Chen Tao [1],
Jiu Zhou [1*],
Meifen Yin [2]

[1]College of Materials and Textiles,
Zhejiang Sci-Tech University,
Hangzhou, Zhejiang, China,
*corresponding author: zhoujiu34@126.com

[2]Shaoxing Entry-Exit Inspection
and Quarantine Bureau,
Shaoxing, Zhejiang, China

Silhouette Identification for Apparelled Bodies

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Abstract

This paper presents an approach to identify apparel silhouettes. A feature region of the human face was first proposed for conducting face detection in fashion pictures with the AdaBoost method, and the head was then located with its positional relation to the facial feature region. The linear relationship between the ratio of the body height to head length and the length of the lower body was ensured by restricting the RBH to a specific range. Under this condition, the apparelled body was divided into several parts, and the boundary of apparel on the lower body was determined considering the influence of the hemline. Based on the widths of the body parts and the apparel on the lower body, shape factors were established to express the extent to which the apparel silhouette approached a certain shape. A computer program was developed for implementation and demonstrated high accuracy in silhouette identification of an appareled body.

Key words: *apparel silhouette, identification, face detection, body proportion, shape factor.*

The apparel silhouette, conventionally consisting of A-, T-, O-, X- and H-shapes [1], delivers the foremost character at the first sight of apparel, and serves as one of the fundamental elements in apparel style. Previous studies on the apparel silhouette with computer technology have followed two kinds of routes.

Most researchers studied the silhouette in mathematical models, such as evaluating clothing easiness with the space between the human body and outline of silhouette in the 3D models [2], combining the naked body and silhouette shapes to form models that allowed many kinds of body figures and postures [3], matching a customer's figure with the apparel silhouette in a virtual apparel fitting system [4], estimating wearability with indices collected from the shirt silhouette in a virtual sewing mechanism [5], establishing a parameterised model for some kinds of clothing in which the variation of silhouette shapes of the same kind could be achieved by altering the parameters [6], etc.

Other studies endeavoured to extract the contour of an apparel silhouette from real images, which might be borrowed in this research. Liu [7] achieved a single-pixel edged body profile through edge detection with the multi-scaled wavelet transform. An [8] introduced such concepts as the contour error and branch-point, and presented a new contour extraction method for apparels with printed patterns. However, these studies aimed at static apparels without being worn and had strict requirements in object placement and image acquisition, which cut into practicability.

Unlike previous studies, this research concerned appareled bodies in the real world, which relaxed the limits on body posture and image conditions, and recognised the outline of apparel as conventional silhouette shapes. The methods presented by this research can help in apparel element collection and fashion trend analysis.

Materials & methods

Materials

The images employed in this study came from fashion shows. In most cases, the models kept straight and walked facing the front, making a posture in which the shape of the apparel could be fully exhibited. Besides, in such situations as a stage show, the object (namely, the apparelled body) is often distinguished clearly from the background, and hence the necessary image segmentation could take effect. The fashion images were filtered and those with an obvious perspective effect or complicated background were discarded. Typical images used in this study are shown in ***Figure 1***.

Scheme

In order to identify the silhouette of apparel, the apparelled body in the image must be located and divided into some parts so that the sizes of apparel on these body parts can be extracted and inspected to make a decision on the silhouette. As a matter of fact, apparels often conceal the structure of human bodies, which makes it unrealistic to distinguish body parts in apparel through the body structure. The only part that is invariably re-

Figure 1. *Fashion images.*

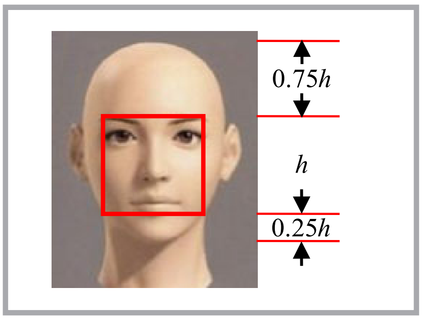

***Figure 2.** Feature region of the face.*

vealed in all these images may be the human face. Therefore the faces in the images become the focus of the issue. This study endeavoured to detect the human face in the image, and locate the head according to the position relationship between the face and head, further divide the body into some parts according to the proportion of body height to head length, and finally identify the silhouette based on the widths of body parts.

