PCA Based Gait Segmentation

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Abstract

A PCA based gait segmentation method is proposed. Background images are used for PCA training. PCA reconstruction, recursive error compensation and single threshold based method is put forward for gait segmentation. Single threshold based method has the same gait segmentation ability as classical adaptive threshold based method, and the former is faster in implementation than the later. Proposed method is better than classical background subtraction based method, and can be compared with Gaussian derivative filter based method. Proposed method converges rapidly and has the excellent capability of gait segmentation for variant background.
Keyword: PCA, Gait segmentation, Gait recognition.

I. Introduction

Gait recognition is one of the main technologies for authenticating a person at a long distance. Other biometrics technologies, such as fingerprint recognition, iris recognition, face recognition, hand recognition and palmprint recognition, can't work effectively when person is far away.
Gait segmentation is the first step for gait analysis and recognition. Gait segmentation can be defined as extracting human body from background in gait image. Usually the result of gait segmentation is a silhouette image. Classical gait segmentation method is background subtraction [1]. This method can't work well when pixel of foreground image has similar gray level value as that of pixel of background image in the same position. Because there are new edges at human body contour in foreground image, human body counter can be found through comparing the edge information between foreground image and background image. We have provided a new gait segmentation method, which is based on comparing filtering results between foreground image and background image using multi-scale and multi-direction Gaussian derivative filters [2]. Better gait segmentation method is still expected.
Face recognition technology has been developed deeply, and a lot of algorithms have been proposed. Successful face recognition method can be used for other biometrics. Some approaches have been

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proposed to extract and remove eyeglasses from facial images. If we take person in gait image as glasses in facial image, glasses removal algorithm can be used for gait segmentation.
Satio reconstructed eyeglassless facial images using PCA [3]. Facial images with eyeglasses are projected into the eigenspace trained by eyeglassless facial images, from which corresponding eyeglassless facial images are reconstructed. The representational capability of PCA depends on the training images. Because the training images have no eyeglasses, the reconstructed images don't have eyeglasses no matter the input facial images have eyeglasses or not. Therefore, reconstruction errors caused by eyeglasses are spread out over the entire reconstructed image. This results in some degradation of quality and some traces of the eyeglasses frame remained. Simple PCA method has some limitations in obtaining natural looking glassless facial images. Cheng Du and Guangda Su removed eyeglasses from facial image using PCA reconstruction, recursive error compensation and adaptive threshold based method [4]. Regions, which are occluded by eyeglasses, are firstly detected by adaptive binarization approach. Then natural looking eyeglassless facial image is obtained by recursive error compensation of PCA reconstruction. The reconstructed images have neither trace of eyeglasses, nor the reflection and shade caused by the eyeglasses. A PCA reconstruction, recursive error compensation and single threshold based method is proposed in this paper.
The rest part of this paper is arranged as follows. PCA and SVD algorithm are introduced in section 2. Simple PCA reconstruction based gait segmentation method and PCA reconstruction, recursive error compensation and single threshold based gait segmentation method will be discussed in section 3. Experiments and results are in section 4. Section 5 is conclusions.

II. PCA Algorithm and SVD Algorithm

Proposed method is derived from PCA algorithm and SVD algorithm. PCA algorithm and SVD algorithm are described as follows.

A. *SVD Algorithm*

SVD algorithm is given firstly. Let $\boldsymbol{A}$ be a $M \times N$ real matrix of a face image, $M > N$, and $rank(\boldsymbol{A}) = K$, the singular value decomposition (SVD) of $\boldsymbol{A}$ is,

$$\boldsymbol{A} = \boldsymbol{U}\boldsymbol{\Sigma}^{\frac{1}{2}}\boldsymbol{V}^T . \tag{1}$$

