pixel in Figure 12b.

Gray Value= (R+G+B) / 3   (1)
Gray Value= (200+20+80)/3=100 for each RGB

When the image is taken as a whole, the average of RGB in every pixel is calculated one by one and replaced within the same pixel, at the end the whole image turns into different shades of gray. In this research, the new developed program ImPrNGF-1.0 is compiled and executed successfully on Microsoft Visual Studio. The algorithm structure C# programming language is used in this program to convert the color image to grayscale and it is as given below:

```
1 private Bitmap griYap(Bitmap bmp)
2 {
3  for (int i = 0; i < bmp.Height - 1; i++)
4  {
5    for (int j = 0; j < bmp.Width - 1; j++)
6    {
7      int gray = (bmp.GetPixel(j, i).R + bmp.GetPixel(j, i).G + bmp.GetPixel(j, i).B) / 3;
8      Color grayscale = Color.FromArgb(gray, gray, gray);
9      bmp.SetPixel(j, i, grayscale);
10   }
11  return bmp;
12 }
```

In this algorithm, for-loops are used and in this case two for-loops are used to reach all of the pixels in the images. The pixels are recognized by the (i, j) components, vertical and horizontal, respectively. Sequentially one pixel is taken with "GetPixel" function, it is transferred to the predefined variable "int gray", the "Color.FromArgb" function takes the average of RGB values of that special pixel, "SetPixel" function replaces the RGB color components of that pixel with the average color value calculated. When (i++, j++) reaches the end, the image in different shades of gray is obtained. An example of gray scale conversion for Person-1 is given in Figure 13.
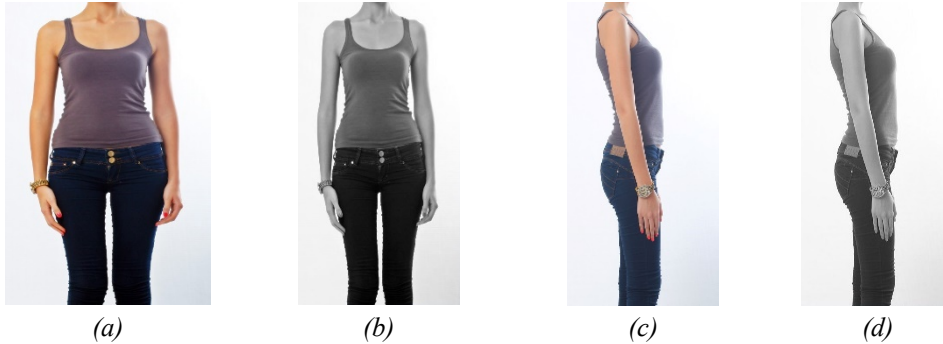

(a)   (b)   (c)   (d)
Figure 13. *Converting the color image of Person-1 to grayscale, a) Color image front,
b) Grayscale image front, c) Color image side, d) Grayscale image side*

Thresholding and Binary Transformation

In the thresholding and binary transformation process, the average color value of each pixel in the grayscale picture is compared with a certain threshold value chosen according to a certain goal, which is such as applying a kind of filter. When a threshold value 240 is chosen; if one special pixel of a grayscale image contains an average color value 220 , then the value of 220 is compared with the threshold value 240 and since it is below the threshold value the program replaces it with 0, so, that pixel is turned into black; in the same way, if another pixel of a grayscale image contains and average color value of 250 , then the value of 250 is compared with the threshold value 240 and since it is above the threshold value the program replaces it with 255, so, that pixel is turned into white (Equation 2). Correspondingly when the same thresholding is applied to all of the pixels in a grayscale image then the image is transformed into a binary system of black and white [15]. In this research the semi-body silhouettes are obtained by thresholding and binary transformations after the color images are converted to grayscale.

$$f(x,y) = \begin{cases} 0, & if \ g(x,y) < T = 240 \\ 255, & g(x,y) \geq 240 \end{cases} \qquad (2)$$

Problems Encountered

In working with different front and side images of females to obtain the body silhouettes via the new developed program ImPrNGF-1.0, some problems are encountered. It is thought that these problems would not lead to sharp silhouettes, so the images are worked on neatly and precisely to overcome these problems. A list of the problems encountered is given below:

- The background of the image is dark, besides the person is wearing dark cloths, there is no contrast between them, so unable to reach a silhouette (The same is true with light colored background and light-colored clothes)
- Presence of some objects disrupting the silhouette line such as a hairpin, hat, ring, watch, bracelet, even a curl of hair itself
- Standing position of the person such as one shoulder up or down, or arms not open enough, or arm covering chest on the side image
- Clothes of the person such as the being loose clothing makes it difficult to get the body silhouette, the pointed end of the short sleeves, traces of garment collar, folds of the clothing, etc.
- The thickness of the silhouette line
- The underarm is not aligned on the horizontal axis in the side image but has an inclined posture
- Noise in the silhouette image
- Shadows reflecting on the background but detected as a part of the body