Facial feature region

The widely used AdaBoost [9] method was adopted for face detection in the images. A feature region needs to be defined for this method to work, then millions of Haar features of the region can be extracted to serve as weak classifiers. The most effective weak classifiers will be collected to form a strong classifier in training, and this mechanism is able to detect faces in the images after massive samples of the feature region have been fed in.

For the purpose of building a relationship between the feature region and the head, the feature region was defined as a four-square, shown in ***Figure 2***.

As indicated, this region is symmetric with the vertical center line of the forehead, and takes the span of eye sockets as the side length and the brow bone as the upside.

Providing that the span of the eye sockets (namely the side length of the feature region) is h, according to the facial organ proportion [10], the distance from 0.75 h the head top to the brow bone is about 0.75 h, and from the brow bone to the jaw - about 1.25 h. Thus once the facial feature region is detected, the head location in the vertical can be figured out.

Appareled body division

It is extremely hard, if indeed possible, to determine the structural positions on an appareled body as they may very often be concealed or shifted by the apparel, as illustrated in ***Figure 3***.

As suggested in the figure, although there does exist a waist position on the body, it does not necessarily exist on the apparel. Therefore instead of finding the structural positions as points of reference, this study divides the appareled body by proportioning, which is elaborated as follows.

Given that the vertical position of the head is determined in the prior stage of facial feature detection, the body is to be divided into several parts based on the ratio of body height to head length (abbr. RBH).

From knowledge of the costume body model, the height of an Asian adult is 7 - 7.5 times the head length [11]. The case of 7 times is illustrated in ***Figure 4***.

As indicated in the figure, the body is divided into five parts, which from top to bottom are the head (abbr. H), shoulder-chest (abbr. SC), chest-waist (abbr. CW), waist-hip (abbr. WH) and legs (abbr. L). Each of the H, SC, CW, WH parts covers 1-head length and the L part - 3-head length.

Human height varies with ethnicity. The European body height may reach 8- to 8.5-head length. With respect to the anatomy, the increased height is mainly manifested in the lower part of the body. Thus, if the RBH varies within a small range, the lengths of the H, SC and CW parts can be considered invariant, and those of parts WH and L vary, as illustrated in ***Figure 5***.

As shown in the figure, the WH and L parts of a 7-head length body are 1-head length and 3-head length, respectively, while those of a body with RBH equaling 8.5 are 1.5- and 4-head length, respectively. With RBH varying from 7 to 8.5, the lengths of the WH and L parts roughly increase in a linear way.

Therefore in the case of the RBH (denoted as r) being within the range [7, 8.5], the lengths of the body parts (denoted as H_h, H_{sc}, H_{cw}, H_{wh}, H_l respectively) can be calculated in the head length with the following formula:

$$H_h = H_{sc} = H_{cw}, = 1$$
$$H_{wh} = (r - 4)/3 \qquad (1)$$
$$H_l = (2\,r - 5)/3$$

Silhouette expression

All of the silhouette shapes take the status of clothing on the lower body into consideration. From the view of the silhouette, the apparel on the lower body covers the WH and L parts as a whole if no clothing hem exists, as in ***Figure 6.b***. However, when the clothing hem exists, it covers the whole WH part and a segment of the L part which starts from the beginning of the part and ends in the hemline, as in ***Figure 6.a***.