where,
$\boldsymbol{\Sigma} = diag(\lambda_0, \lambda_1, ..., \lambda_{K-1}, 0, ..., 0)$,
$\boldsymbol{U} = [\boldsymbol{u}_0, \boldsymbol{u}_1, ..., \boldsymbol{u}_{K-1}, \boldsymbol{u}_K, \boldsymbol{u}_{K+1}, ..., \boldsymbol{u}_{M-1}]$,
$\boldsymbol{V} = [\boldsymbol{v}_0, \boldsymbol{v}_1, ..., \boldsymbol{v}_{K-1}, \boldsymbol{v}_K, \boldsymbol{v}_{K+1}, ..., \boldsymbol{v}_{N-1}]$,
$\boldsymbol{\Sigma}$ is a $M \times N$ matrix,
$\boldsymbol{U}$ is a $M \times M$ matrix,
$\boldsymbol{V}$ is a $N \times N$ matrix,
$\lambda_i, i = 0,1,..., K-1$ are eigenvalues of $\boldsymbol{A}\boldsymbol{A}^T$ as well as $\boldsymbol{A}^T\boldsymbol{A}$, and $\lambda_0 > \lambda_1 > ... > \lambda_{K-1}$,
$\sqrt{\lambda_i}, i = 0,1,..., K-1$ are singular values of $\boldsymbol{A}$,
$\boldsymbol{u}_i, i = 0,1,..., M-1$ are column eigenvectors of $\boldsymbol{A}\boldsymbol{A}^T$,
$\boldsymbol{v}_i, i = 0,1,..., N-1$ are column eigenvectors of $\boldsymbol{A}^T\boldsymbol{A}$.

The relationship of $\boldsymbol{U}$ and $\boldsymbol{V}$ is

$$\boldsymbol{U} = \boldsymbol{A}\boldsymbol{V}\boldsymbol{\Sigma}^{-\frac{1}{2}}. \tag{2}$$

B. *PCA Algorithm*

PCA (principal component analysis) algorithm is discussed as follows. Let $\boldsymbol{I}_i, i = 0,1,...,M-1$ be $N \times N$ face images for training, and it can be represented as $N^2 \times 1$ vectors $\boldsymbol{\Gamma}_i, i = 0,1,...,M-1$. The difference vector $\boldsymbol{\Phi}_i$ is defined as $\boldsymbol{\Phi}_i = \boldsymbol{\Gamma}_i - \boldsymbol{\Psi}$, where $\boldsymbol{\Psi} = \frac{1}{M}\sum_{i=0}^{M-1}\boldsymbol{\Gamma}_i$. $\boldsymbol{\Psi}$ is the average vector of $\boldsymbol{\Gamma}_i$. The $N^2 \times N^2$ covariance matrix $\boldsymbol{C}$ is defined as,

$$\boldsymbol{C} = \frac{1}{M}\sum_{i=0}^{M-1}\boldsymbol{\Phi}_i\boldsymbol{\Phi}_i^T = \frac{1}{M}\boldsymbol{A}\boldsymbol{A}^T. \tag{3}$$

where $\boldsymbol{A} = [\boldsymbol{\Phi}_0, \boldsymbol{\Phi}_1, ..., \boldsymbol{\Phi}_{M-1}]$. Directly computing eigenvectors $\boldsymbol{u}_i$ of $N^2 \times N^2$ matrix $\boldsymbol{A}\boldsymbol{A}^T$ is difficult, so eigenvectors $\boldsymbol{v}_i$ of $M \times M$ matrix $\boldsymbol{A}^T\boldsymbol{A}$ is computed ($M << N^2$). According to SVD, $\boldsymbol{A}\boldsymbol{A}^T$ and $\boldsymbol{A}^T\boldsymbol{A}$ have same eigenvalue λ_i, and the relationship of $\boldsymbol{u}_i$ and $\boldsymbol{v}_i$ is $\boldsymbol{u}_i = \frac{1}{\sqrt{\lambda_i}}\boldsymbol{A}\boldsymbol{v}_i$.

