J. Vis. Commun. Image R. 38 (2016) 396–406

Contents lists available at ScienceDirect

J. Vis. Commun. Image R.

journal homepage: www.elsevier.com/locate/jvci

A new approach for multi-view gait recognition on unconstrained paths ☆

D. López-Fernández *, F.J. Madrid-Cuevas [1], A. Carmona-Poyato [1], R. Muñoz-Salinas [1], R. Medina-Carnicer [1]

Department of Computing and Numerical Analysis, Maimónides Institute for Biomedical Research (IMIBIC), University of Córdoba, Córdoba, Spain

ARTICLE INFO

Article history:
Received 16 June 2015
Revised 12 December 2015
Accepted 20 March 2016
Available online 22 March 2016

Keywords:
Gait recognition
Unconstrained paths
Rotation-invariant
Angular analysis
Curved trajectories
3D reconstruction

ABSTRACT

Direction changes cause difficulties for most of the gait recognition systems, due to appearance changes. We propose a new approach for multi-view gait recognition, which focuses on recognizing people walking on unconstrained (curved and straight) paths. To this effect, we present a new rotation invariant gait descriptor which is based on 3D angular analysis of the movement of the subject. Our method does not require the sequence to be split into gait cycles, and is able to provide a response before processing the whole sequence. A Support Vector Machine is used for classifying, and a sliding temporal window with majority vote policy is used to reinforce the classification results. The proposed approach has been experimentally validated on "AVA Multi-View Dataset" and "Kyushu University 4D Gait Database" and compared with related state-of-art work. Experimental results demonstrate the effectiveness of this approach in the problem of gait recognition on unconstrained paths.

1. Introduction

Research on human gait as a biometric feature for identification has received a lot of attention due to the apparent advantage that it can operate at a distance and can be applied discreetly without needing the active participation of the subject [1]. However, gait recognition performance is significantly affected by changes in various covariate conditions such as clothing [2], camera viewpoint [3,4], load carrying [5], and walking speed [6].

According to camera viewpoint, the previous work can be categorized into two approaches: view-dependent and view-independent approaches. View-dependent approaches assume that the viewpoint does not change while walking. In such methods, a change in the appearance, caused by a viewpoint change, will adversely affect to the recognition [7]. For example, when a subject walks along a curved trajectory, the observation angle between the walking direction of the subject and the camera optical axis is gradually changed during the gait cycle. Fig. 1 shows the influence of a curved path on the silhouette appearance. On the contrary, the view-independent approaches aim to recognize people under different viewing angles. However, some of them do not allow curved trajectories or direction changes during walking.

This paper presents a new approach to recognize people walking along curved trajectories on unconstrained paths. Some potential applications of this work are access control in special or restricted areas (e.g. military bases, governmental facilities) or smart video surveillance (e.g. bank offices). This work also can be used for staff identification on laboratories or medical isolation zones where subjects wear special clothes that do not allow them to show the face or use the fingerprint (e.g. protective clothing for viral diseases).

The rest of the paper is structured as follows. Section 2 presents the most relevant works related to ours, making a clear distinction between view-dependent and view-independent methods. Section 3 presents a new rotation invariant gait descriptor. Section 4 shows the details of our gait recognition method. An analysis of the performance is given in Section 5. Finally, we conclude this paper in Section 6.

2. Related work

2.1. View-dependent approaches

One of the earliest view-dependent approaches can be seen in [8], where it is used the width of the outer contour of the binarized silhouette from a side view, to build a descriptor which contains

☆ This paper has been recommended for acceptance by Chang-Su Kim.

* Corresponding author at: Computing and Numerical Analysis Department, Edificio Einstein, Campus de Rabanales, Córdoba University, 14071 Córdoba, Spain.

E-mail addresses: i52lofed@uco.es (D. López-Fernández), fjmadrid@uco.es (F.J. Madrid-Cuevas), ma1capoa@uco.es (A. Carmona-Poyato), rmsalinas@uco.es (R. Muñoz-Salinas), rmedina@uco.es (R. Medina-Carnicer).

[1] Computing and Numerical Analysis Department, Edificio Einstein, Campus de Rabanales, Córdoba University, 14071 Córdoba, Spain.

http://dx.doi.org/10.1016/j.jvcir.2016.03.020
1047-3203/

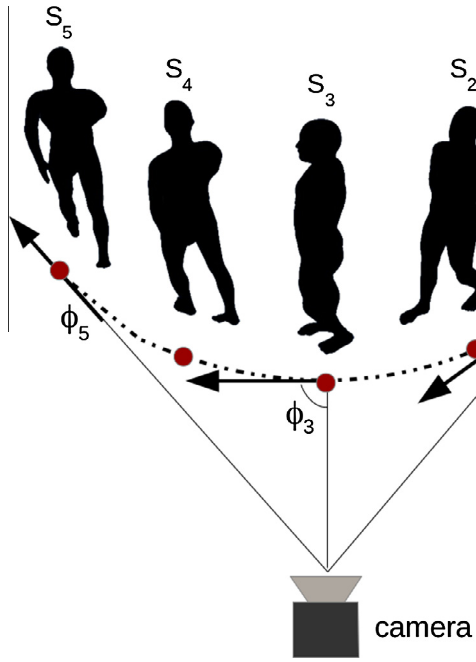

Fig. 1. In a curved path, the observation angle between the walking direction of the subject and optical axis of the camera is gradually changed, which affects the silhouette appearance.

both structural features and dynamic aspects of gait. Feature vectors derived from binary silhouettes have been also used to train Hidden Markov Models [9]. The contours of silhouettes have also been used [10,11].