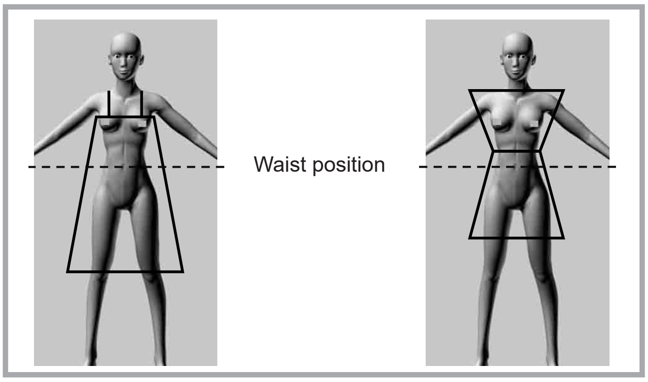

***Figure 3.** Waist position concealed by A-shaped dress (left) and improved by X-shaped dress (right).*

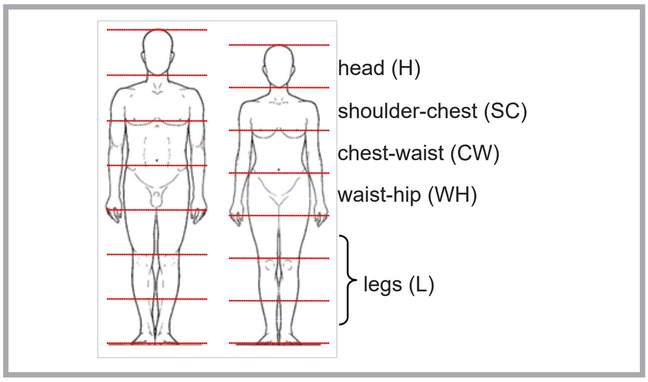

***Figure 4.** Five parts of body divided by head length.*

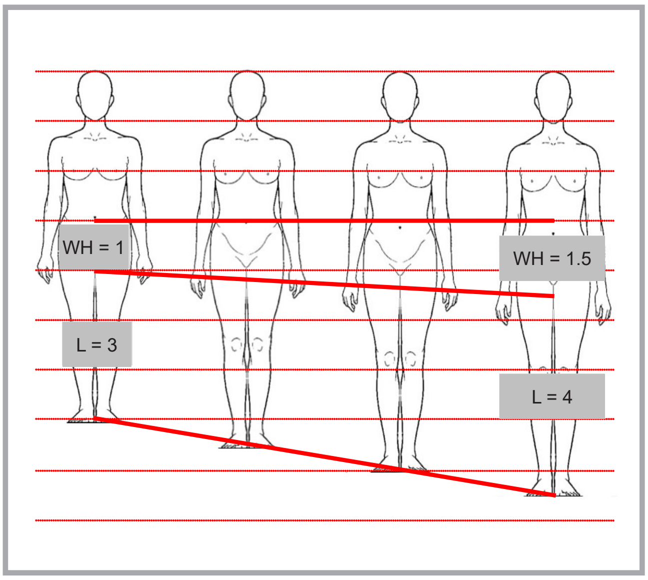

Figure 5. Heights variation of the WH and L parts with RBH.

Figure 6. Apparel on lower body.

Thus before any silhouette shapes of apparel could be expressed in mathematics, it is necessary to recognise whether a hemline exists. The hemline can be revealed by probing into the width along the height of the L part, as illustrated in *Figure 7*.

As the figure suggests, there is a sharp decline in the width of the L part of the image in *Figure 6.a*, which is different from that of the image in *Figure 6.b*, being in the position where a sharp decline occurs i.e. where the the hemline lies. This was used to locate the hemline in the computer program implementation.

Given the body has been divided vertically into several parts, and the range of the apparel on the lower body determined depending on the presence or absence of the hemline, the width of each part and lower body of the apparel can be measured by horizontal scanning in the image. Some shape factors can be established to express the shape of the apparel silhouette.

The A-shape is featured with the close-fitting upper body and expansive in the lower, as in *Figure 1.a*. Thus the A-shaped factor (denoted as F_A) can be defined as follows:

$$F_A = \frac{1}{F_T} = \frac{W_{whl}^2}{W_{sc}\,W_{cw}} \qquad (2)$$

where, W_{sc}, W_{cw}, W_{whl} are the average widths of the *SC* part, *CW* part as well as the lower body of the apparel, respectively. The A-shape feature manifests when $F_A > 1$. A larger F_A value suggests a more obvious A-shaped feature of the silhouette, whereas a T-shape, characterised by extended shoulders, a relaxed waist and tightened lower body, as in *Figure 1.b*, is quite the contrary to the A-shape. Hence F_T is defined as the reciprocal of F_A.