Image $\boldsymbol{I}_{N\times N}$ can be represented as vector $\boldsymbol{\Gamma}_{N^2\times 1}$, and related difference vector is $\boldsymbol{\Phi} = \boldsymbol{\Gamma} - \boldsymbol{\Psi}$. The feature of $\boldsymbol{I}_{N\times N}$ is $\boldsymbol{F} = \boldsymbol{U}^T\boldsymbol{\Phi}$. The reconstructed $\hat{\boldsymbol{\Phi}}$ is $\hat{\boldsymbol{\Phi}} = \boldsymbol{U}\boldsymbol{F}$. The reconstructed image vector $\hat{\boldsymbol{\Gamma}}$ is

$$\hat{\boldsymbol{\Gamma}} = \hat{\boldsymbol{\Phi}} + \boldsymbol{\Psi}. \tag{4}$$

III. Gait Segmentation Method

Simple PCA reconstruction based method, and recursive error compensation and single threshold based method, are depicted as follows.

A. *Simple PCA Reconstruction Based Method*

Firstly background images are used to train PCA algorithm [3]. Secondly foreground image $\boldsymbol{I}$ is projected to the eigenspace trained by background images. Then reconstructed image $\boldsymbol{I}^R$ of foreground image can be computed from eigenspace using PCA reconstruction algorithm. Because training images have no person, the reconstructed image has no person yet. Finally, reconstructed image is subtracted from original foreground image, and segmented binary image $\boldsymbol{I}^O$ can be gained by threshold,

$$\boldsymbol{I}^O = TH\left(\left|\boldsymbol{I} - \boldsymbol{I}^R\right|\right). \tag{5}$$

where TH is threshold operator.

B. Recursive Error Compensation and Single Threshold Based Method

PCA reconstruction, recursive error compensation and single threshold based gait segmentation method is given as follows. It is followed by a postprocessing, in order to obtain good gait segmentation results.

The quality of $\boldsymbol{I}^O$ from simple PCA reconstruction based method is not very good. Recursive error compensation and single threshold based method should be used [4]. The main difference between proposed method and method in [4] is, using single threshold to take the place of adaptive threshold. The proposed method is depicted as follows.

$$\boldsymbol{I}_j^C = \boldsymbol{W} \cdot \boldsymbol{I}_j^R + (1-\boldsymbol{W}) \cdot \boldsymbol{I},\ j = 1,2,\ldots,J\ . \tag{6}$$

$$\boldsymbol{I}_j^R = \begin{cases} PCA\_REC(\boldsymbol{I}),\ j=1 \\ PCA\_REC(\boldsymbol{I}_{j-1}^C),\ j=2,3,\ldots,J \end{cases}. \tag{7}$$

$$\boldsymbol{W}(m,n) = \begin{cases} 1, \boldsymbol{I}_j^O(m,n) = 1 \\ 0, \boldsymbol{I}_j^O(m,n) = 0 \end{cases}. \tag{8}$$

$$\boldsymbol{I}_j^O = TH\left(\left|\boldsymbol{I} - \boldsymbol{I}_j^R\right|\right). \tag{9}$$

where,

j is the number of iteration,

$\boldsymbol{I}$ is original foreground image,

$\boldsymbol{I}_j^C$ is error compensation image,

$\boldsymbol{I}_j^R$ is PCA reconstructed image,

$\boldsymbol{I}_j^O$ is the segmented binary image,

PCA_REC is PCA reconstruction algorithm,

$\boldsymbol{W}$ is weight matrix,

TH is single threshold operator, which is take the place of adaptive threshold.

If $\left\|\boldsymbol{I}_j^C - \boldsymbol{I}_{j-1}^C\right\| < \varepsilon$, where ε is a small threshold, the algorithm is terminated.

$\boldsymbol{I}_J^O$ is the ultimate segmented silhouette image.

Distance between PCA reconstructed image and original image is defined as

$$\boldsymbol{D}(j) = SUM\left(\left|\boldsymbol{I}_j^R - \boldsymbol{I}\right|\right),\ j = 1,2,\ldots,J\ . \tag{10}$$

Because there are small regions and holes in $\boldsymbol{I}_J^O$, a postprocessing is needed. Firstly a morphological close operator is used to merge small and near regions in $\boldsymbol{I}_J^O$. Then binary image are labeled and small regions are removed. Finally a hole-filling operator is used to fill the hole in binary image.