The main screen of the new developed program ImPrNGF-1.0 is shown in Figure 14 and examples of the problems encountered by applying ImPrNGF-1.0 to Person-9 (Figure 15) and Person-10 (Figure 16) are given. First the color images are converted to grayscale and then are studied at the 180 threshold to obtain the silhouettes. The silhouettes are successfully obtained but there are problems encountered as mentioned above. For example, in Figure 15, the shadow of the right leg and the shadow of the left arm fall on the door, unfortunately silhouettes for these shadows are also obtained. Similarly, in Figure 15, the traces of the collar create a silhouette, which is not needed in the present research and considered as noise. Another example in Figure 16, there are problems with the folding of the T-shirt at the waist both in the front and a side image, the standing position of the lady is inclined, and the edge of the short sleeve T-shirt of right arm. Both have a curl of hair seen in the side image (Figure 15) and front image (Figure 16) disrupting the silhouette. Excessive amount of noise in the form of black dots appeared around the neck of the body silhouette obtained, which disrupt the silhouette and lead to redundant pixels as seen in Figures 15 and 16.
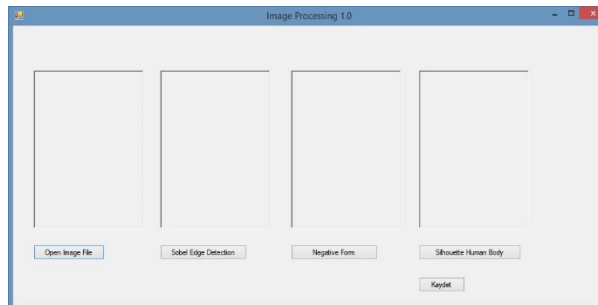

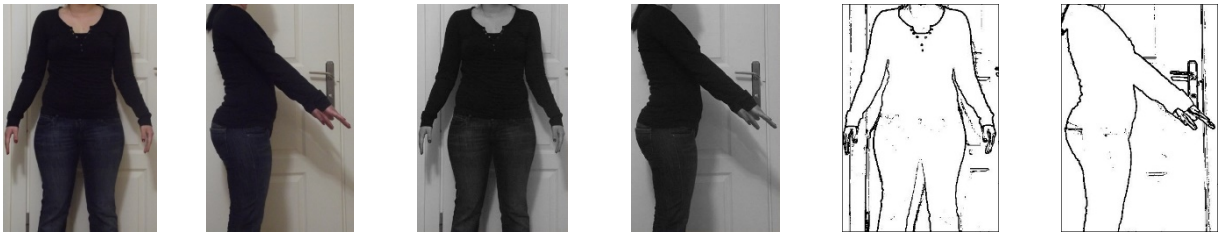**Figure 14.** *Main screen of the new developed program ImPrNGF-1.0*

Figure 15. *Original color images of Person-9 front and side; grayscale images, and silhouettes obtained with ImPrNGF-1.0 at threshold 180*

Figure 16. *Original color images of Person-10 front and side; grayscale images, and silhouettes obtained with ImPrNGF-1.0 at threshold 180*

First of all, the problems encountered needs to be solved. To clarify the problems mentioned above, various studies have been conducted, each having different approaches and different points of views. In these studies, (1) thresholding and binary transformation studies with the new developed program ImPrNGF-1.0, (2) thresholding and binary transformation studies with the new developed program PyNGF-1, (3) background (noise) removal studies with Paint 3D Program are carefully applied with changing parameters to obtain a sharp body silhouette. A schematic workflow of the studies to clarify the problems to obtain a sharp body silhouette done is given in Figure 17.
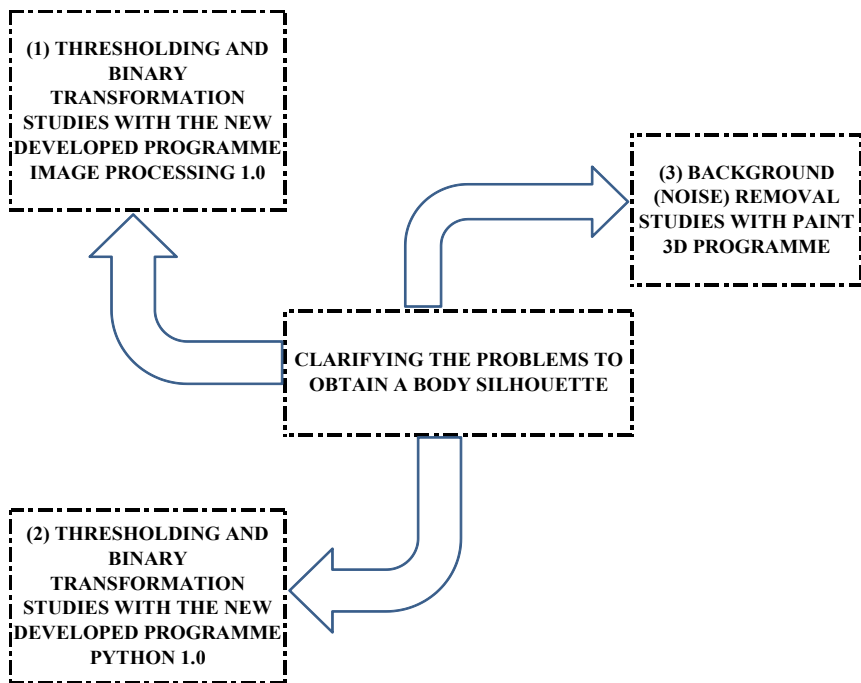

Figure 17. *Schematic workflow of studies to clarify the problems to obtain a sharp body silhouette*

Thresholding and Binary Transformation Studies with the New Developed ImPrNGF-1.0