The X-shape features relaxed shoulders, a tightened waist and expansive hem, as in *Figure 1.d*, and the definition of the X-shaped factor (denoted as F_X) is given:

$$F_X = \frac{1}{F_O} = \frac{W_{cs}\,W_{whl}}{W_{cw}^2} \qquad (3)$$

The X-shape feature manifests when $F_X > 1$. The bigger the F_X value is, the more notably the X-shape feature exhibits. The O-shape is characterised by a tightened upper, lower and expansive waist, as in *Figure 1.c*, which is quite the opposite to the X-shape. Thus F_X and F_O are reciprocal to each other.

The H-shape features fitting or relaxed shoulders, waist and hem, as in *Figure 1.e*, which are roughly the same width and present a straight tube looking whole. Actually the H-shape can be viewed as in-between in the transition from the A- to T-shape, or from the X- to O-shape. Strictly speaking, the H-shape forms providing $F_A = F_X = 1$, although they are not likely to be equal to exactly 1 in practice. Thus the H-shape factor F_H is intended to convey how close F_A and F_X are to 1. Taking into account dimensional consistency with other factors, F_H is defined as follows:

$$F_H = \frac{F_A F_X}{\sqrt{|(F_A - 1)(F_X - 1)|}} \qquad (4)$$

A large F_H value indicates a prominent H-shaped feature of the silhouette.

The shape corresponding to the largest value of F_A, F_T, F_X, F_O, F_H can be con-

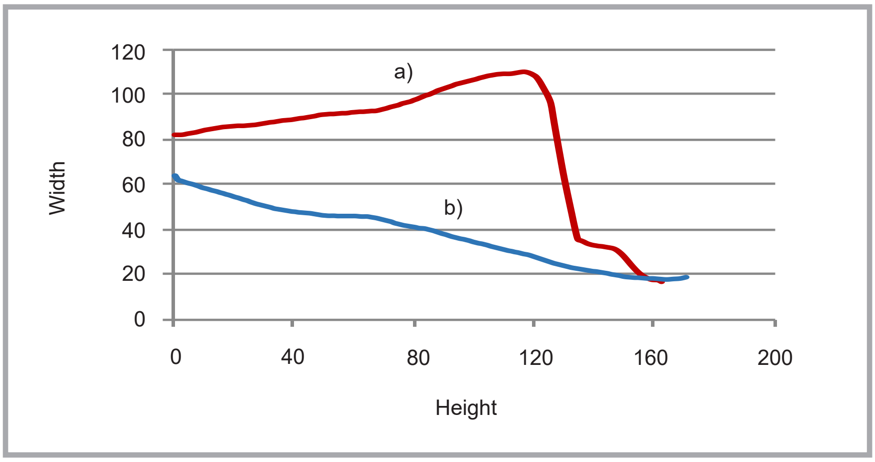

Figure 7. Width along the height of the L part.