IV. Experiments and Results

Gait images come from CMU MOBO database [5]. This database has 25 persons, six different view angles, and four types of walk: slow walk, fast walk, slow incline walk and slow walk holding a ball.

A. *PCA Training with Similar Background Images*

18 similar background images of view angle 1 are used for PCA training.

Fig. 1 is the result of proposed method. Fig. 1(a) is the background image. Fig. 1(b) is the foreground image. Fig. 1(c) is $\boldsymbol{I}_J^O$. Fig. 1(d) is the result image of morphological close operator. Fig. 1(e) is the result image of removing small regions. Fig. 1(f) is the result image of hole filling. Fig. 1(f) shows that proposed method has perfect ability of gait segmentation.

Fig. 1(g) is the result image of background subtraction based method. Comparing Fig. 1(g) and Fig. 1(f), it shows proposed method is better than background subtraction based method.

Fig. 1(h) is the result image of Gaussian derivative filter based method. Comparing Fig. 1(h) and Fig. 1(f), it shows proposed method is as good as Gaussian derivative filter based method.

Fig. 1(i) is the result image of PCA reconstruction, recursive error compensation and adaptive threshold based method. Comparing Fig. 1(i) and Fig. 1(f), it shows proposed method has the same ability as PCA reconstruction, recursive error compensation and adaptive threshold based method. Because proposed method uses single threshold and need not compute adaptive threshold, whose computation load is large, it is faster in implementation than adaptive threshold based method.

Fig. 2 and Fig. 3 further study the ability of single threshold based method and adaptive threshold base method. Fig. 2(a)~2(d) are $\boldsymbol{I}_1^O$ ~ $\boldsymbol{I}_4^O$ of single threshold based method. Fig. 2(e)~2(h) are $\boldsymbol{I}_1^O$ ~ $\boldsymbol{I}_4^O$ of adaptive threshold based method. It shows the biggest difference is in the first iteration. This is because, single threshold based method uses a uniquely small threshold and adaptive threshold based method uses variant threshold, which is in direct proportion to the mean of $\left|\boldsymbol{I} - \boldsymbol{I}_j^R\right|$. Fig. 3 is the relationship curve of distance $\boldsymbol{D}(j)$ and the number of iteration. The solid line is the curve of single threshold based method, and the dashed is the curve of adaptive threshold based method. It shows the biggest difference is in second iteration. This because $\boldsymbol{I}_1^R$ is same in both methods of the first iteration. Fig. 2 and Fig. 3 show single threshold based method has the same ability for gait segmentation as adaptive threshold based method. Fig. 3 also shows proposed method will terminate at the fifth iteration. So proposed method converges rapidly. This is very important for realtime gait recognition system.

Fig. 4 has more examples of proposed method.

B. *PCA Training with Four Kinds of Background Images*

25 background images of view angle 1 are used for PCA training. These back-ground images can be divided into four kinds. Fig. 5 shows four kinds of background and its gait segmentation examples. Fig. 5 shows that proposed method can be used for variant background. This is very important for practical gait recognition system.

V. Conclusion

A PCA based gait segmentation method is proposed. Firstly background images are used for PCA training. Then PCA reconstruction, recursive error compensation and single threshold based method is brought forward for gait segmentation. Finally a postprocessing is adopted for obtaining well segmented image. Single threshold based method has the same ability as classical adaptive threshold based method, and the former is faster in implementation than the later, because single threshold based method uses a uniquely small threshold and adaptive threshold based method uses variant threshold. Proposed method is better than classical background subtraction based method, and can be compared with Gaussian derivative filter based method. Proposed method converges rapidly and can be used for variant background.

The main drawback of proposed method is that shade removing is not included. In future work shade removing will be studied.