The thresholding and binary transformations are applied to Person-9 in the new developed program ImPrNGF-1.0. The threshold values 100 , 140 , 200 , 220 , and 240 are applied as seen in Figures 18 – 22, respectively, and the body silhouettes are extracted. The outcome of each threshold value is examined in-depth and is observed that at the threshold values 100 and 140 there are some skipping points of the body silhouette especially at the right leg as seen in Figures 18 and 19, respectively; on the other hand at the threshold values 200 , 220 , and 240 the noise of the silhouettes obtained are increasing as the threshold values increase, so they become darker and darker, and the problem of the shadow of the legs falling on the door also noted as a silhouette are seen in Figures 20 – 22, respectively. No sharp body silhouettes are obtained with the new developed program ImPrNGF-1.0 demonstrated according to the criteria of this research. This situation exhibited excessive amount of noise in the form of black dots evident around the neck of the body silhouette obtained, which disrupt the silhouette and lead to redundant pixels as seen in Figures 18-22, needed denoising.
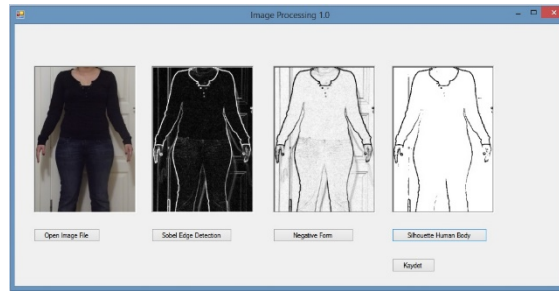

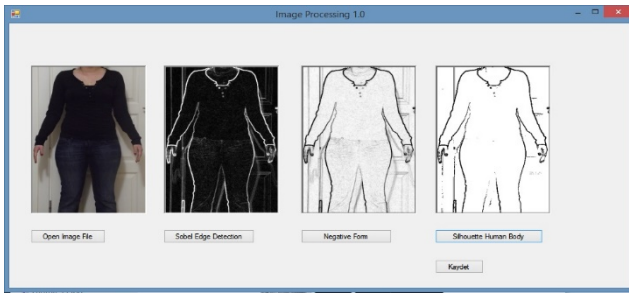**Figure 18.** *Silhouette extraction with ImPrNGF-1.0 for Person-9 at threshold value 100*

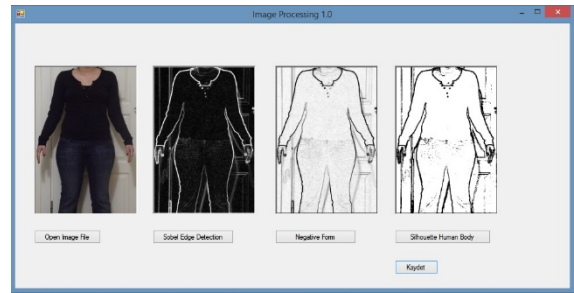**Figure 19.** *Silhouette extraction with ImPrNGF-1.0 for Person-9 at threshold value 140*

Figure 20. *Silhouette extraction with ImPrNGF-1.0 for Person-9 at threshold value 200*
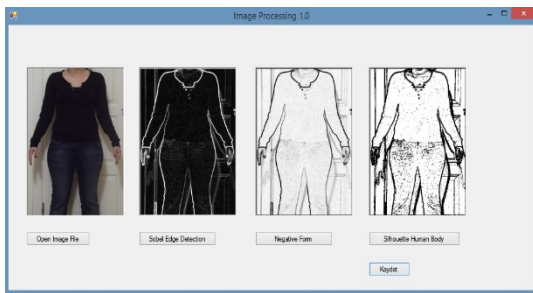

Figure 21. *Silhouette extraction with ImPrNGF-1.0 for Person-9 at threshold value 220*
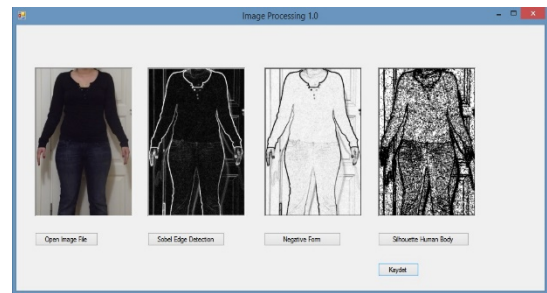

Figure 22. *Silhouette extraction with ImPrNGF-1.0 for Person-9 at threshold value 240*

Thresholding and Binary Transformation Studies with the New Developed Program PyNGF-1

The objective of applying different thresholding and binary transformations and attaining their negatives is to obtain sharp body silhouettes. To achieve this target, another program is developed in the Python programming language in Visual Studio Code compiler and is named PyNGF-1. The main screen of the new developed program PyNGF-1 is seen in Figure 23 for Person-1. The different threshold values 200, 220, 230,

240 and 250 are applied with this new program as seen in Figure 24 a-e. The outcome of each threshold value is examined in-depth and is noted that at the threshold value 200, white spots occurred around the neck which disrupt the silhouette and lead to redundant pixels; at the threshold values 220 and 230 , black and heavy black shadows appeared at the lower right corners, respectively; at the threshold value 240 , these shadows appeared on both sides of the image, even more intensely; at the threshold value 250 , the black color dominated the whole image and no clear silhouettes are obtained. Nevertheless, the research is continued and to reach the goal of obtaining clear silhouettes, the negatives of each image is attained at different threshold values with the new developed program PyNGF-1. In Figure 25, the attained negatives of the threshold values 200, 220, 230, 240 and 250 are seen. The outcome of negative of each threshold value is examined in-depth and is observed that at each of the threshold value there are some skipping points in the silhouette, noise occurred, the silhouette starts to disappear at the left leg at the threshold value 240, and almost totally disappearing in 250, revealing to no apparent silhouettes.
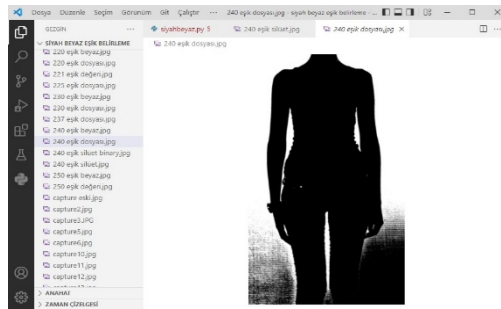