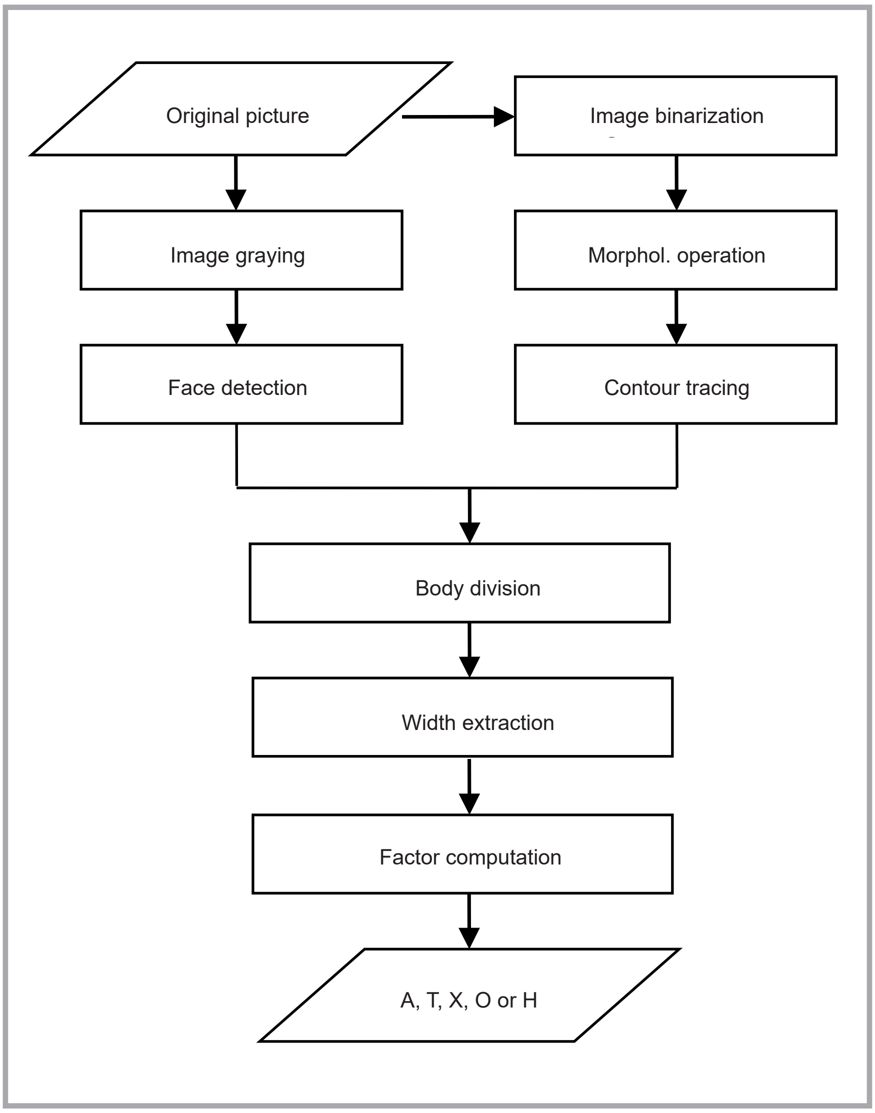

Figure 8. *Procedures of computer processing.*

Figure 9. *Major steps in image processing. a) OTSU thresholding, b) Morphol. Operation, c) Contour tracing, d) Body division.*

sidered as the resulting silhouette shape of the apparel.

Implementation

The scheme of silhouette identification stated above was implemented with computer programming in this study. The procedures of computer processing are illustrated in ***Figure 8***.

After the original image of the appareled body is put into the computer, the program raises an executing thread on which the image is first transformed into a grayscale image. Then face detection follows to detect the facial feature region from which the head location of the body in the vertical is figured out.

Meanwhile on another thread the image is converted into a binary image with OTSU thresholding [12], as in ***Figure 9.a***. The morphological operation [13] is followed to fill the small gaps in the object so as to introduce closed contours, as in ***Figure 9.b***. The contour tracing [14] technique is then employed to acquire object contours among which the largest and outmost one is considered as the outline of the appareled body, as marked with red in ***Figure 9.c***.

Then the program makes use of the horizontal line of the head-top (determined by the head location in the vertical) and that of the feet-bottom (determined by the lowest level of the body contour) to calculate the body height and RBH. According to ***Equation 1***, the appareled body is divided into five parts, as in ***Figure 9.d***, and also the range of the lower body of apparel determined by searching for the sharp change in the width of the L part. Afterwards the lengths of horizontal lines in each body part are extracted to figure out the average width of the part, based on which the shape factors are computed with ***Equation 2, 3, 4***, and the shape corresponding to the largest value is selected as the final result.

Some work was carried out to verify the computer program for silhouette identification. Three costume designers were involved to pick out 1000 pictures for each silhouette shape from a photo gallery which contains tens of thousands of pictures from fashion shows. A picture was adopted only when the judgements from three professionals agreed, and the disputable ones were discarded. The pictures adopted were sent to

Table 1. Accuracy rate of silhouette identification.

Silhouette Shape	Amount	Matched	Accuracy
A	1000	977	97.7%
T	1000	984	98.4%
X	1000	979	97.9%
O	1000	981	98.1%
H	1000	993	99.3%

the computer program to make decisions, and the accuracy rates for silhouette shapes are summarized in ***Table 1***.

Results & discussion

This study presented such methods of silhouette identification as follows.

Facial feature region

A deliberately schemed feature region of the face was established to suggest the relative position of the human head of an appareled body. When the facial feature region was detected in the picture by the AdaBoost method, the head location could be deduced.