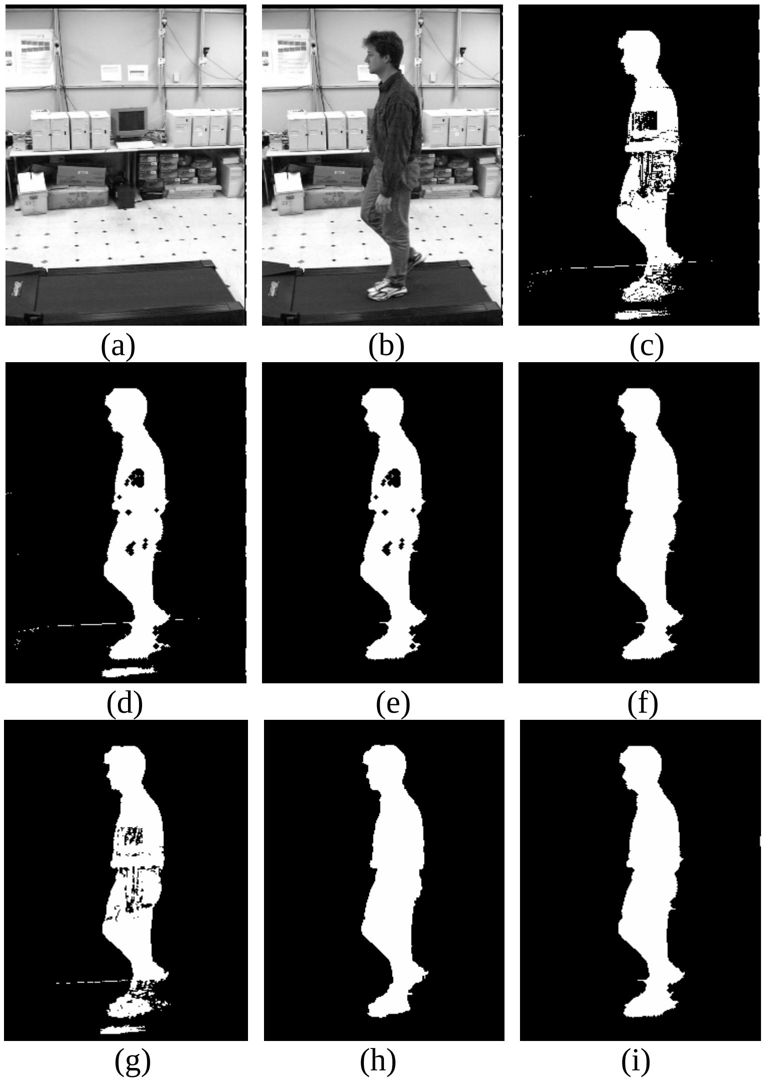


Fig. 1. (a) Background image, (b) foreground image, (c) I_J^O, (d) result image of morphological close operator, (e) result image of removing small regions, (f) result image of hole filling operator, (g) result image of background subtraction based method, (h) result image of Gaussian derivative filter based method, (i) result image of PCA reconstruction, recursive error compensation and adaptive threshold based method.