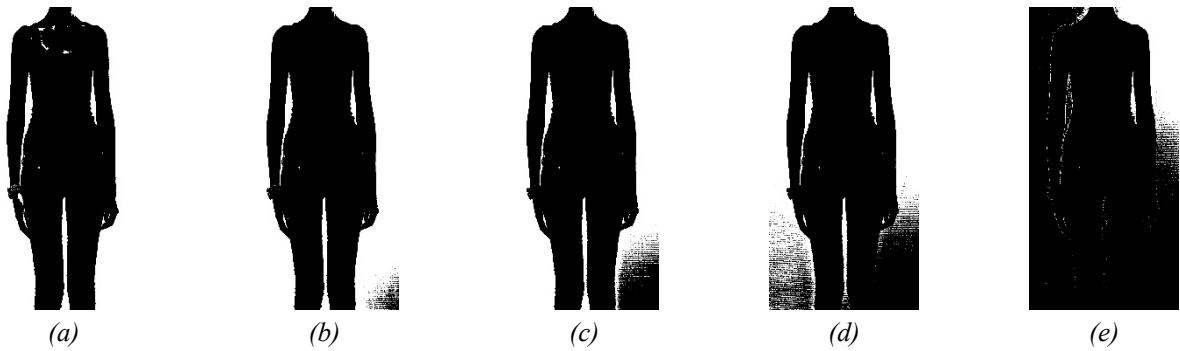**Figure 23**. *Main screen of the new developed program PyNGF-1 for Person-1*

(a)   *(b)*   *(c)*   *(d)*   *(e)*

Figure 24. *Different threshold values with PyNGF-1 for Person-1, a) 200, b) 220, c) 230, d) 240, e) 250*

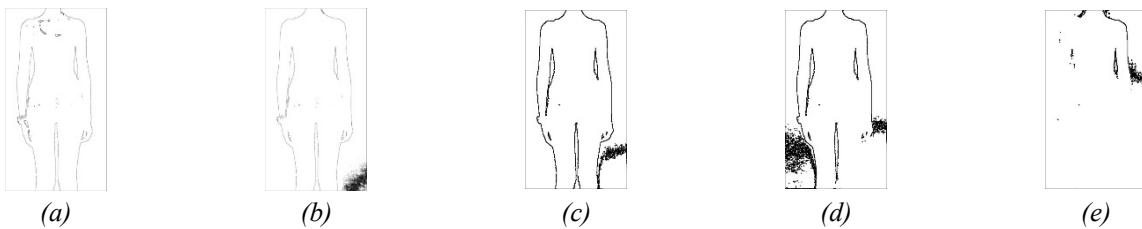
(a)   *(b)*   *(c)*   *(d)*   *(e)*

Figure 25. *Negatives of different threshold values with PyNGF-1 for Person-1,*
a) 200, b) 220, c) 230, d) 240, e) 250

Background (noise) Removal Studies with Paint 3D Program (Background Cleaning)

The edge detection performed with the new developed program ImPrNGF-1.0 could not eliminate the problems to obtain a sharp body silhouette. To express more clearly, the background is included in the thresholding and binary transformations, in silhouette formation, and in attaining the negative. In this case, to achieve the goal of obtaining of a sharp body silhouette, the Paint 3D program is used to remove the background of the color image. The steps of background removal process in Paint 3D are; the color image is

loaded first (Figure 26a) then with the magic selection button the object to be focused on is selected, Person-10 in this case, the magic selection selects this object and determines its outlines (Figure 26b), at this point minor changes can be done slightly to arrange some edge regions of the object with the "Add/Remove" button, and then it removes the background of the color image and a clear object is left. In Figure 26c, the selected object which is saved as a new image file is seen where the background is removed.
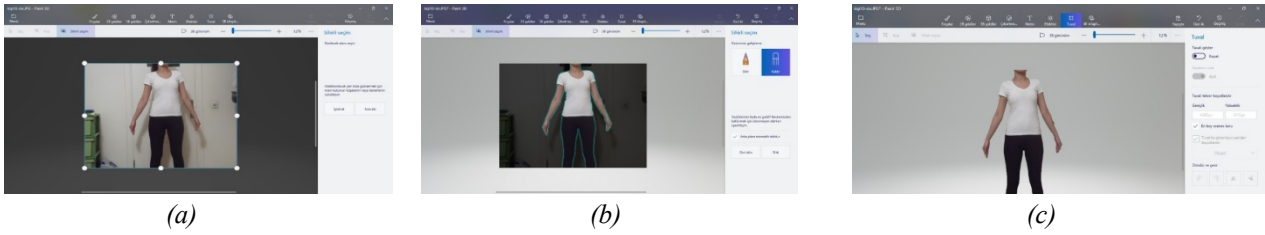

| (a) | (b) | (c) |

Figure 26. *Working with Paint 3D Program, a) Color image loaded, b) Magic selection of the object, c) Selected object and removed background*

Obtaining Body Silhouettes with the New Developed Program ImPrNGF-2.0

After the background is removed, the new image file is processed with another new developed program ImPrNGF-2.0 based on Microsoft Visual Studio in C# programming language. The main screen of this other new developed program ImPrNGF-2.0 is seen in Figure 27.