In addition, in [12] it is presented a gait recognition method which analyses the shape of the silhouette using Procrustes Shape Analysis and Elliptic Fourier Descriptors. In [13] it is proposed a gait representation called Gait Energy Image (GEI), which is the average of all silhouette images for a single gait cycle.

Based on the idea of GEI, Depth Energy Image (DEI) was defined in [14], which is simply the average of the depth silhouettes taken along a gait cycle, over the front view. GEI is also extended in [15] to consider depth information from the side view, by means of a new feature called Depth Gradient Histogram Energy Image (DGHEI). In [16] a time-sliced averaged motion history image (TAMHI) alongside the histograms of oriented gradients (HOG) to generate gait signatures.

In [17] it is presented the Gait Energy Volume (GEV), a binary voxel-discretized volume which is spatially aligned and averaged over a gait cycle. The authors apply the GEV on partial reconstructions obtained with depth sensors from the front view of the individual. An extended work from GEV [17] that combines the frontal-view depth gait image and side-view 2D gait silhouette by means of a back-filling technique is presented in [18]. In [19], the depth and RGB frames from Kinect are register to obtain smooth silhouette shape along with depth information. A partial volume reconstruction of the frontal surface of each silhouette is done and the Pose Depth Volume (PDV) feature is derived from this volumetric model.

The performance of the above methods depends on the viewpoint. As was stated above, appearance changes due to viewing angle changes cause difficulties for most of the gait recognition methods, and this situation cannot be easily avoided in practical applications.

2.2. View-independent approaches

There are three major approach categories to sort out this problem [3], namely: (1) approaches that construct 3D gait information through multiple calibrated cameras; (2) approaches that extract gait features which are invariant to viewing angle changes; (3) approaches whose performance relies on learning mapping/projection relationship of gaits under various viewing angles.

Approaches of the first category are represented by [4,20–22]. In [21], a 3D approximation of a Visual Hull (VH) [23] is used to design a multi-modal and model-based gait recognition approach. Seely et al. [20] proposed an appearance-based approach which uses 3D volumetric data to synthesize silhouettes from a fixed viewpoint relative to the subject. The resulting silhouettes are then passed to a standard 2D gait analysis technique, such as the average silhouette.

Another approach that applies image-based rendering on a 3D VH model to reconstruct gait features under a required viewing angle is presented in [22]. This approach tries to classify the motion of a human in a view-independent way, but it has two drawbacks. On the one hand it considers only straight paths to estimate the position and orientation of a virtual camera. Tests were performed only on straight path motions. On the other hand, not all the 3D information available in the VH is used, because feature images are extracted from 2D images rendered only from a single view.

In [4], an observation angle at each frame of a gait sequence is estimated from the walking direction, by fitting a 2D polynomial curve to the foot points. Virtual images are synthesized from a 3D model, so that the observation angle of a synthesized image is the same that the observation angle for the real image of the subject, which is identified by using affine moment invariants extracted from images as gait features. The advantage of this method is that the setup assumes multiple cameras for training, but only one camera for testing. However, this approach requires to split the sequence into gait cycles and assumes that the gait phase of the first frame of a gait cycle of a subject is the same for each person in the database. Besides, shadows on the floor complicate the estimation of the foot points in silhouette images.

In the above four works, despite 3D models are used, the gait recognition scheme is based on silhouette analysis, what restricts a large amount of discriminant information because the recognition relies on single view silhouette analysis, instead of analyze the 3D information.

Approaches of the second category extract gait features which are invariant to viewing angle change. In [24], it is described a method to generate a canonical view of gait from any arbitrary view. This method can work with a single calibrated camera but the synthesis of a canonical view is only feasible from a limited number of initial views. The performance is significantly dropped when the angle between image plane and sagittal plane is large.

In [25], a method based on homography to compute view-normalized trajectories of body parts obtained from monocular video sequences was proposed. But this method efficiently works only for a limited range of views. Planar homography has also been used to reduce the dependency between the motion direction and the camera optical axis [26], however this method seems not to be applicable when the person is walking nearly parallel to the optical axis. In [27] view-invariant features are extracted from GEI. Only parts of gait sequences that overlap between views are selected for gait matching, but this approach cannot cope with large view angle changes under which gait sequences of different views can have little overlap. Neither it can be applied to recognize people walking on curved trajectories.

A self-calibrating view-independent gait recognition based on model-based gait features is proposed in [28]. The poses of the lower limbs are estimated based on markerless motion estimation. Then, they are reconstructed in the sagittal plane using viewpoint rectification. This method has two main drawbacks that are worth mentioning: (1) the estimation of the poses of the limbs is not