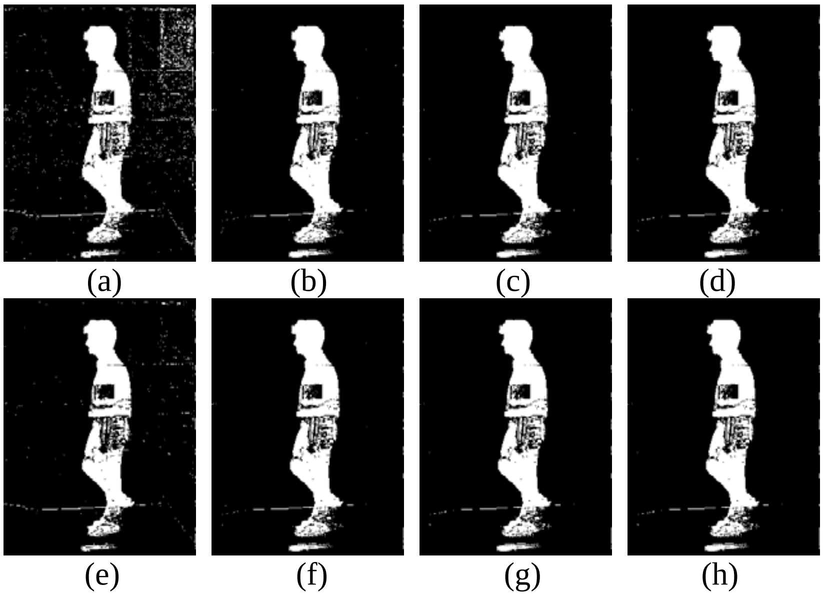


Fig. 2. (a) $\boldsymbol{I}_1^O$ of single threshold, (b) $\boldsymbol{I}_2^O$ of single threshold, (c) $\boldsymbol{I}_3^O$ of single threshold, (d) $\boldsymbol{I}_4^O$ of single threshold, (e) $\boldsymbol{I}_1^O$ of adaptive threshold, (f) $\boldsymbol{I}_2^O$ of adaptive threshold, (g) $\boldsymbol{I}_3^O$ of adaptive threshold, (h) $\boldsymbol{I}_4^O$ of adaptive threshold..

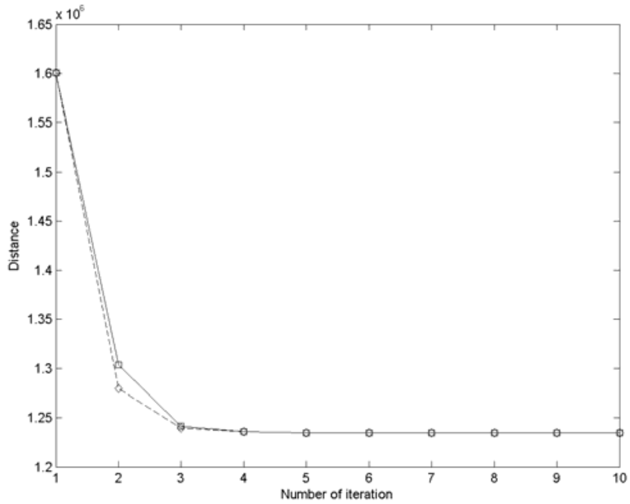


Fig. 3. The relationship curve of distance and the number of iteration. Solid line is the curve of single threshold, and dashed is the curve of adaptive threshold.