Thresholding and Binary Transformation Studies with the New Developed ImPrNGF-2.0

Person-10 is processed with ImPrNGF-2.0, the different threshold values 200 and 240 are applied as seen in Figures 28-31. The outcome of each threshold value is examined in-depth and is noted that at the threshold value 200, much noise in the form of black dots appeared around the neck of the body silhouette obtained which disrupt the silhouette and lead to redundant pixels as seen in Figure 28 and 29, Person-10 front and side, respectively. At the threshold value 240, a sharp silhouette is satisfactorily extracted, the resultant silhouette reveals essentially no redundant pixels, as seen in Figures 30 and 31, Person-10 front and side, respectively, which provides the silhouette to be used in the following sections of the present research. From the aspect of effectiveness, obtaining sharp silhouettes is achieved.
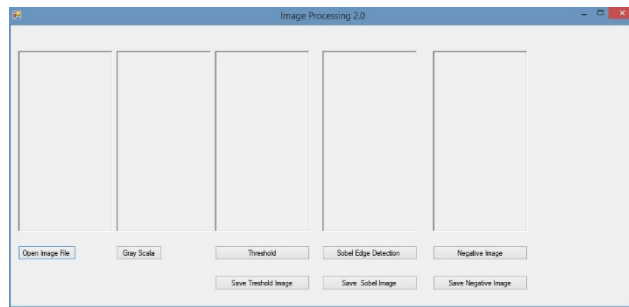

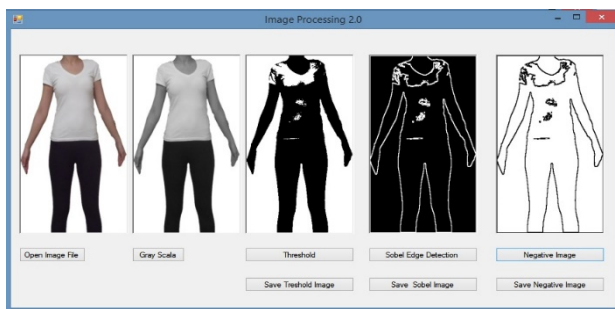**Figure 27.** *Main screen of another new developed program ImPrNGF-2.0*

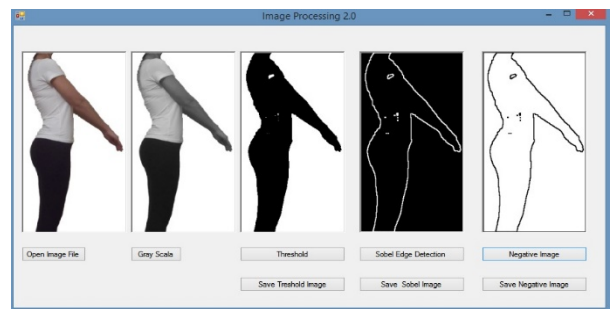**Figure 28.** *Silhouette extraction with ImPrNGF-2.0 for Person-10 front at threshold value 200*

Figure 29. *Silhouette extraction with ImPrNGF-2.0 for Person-10 side at threshold value 200*
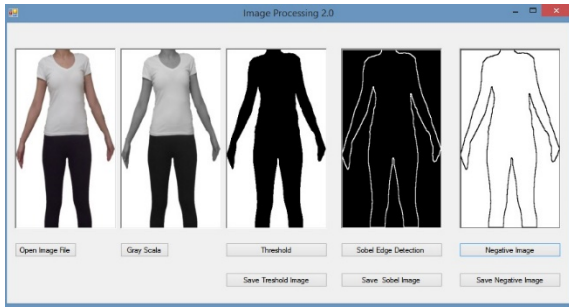
Figure 30. *Silhouette extraction with ImPrNGF-2.0 for Person-10 front at threshold value 240*
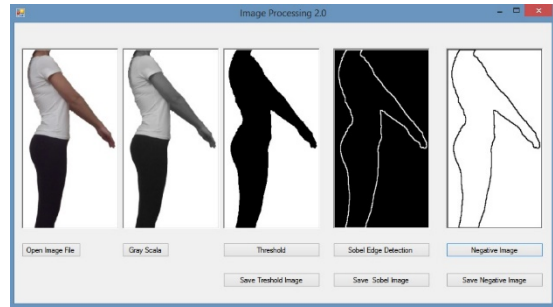
Figure 31. *Silhouette extraction with ImPrNGF-2.0 for Person-10 side at threshold value 240*

Edge Detection Algorithm (Sobel Filter) with the New Developed Program

While extracting the silhouette of the body, it is as well important to detect the edges of it also. In this new developed program ImPrNGF-2.0 it is taken the advantage of Sobel filter which detects the areas of high color variations in a grayscale. Besides detecting, this filter can efficiently dissociate the color differences and highlights them as edges. Sobel filter does these processes with masks and in the present research two different masks are used for edge detection, one for the vertical axis and one for the horizontal axis. An example of Sobel masks is given as in Figure 32 [16].

G_x Mask G_y Mask

Figure 32. *Example of Sobel masks, a) Vertical axis edge detection mask, b) Horizontal axis edge detection mask [16]*

An application of Sobel masks is given in Figure 33 where A is an example of an original image, Gx and Gy masks are the matrices of the vertical and horizontal axes, respectively, Gx and Gy values are the multiplication of Gx and A, and of Gy and A. To determine the edge regions, the Gx and Gy masks are applied starting from the second row and second column of the original image as shown in Equations 3 and 4 where the Gx and Gy values are calculated. For the calculation of Gx value, the matrix of the original image A and the matrix of Gx mask are multiplied, the result is Gx=400. Similarly, for the calculation of Gy value, the matrix of the original image A and the matrix of Gy mask are multiplied, the result is Gy=0 . The mathematical model of their squares for the Sobel filter masking G value is given in Equation 5 and is the square root of the sum of the Gx and Gy values where the result is G = 400.