Before face detection could be carried out, 1000 positive samples (namely, the facial feature regions) and 4000 negative samples in pictures from the fashion gallery were collected manually to conduct classifier training. Owing to the simple background in fashion shows bring little interference to the facial feature, the weak classifiers went into convergence after a number of iterations in the training course, as illustrated in ***Figure 10***.

As the figure indicates, after around 2000 iterations, the classifiers began to exhibit a stable error rate of about 0.16. This was a sign of high effectiveness of the AdaBoost method in detecting the facial feature regions in fashion pictures.

These 2000 weak classifiers were combined to make up a strong classifier. The strong classifier was used to detect facial feature regions in the fashion pictures, achieving an accuracy of 100.00%.

Appareled body division

In certain circumstances, according to human body proportions, the apparelled body was divided vertically into five parts, including the head, shoulder-chest, chest-waist, waist-hip and legs.

There are two premises with this kind of body division. One is that the growth of human height is mainly reflected in the lower body, while the change in length of the upper body can be overlooked. Another is that the length variation of the lower body has a linear relationship with the RBH. These two premises were guaranteed by confining the RBH in the range 7 - 8.5, where a general adult's RBH lies. For children and those with exceptional body proportions, this approach to body division would be inappropriate.

Additionally the heeled shoes worn by ladies may introduce some errors to this kind of body division as the body height is boosted with them. The heels affect the RBH, and in turn the length of the WH part as well as the L part according to ***Equation 1***. Take, for example, shoes with 10 cm-high heels, they make about a 5.8 cm increase in the wearer's height [15]. Their effect on body division on a general 175 cm-tall lady with an RBH of 7.5 can be calculated as in ***Table 2***.

As indicated in the table, the heeled shoes cause errors of 7.10% in H_{wh} and 4.97% in H_l. Similarly errors introduced by the shoes with wearers of different heights and RBHs can be figured out, as in ***Table 3***.

As shown in the table, the body height varies from 170 cm to 185 cm, and RBH from 7.0 to 8.5. The errors caused by heeled shoes are provided for each combination of height and RBH. The data in this table suggest the following:

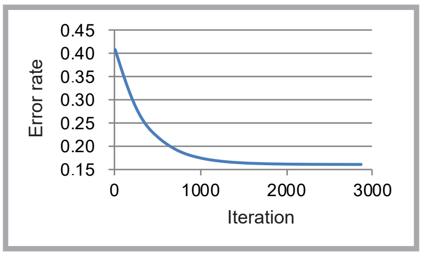

***Figure 10.** Convergence of weak classifiers.*

1. The errors decrease as the body height increases given that RBH remains consistent;
2. The errors decrease as the RBH increases given the body height remains constant.
3. Less than 8% is the maximum error that 10cm-high heeled shoes (or 5.8cm-high flat shoes) could bring about in body division.

Silhouette expression

By establishing the sharp change in width of the L part of an appareled body, which suggested the position of the hemline, the range of apparel on the lower body was determined. According to the connotations of the silhouette shapes, five shape factors based on the width of the SC part, the CW part and the lower body were established to express the proximity to the A-, T-, X-, O- and H-shapes, respectively. The silhouette shape of the apparel depended upon the largest value of the shape factors.

Implementation

In the concrete implementation of the scheme, a computer program was

***Table 2.** Effect of 10 cm-high heels on body division for a 175 cm-tall wearer.*

	Shoeless	Shoed	Error, %
Height, cm	175	175 + 5.8 = 180.8	3.31
Head length, cm	23.33	23.33	0.00
RBH	175/23.33 = 7.50	180.8/23.33 = 7.75	3.31
H_{wh}	(7.50 - 4)/3 = 1.17	(7.75 - 4)/3 = 1.25	7.10
H_l	(2×7.50 - 5)/3 = 3.33	(2×7.75 - 5)/3 = 3.50	4.97

***Table 3.** Errors caused by 10 cm-high heeled shoes on the body division with wearers of various height and RBH. **Note:** E_{wh} and E_l refer to the errors in H_{wh} and H_l, respectively.*

