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Identification of people walking along curved trajectories ☆

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ABSTRACT

Conventional methods of gait analysis for person identification use features extracted from a sequence of camera images taken during one or more gait cycles. The walking direction is implicitly assumed not to change. However, with the exception of very particular cases, such as walking on a circle centered on the camera, or along a line passing through the camera, there is always some degree of orientation change, most pronounced when the person is closer to the camera. This change in the angle between the velocity vector and the position vector in respect to the camera causes a decrease in performance for conventional methods. To address this issue we propose in this paper a new method, which provides improved identification in this context of orientation change. The proposed method uses a 4D gait database consisting of multiple 3D shape models of walking people and adaptive virtual image synthesis with high accuracy. Each frame, for the duration of a gait cycle, is used to estimate the walking direction of the subject, and a virtual image corresponding to the estimated direction is synthesized from the 4D gait database. The identification uses affine moment invariants as gait features. The efficiency of the proposed method is demonstrated through experiments using a database that includes 42 subjects.

1. Introduction

Biometric research uses a large number of characteristics to identify a person. Gait is one of biometrics that do not require interaction with the subject and can be obtained from a distance [11,17,13]. Person identification methods that extract features from gait images taken by a camera have been used with good results for human identification [5,12,10,15]. However, since image-based gait recognition is sensitive to changes in appearance, the correct classification rate is low in cases in which the subject's appearance is different from that in the database. One possible situations in which this problem can occur is the case in which the subject's waking direction with respect to the camera is different from that in the database.

Several methods have been proposed in order to address this problem. Makihara et al. introduced a view transformation model to synthesize virtual viewpoint images from captured images [10]. In their method, the view transformation model is obtained from training datasets of multiple people who were imaged from multiple viewpoints. We also introduced a 4D gait database consisting of multiple 3D shape models of walking subjects and a method that identified subjects using virtual viewpoint images synthesized from 3D models in the database [14]. Kusakunniran proposed a method by which to create a View Transformation Model (VTM) from a different viewpoint using Support Vector Regression (SVR) [6]. Goffredo et al. introduced a model-based method for viewpoint-independent gait recognition [7]. In their method, the pose estimation of the joint positions of walking people was performed through a markerless view-independent gait analysis, followed by rectification and normalization of the gait features. These methods implicitly assume that people walk along straight paths and that their walking direction does not change during a single gait cycle (i.e., that people do not walk along curved trajectories). However, in reality, people walk along curved trajectories when turning corners or avoiding obstacles, as shown in Fig. 1(a).

The large diversity of curved trajectories makes the collection of complete real world data in a database infeasible. This change in the direction of the velocity vector of walking people causes a decrease in performance for conventional methods, which assume that the walking direction is straight. The reason for this performance decrease is that, when a subject walks along a curved trajectory (except when walking on a circle centered on the camera), the viewing angle ϕ between the walking direction of the subject and the direction of the camera with respect to the subject gradually changes for all frames during a gait cycle, as shown in Fig. 1(a1).