A: Example of an original image
G_x mask: Matrix of the vertical axis
G_x value: Multiplication of G_x and A
G_y mask: Matrix of the horizontal axis
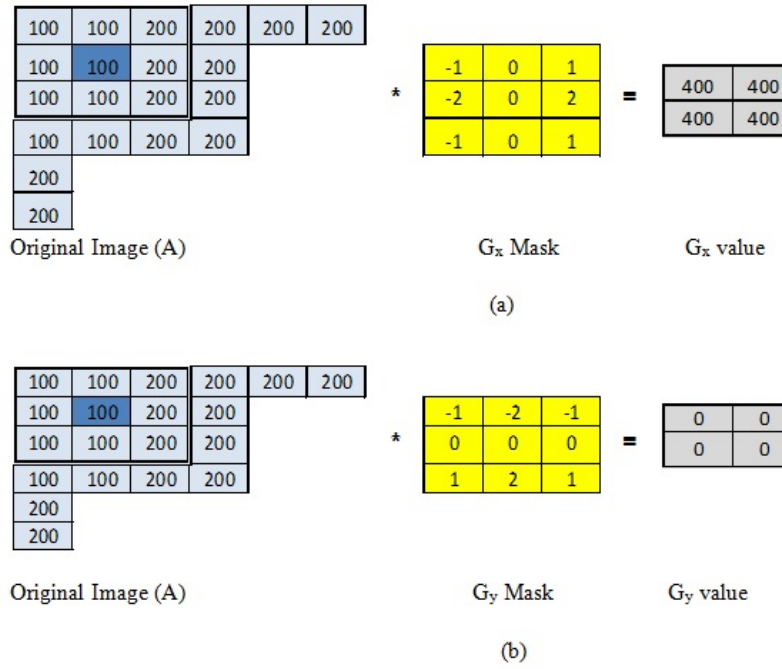G_y value: Multiplication of G_y and A

(a)

(b)

Figure 33. *Sobel Filter, a) Vertical mask, b) Horizontal mask*

$$A = \begin{bmatrix} 100 & 100 & 200 \\ 100 & 100 & 200 \\ 100 & 100 & 200 \end{bmatrix} \quad Gx = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} * A \quad Gy = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} * A \tag{3}$$

$$Gx(2,2) = \begin{bmatrix} 100 & 100 & 200 \\ 100 & 100 & 200 \\ 100 & 100 & 200 \end{bmatrix} * \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

$$Gx(2,2) = [100*(-1) + (100*0) + (200*1) + 100*(-2) + (100*0) + (200*2)$$
$$+ (100*(-1)) + (100*0) + (200*1)] = -400 + 800 = 400$$

$$Gy(2,2) = \begin{bmatrix} 100 & 100 & 200 \\ 100 & 100 & 200 \\ 100 & 100 & 200 \end{bmatrix} * \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \tag{4}$$

$$G^2 = Gx^2 + Gy^2$$
$$G^2 = 400^2 + 0^2$$
$$G^2 = 400^2 \text{ and } G = 400 \tag{5}$$

This procedure of Sobel filter masking is for only one pixel, so the same have to be done for all the pixels in the image. At the end, an image is obtained showing the edges of the original image. In the present research Sobel filter is applied to the image of Person-10 obtained with the new developed ImPrNGF-2.0. Since the determined threshold value is 240, Sobel filter compares the calculated G value for each pixel with this threshold value, and if it is higher than 240 that pixel is assigned as white, and if it is lower than 240 that pixel is assigned as black. The background removed image and the resulting silhouette image provided after Sobel filter is given in Figure 34.

Figure 34. *Person-10, a) Background removed image, b) Silhouette obtained after Sobel filter*

Attaining the Negative Image with the New Developed Program ImPrNGF-2.0

When Sobel filter process is completed, an image in black and a white silhouette line is derived from the color image. A need arouses to change the colors to just the opposite where the black areas will be white and the white silhouette line black. Since it is explained in Section 3.1.4 that black is symbolized with the number 0 and white the number 255 in the RGB color components, to attain the negative of the image simply each pixel color value must be subtracted from the number 255 in a for-loop. The remaining pixel color value gives the negative pixel color value accordingly [15]. In the current research, the silhouette is obtained by taking the negatives of the front and side image after Sobel filters process. Figure 35 shows Sobel filter process and after the negative image attained for Person-10.
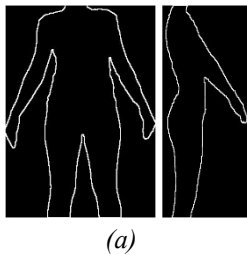

Figure 35. *Person-10, a) Sobel filter process, removed image, b) Negative image attained*

Figure 36. *Person-10, a) Background b) silhouette image*

For Person-10, the background removed image for the front and side to directly their silhouettes as the negative images attained are performed as seen in Figure 36.

The same reasonable operations are applied to Person-1, Person-9 and Person-14, and their background removed images for the front and side directly to their silhouettes as the negative images attained are provided in Figures 37-39, respectively.
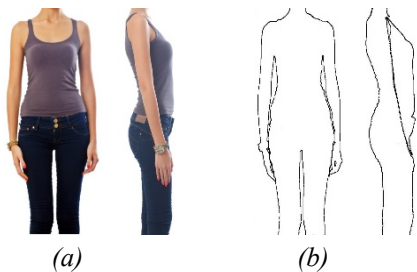

Figure 37. *Person-1, a) Background removed image, b) Silhouette image*

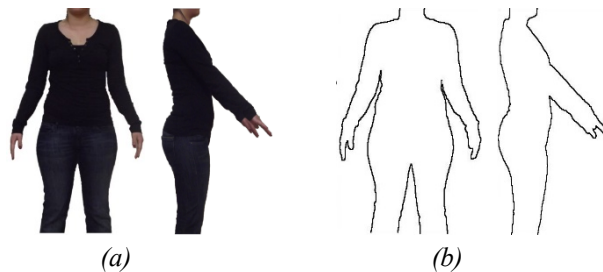**Figure 38.** *Person-9, a) Background removed image, b) Silhouette image*