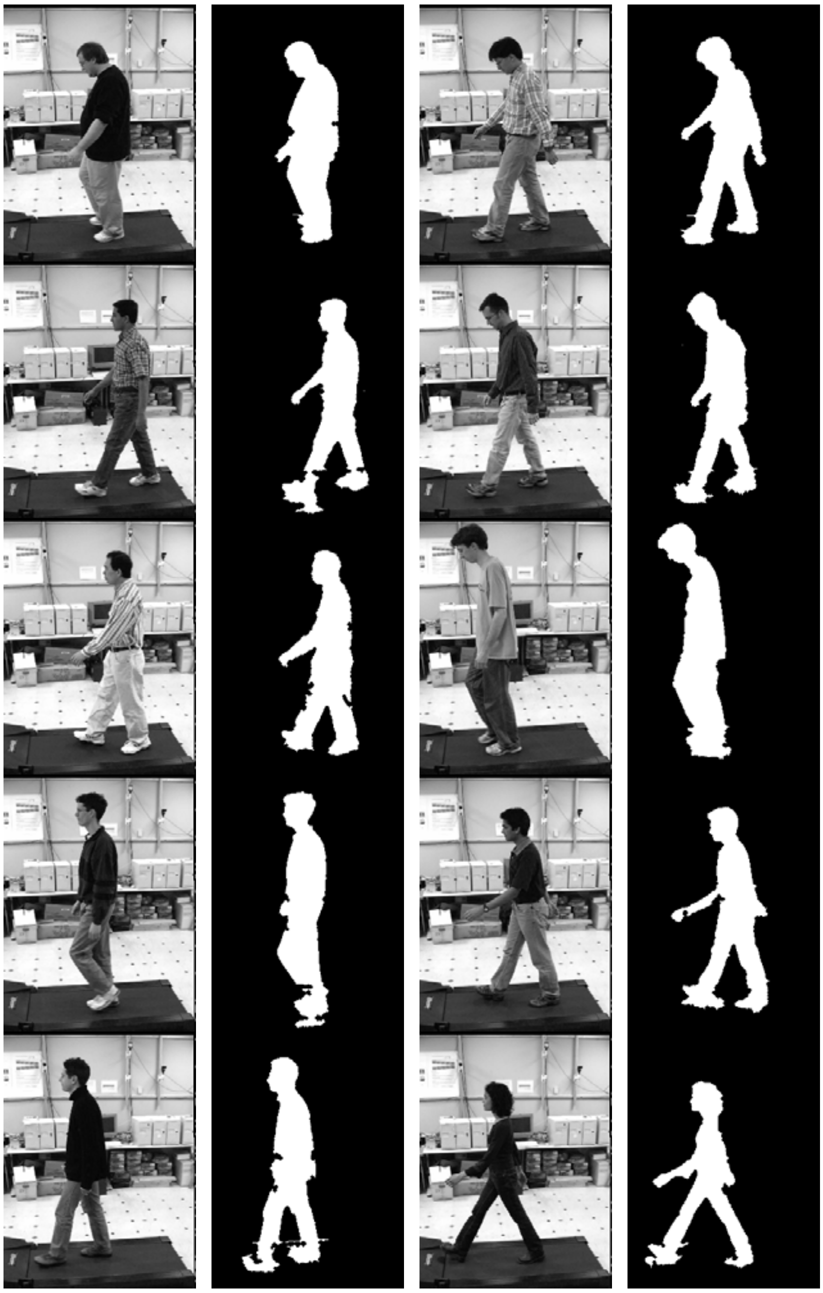
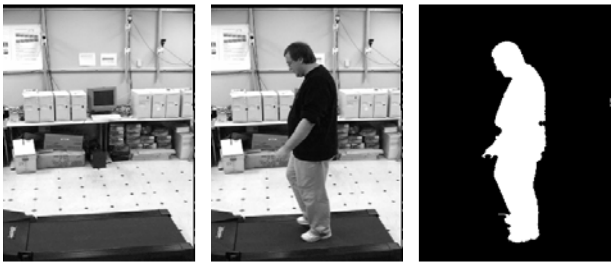
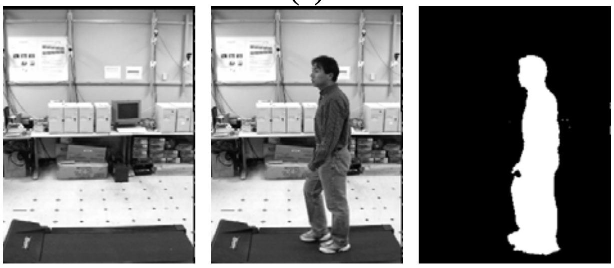


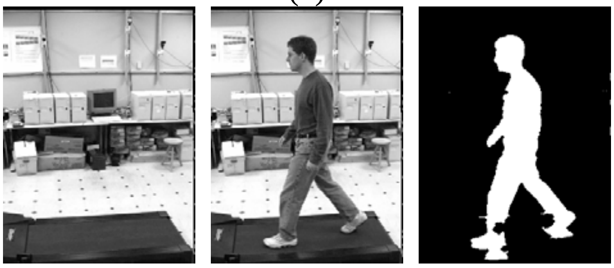
Fig. 4. More examples for foreground images and related segmented images.



(a)



(b)



(c)

(d)

Fig. 5. Four kinds of background and its gait segmentation examples. (a) background 1 and its gait segmentation example, (b) background 2 and its gait segmentation example, (c) background 3 and its gait segmentation example, (d) background 4 and its gait segmentation example.

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