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0167-8655/

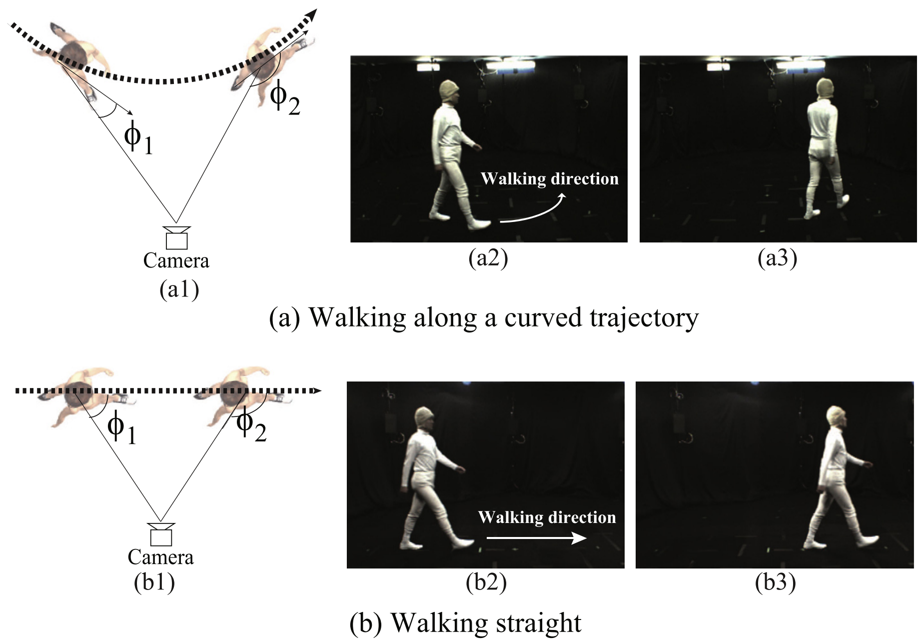

Fig. 1. (a) Subject walking along a curved trajectory ((a1) changes in viewing angle, (a2) first and (a3) last frames for one gait cycle), (b) subject walking along a straight trajectory ((b1) changes in viewing angle, (b2) first and (b3) last frames for one gait cycle).

Fig. 1(a2) and (a3) shows examples of actual images, which are the first and last frames, respectively, for one gait cycle. This problem occurs even when people walk along straight paths, as shown in Fig. 1(b1) [1], except when walking along a line passing through the camera. Akae et al. showed that, theoretically, the changes in viewing angle in one gait cycle affect the performance of gait identification, especially for cases in which the distance between the camera and the subject is small and side-view images are captured [1]. Fig. 1(b2) and (b3) shows examples of actual images, which are the first and last frames, respectively, for one gait cycle. The viewing angles in these images are clearly different.

Jean et al. proposed a method by which to generate view-normalized body trajectories [8] and performed experiments involving people walking along curved trajectories. Body trajectories are normalized based on the computation of walking planes and a homography transformation for each walking plane. Since homography transformation is a linear relation between two planes, this method assumes that the body trajectories are locally linear, even in the case of curved trajectories. Thus, entire-body curved trajectories cannot be normalized precisely.

We previously proposed a method for identifying people that is robust to changes in the viewing direction, which is defined by azimuth and elevation angles [16]. Here, the details of the azimuth and elevation angles are explained in Section 2. The method used a 4D gait database consisting of sequential 3D models of multiple people walking along straight paths and adaptive virtual image synthesis. In this method, one first estimates the position of the subject, more specifically projecting the subject's foot position onto the floor in 3D space, for each and every image during the duration of one gait cycle. Here, the foot position is defined by the projection to the ground of the center of area of the subject. The subject's walking direction in each frame is calculated based on the estimated positions. Next, the viewing direction in each frame is estimated from the estimated walking direction, and a virtual image is adaptively synthesized from each 3D model for the duration of one gait cycle in the 4D gait database, so that the viewing direction of the synthesized image is the same as that of the frame of the subject. Finally, the subject is identified using affine moment invariants extracted from images as gait features. Experiments using images of people walking along straight paths and curved trajectories demonstrated the effectiveness of the proposed method. However, since the subject's position on the floor was estimated using the captured image, there was a gap between the estimated and real positions. Thus, the synthesized image was not the same as the actual image. Moreover, since this difference results in high-frequency noise, the performance of the proposed method was not high enough. In the present paper, we expand the previous method [16] to synthesize virtual images with higher accuracy and propose an improved high-performance person identification method. The efficiency of the proposed method is demonstrated experimentally using a database that includes data for 42 subjects.

The remainder of the present paper is organized as follows. Section 2 briefly describes the previous method [16]. Section 3 introduces a method to improve the accuracy of the virtual image synthesis and a method for identifying people that is robust to high-frequency noise. Section 4 describes experiments performed to demonstrate the efficiency of the proposed method using a 4D gait database, and Section 5 presents our conclusions.

2. Person identification that is robust to changes in viewing direction [16]

In this section, we explain the changes in viewing direction in one gait cycle when a subject walks along a curved or straight trajectory and briefly explain the previously proposed method [16], including the virtual image synthesis and person identification.

2.1. Changes in viewing direction during one gait cycle

The viewing direction in each frame in one gait cycle is defined in terms of the azimuth angle $\phi^a_{P_n}$ and the elevation angle $\phi^e_{P_n}$ at each position P_n in one gait cycle, as shown in Fig. 2(a). More specifically, the azimuth and elevation angles are defined in a local coordinate system in each frame, as explained in the following. In the local coordinate system, the normal vector of the floor and the normalized velocity vector of the subject are defined as z and y axes, respectively, and the cross product of y and z axes is defined as x axis. The origin of the local coordinate system is at the foot