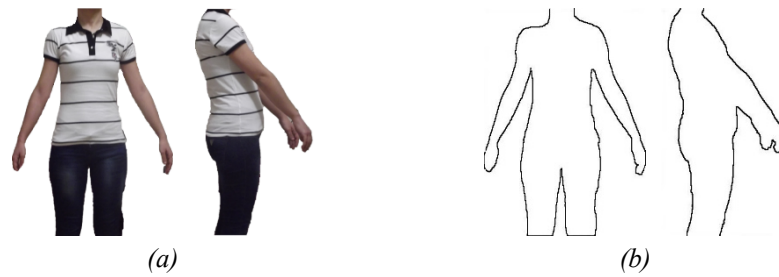*(a)*   *(b)*

Figure 39. *Person-14, a) Background removed image, b) Silhouette image*

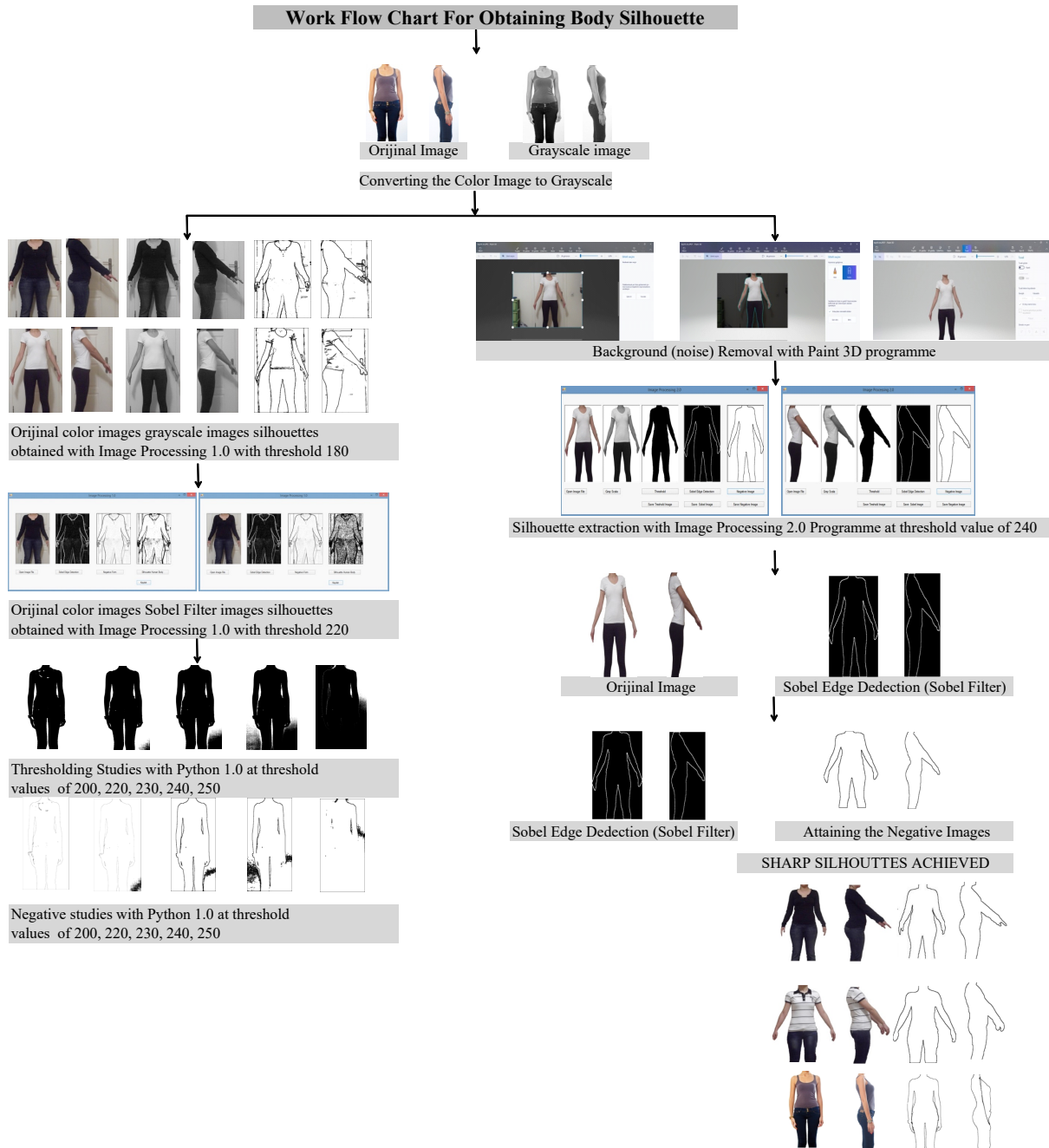The workflow chart of procedures followed in this research is briefly summarized in Figure 40.

Figure 40. *Workflow chart of procedures followed in this research*

CONCLUSION

Body measurements are one of the most important data in apparel making. When done in tailor sense, tailor takes body measurements from our body by hand and the end-product fits us. With the improvement of ready-wear industry, it is unknown to whom the product will be sold, so body measurements are generalized. Size expressions like S, M, L or 36, 38, 40, etc. are developed and apparel mass produced but then the unfit problem to one's body aroused. Body scanning technologies are developed to get over the unfit problem. Besides, e-shopping of garments is increasing rapidly and the biggest problem encountered in these cases is the purchased product is not suitable for the person's body, again the unfit problem. Body scanning technologies and manually taken body measurements all need the human body to take body measurements. In order to eliminate the need for the human body and to solve the unfit problem, it is thought to obtain 3D body measurements from 2D images and in the current paper it is presented how sharp silhouettes are obtained for this purpose. The 2D images are one photograph taken from the front and one from the side rotated 90^0, female participants between ages 18-25, all volunteers, between weights 43-85 kg, wearing tight clothes, from 3 m distance, from neck and to the knees, arms and legs slightly open, using a camera that focuses on the waist and parallel to the ground [2, 13].