RBH	Height, cm	170	175	180	185
7.0	E_{wh}, %	7.96	7.73	7.52	7.32
	E_l, %	5.31	5.16	5.01	4.88
7.5	E_{wh}, %	7.31	7.10	6.90	6.72
	E_l, %	5.12	4.97	4.83	4.70
8.0	E_{wh}, %	6.82	6.63	6.44	6.27
	E_l, %	4.96	4.82	4.69	4.56
8.5	E_{wh}, %	6.44	6.26	6.09	5.92
	E_l, %	4.83	4.70	4.56	4.44

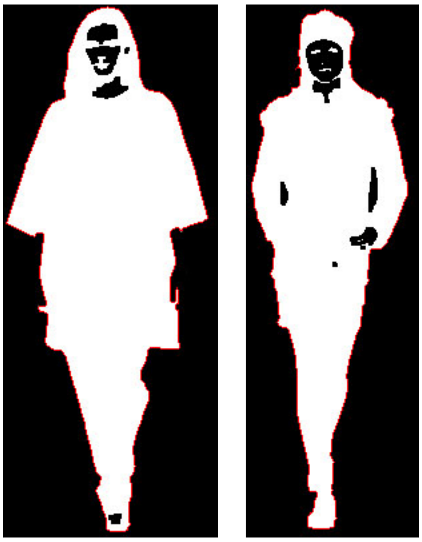

Figure 11. Appareled body contours with sleeves.

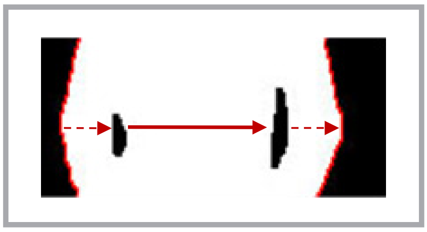

Figure 12. Exclusion of sleeves from the silhouette.

designed to achieve the following functions.

1. Find facial feature regions in the pictures by AdaBoost and estimate the location of the head.
2. Obtain the outline of the appareled body through image segmentation, morphological operation and contour tracing, then determine the body height, RBH and boundary of each body part.
3. Determine the boundary of apparel on the lower body by establishing the sharp change in the width of the L part.
4. Extract the widths of body parts, and calculate the shape factors and output of the resulting silhouette shape.

One of the detailed issues in the implementation was to deal with the sleeves of apparel. They would affect the appareled body contours which were acquired by the contour tracing technique, as illustrated in ***Figure 11***.

Figures 11.a. & 11.b indicate the contours acquired corresponding to ***Figures 1.c & 1.d***. Both include the sleeves. As a matter of fact, sleeves have an effect on the apparel silhouette. But whether or not the sleeves can be considered as part of the apparel silhouette is still controversial. In some cases like ***Figure 1.c***, the sleeves were intentionally expanded to match the style of the whole. Whether from the subjective intent of the designer or from thre visual perception of viewers, the sleeves play a role in the shape of apparel and should be embraced in the silhouette. However, in other cases like ***Figure 1.d***, the sleeves fit well with the arms and make no contribution to the shape of the apparelled body, and thus should not be counted as part of the silhouette.

For the latter type metioned above, there often exist gaps between the sleeves and the appareled body, as featured in ***Figure 12***. Therefore the longest line segment (indicated by a solid arrow in ***Figure 12***) was considered when horizontal scanning was carried out on the apparelled body contour for width calculation, with other segments (indicated by ta dotted arrow) being ignored. In this way, most sleeves that cannot help in shape expression could be excluded from the silhouette.

Conclusion

This study first put forward a feature region of the human face which could be detected in fashion pictures by the AdaBoost method. The head was located in the picture taking advantage of its positional relation to the facial feature region. The appareled body was then divided into several parts based on the ratio of the body height to head length, and the boundary of apparel on the lower body was determined considering the sharp change in the width of the L part, which indicated the hemline of the apparel. Possible errors on this kind of body division resulted from the heeled shoes, also inspected, with a maximum error less than 8% being revealed. The shape factors were built on the widths of body parts to express to what extent the silhouette approached a certain silhouette shape. In some cases the sleeves were excluded from width calculation, taking advantage of the gaps beside them. This scheme was implemented by computer programming, achieving high accuracy in apparel silhouette identification.

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