In this research, photographs from the front and side are used to quickly and accurately acquire sharp silhouettes for obtaining 3D body measurements from 2D images. First the color images are converted to grayscale and thresholding and binary transformation is applied with the new developed program in image processing program named ImPrNGF-1.0. But problems are encountered at this step such as no contrast with the background and the color of cloth worn, some objects disrupting the silhouette line, standing position of the person, clothes of the person, thickness of the silhouette line, side image arm position, noise in the silhouette image, and shadows reflecting on the background but detected as a part of the body. To clarify these problems, image processing studies with the new developed program in Python programming language named PyNGF-1 is conducted besides thresholding and binary transformation studies with the new developed ImPrNGF-1.0 but was not satisfactory for the current research. Then, background (noise) removal with Paint 3D (background cleaning) program is used which is helpful to get good looking front and side images. Another programd is developed ImPrNGF-2.0 and is successful. With this program it is concluded that the threshold value 240 is appropriate. After applying edge detection algorithm (Sobel filter) and attaining the negative image with the new developed ImPrNGF-2.0, perfect sharp silhouettes are achieved, revealing essentially no redundant pixels, for obtaining 3D body measurements from 2D images. A workflow chart is also presented to summarize the procedures followed in this research and the same are applied to other photographs taken.

The prescribed research is of remarkable significance to assist future work to obtain 3D body measurements from 2D front and side images. By this means, the need for human body when taking body measurements by hand and body scanners will be eliminated, made-to-fit apparel like tailor sense will be realized, the unfit problem in mass production and e-shopping will be solved and e-shopping will be much easier and extensive, and will promote less costs at today's level of competition.

REFERENCES

[1] Turkish Statistical Institute (TÜİK). Households' Use of Information Technologies, (2021). https://data.tuik.gov.tr/Bulten/Index?p=Hanehalki-Bilisim-Teknolojileri-(BT)-Kullanim-Arastirmasi-2021-37437 (Date of Access: 01.05.2022)

[2] R.C. Eren, and A. Güngör, A Different Method for Reaching Body Measurements, *Graduation Project*, Uşak University, Faculty of Engineering, Department of Textile Engineering, Uşak, (2013). Supervisor: Doctoral Lecturer Nefise Gönül ŞENGÖZ (received support from TÜBİTAK 2209-A-2012-1), p.3-16.

[3] F. Bayraktar, Setting the standardization for body size to be employed in the production of ready-made

apparel for plus size women, PhD thesis, Gazi University, *Institute of Educational Sciences,* Department of Clothing Industry and Fashion Design Education*,* Ankara, 2007.

[4] Ş. Eğri, (2011). A Case Study on The Problems Encountered in Three-Dimensional Body Scanning Systems (Kardem and İma example), Master's thesis*,* Gazi University*, Institute of Educational Sciences*, Clothing Industry and Clothing Department of Arts, Ankara, 2011.

[5] H. Yüksel, M. Oktav Bulut (2019). Three-Dimensional Body Scanning Systems, Journal of Textiles and Engineer, 26: 116, 406-414. https://doi. org/10.7216/1300759920192611612

[6] H. Yüksel, M. Oktav Bulut (2020). Analyses of body measurement with depth image data using motion capture sensor. Industria Textila, 71(6), 530-537.

[7] P. Apeagyei (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.

[8] A. Vuruşkan, E. Bulgun (2013). "Fit analysis for made-to-measure garments". Journal of Textiles and Engineer, 20: 90, 42-53.

[9] B. Gu, G. Liu and B. Xu, Individualizing Women's Suit Patterns Using Body Measurements From Two-dimensional Image, *Textile Research Journal*, 2017, Vol.87, Issue 6, p.669-681

[10] P. Guerlain, B. Durand B, Digitizing and Measuring of the Human Body for the Clothing Industry, *International Journal of Clothing Science and Technology*, 2006, Vol. 18 Issue: 3, p.151–165.

[11] Z. Öndoğan, O. Pamuk, E. Topal, Investigation of Simulation Systems in Clothing Design, Body Measurement and Clothing Marketing*, Textile and Apparel*, 2007, p.265-272.

[12] P.R. Pargas, J.N Staples, J.S Davis, Automatic Measurement Extraction for Apparel from a Three-Dimensional Body Scan, *Elsevier Science Limited*, 1997, p. 157–172.

[13] N.G. Şengöz, R.C. Eren, and A. Güngör, Development of a Method for Obtaining Body Measurements from Two-Dimensional Images, *IITAS-2017 XIV. International Textile and Apparel Symposium*, 2017, p.109-112, İzmir.

[14] w3Schools, Web Developers, color RGB. https://www.w3schools.com/colors/colors_rgb.asp (Date of Access: 01.05.2022).

[15] İ. Çayıroğlu, Image Processing with C#, Week 2 Lecture Note", Karabük University, *Faculty of Engineering*, 2013 p1-23.

[16] M.F. Özçelik, Implementation of Image Processing Algorithms on Fpga Hardware, M.Sc. Thesis, *Gazi University Informatics Institute,* 2012, Ankara, p.35-39.