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Individual identification using a gait dynamics graph

Muqing Deng[a,b,*], Cong Wang[c,**], Tongjia Zheng[d]

[a] Institute of Information and Control, Hangzhou Dianzi University, Hangzhou, China
[b] Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong, Hong Kong
[c] College of Automation, South China University of Technology, Guangzhou, China
[d] College of Engineering, University of Notre Dame, Notre Dame, IN, USA

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ABSTRACT

In this paper, we propose a new gait representation—gait dynamics graph (GDG) for individual identification. For each gait sequence, lower limbs joint angles are extracted as gait parameters, and gait system dynamics underlying time-varying gait parameter trajectories is captured by using deterministic learning algorithm. Gait dynamics graph (GDG) is then generated by plotting the extracted dynamics information into three-dimensional graphic. Unlike other gait representations, which are not embedded with dynamics information, GDG demonstrates nonlinear gait dynamics in a new, visually intuitive manner using three-dimensional graphic representation. Both direct matching method and nonlinear dynamics analysis method can be used for GDG recognition independently. The performance of the proposed representation is evaluated and compared with the other representations experimentally on five large benchmark gait databases. This kind of gait representation is embedded with more distinctive information and preserves temporal dynamics information of human walking, which does not rely on shape or silhouettes information. Experimental results show that the GDG representation can further improve recognition rates and avoid the great drop of recognition rate when the training and test sets are under different walking conditions.

1. Introduction

Gait, known as the manner and style of human walking, is a new behavioral biometric for individual identification. Early medical research has shown that gait is unique to each individual and difficult to disguise [1]. Compared with other biometrics, gait has great prominent advantages in non-contact identification at a distance without subjects' cooperation, making it particularly attractive for surveillance, access control, criminal investigation and other security operations [2].

1.1. Motivation of gait dynamics graph (GDG)

There are a variety of gait representation methods for individual identification. These methods generate new gait data representations from series of gait sequences for recognition, greatly reducing the data size, but still retaining the distinctive information of human walking [3,4]. So far, despite that much progress has been made for gait representation, only limited success has been reported in the literature for the representation of gait dynamics information. Most of the existing works, i.e. the commonly used gait energy image (GEI) [3], represent the recency of the human walking motion, however, they are not embedded with any movement or dynamics information [5].

Regular human walking is a continuous and dynamical process. The dynamics nature is the essential characteristic of human walking, fundamentally different from the time/frequency domain characteristics used in the literature [6]. After pioneering works in [2,7], the importance of gait dynamics in the identification tasks has been recognized. The fundamental assumption made here is: gait characteristics underlying spatiotemporal gait representations without dynamics information are relatively limited and not comprehensive enough to reflect the essential characteristics of human walking. Under this assumption, one possible method is to extract gait dynamics underlying time-varying gait sequences and represent the dynamics information in a single form for dynamical gait recognition.

In our previous works [8,9], a dynamical neural learning mechanism was applied for capturing the dynamics information underlying time-varying gait parameters. We successfully extracted gait

* Corresponding author at: Institute of Information and Control, Hangzhou Dianzi University, Hangzhou, China
** Corresponding author.
E-mail addresses: dengmuqing@hdu.edu.cn (M. Deng), wangcong@scut.edu.cn (C. Wang).

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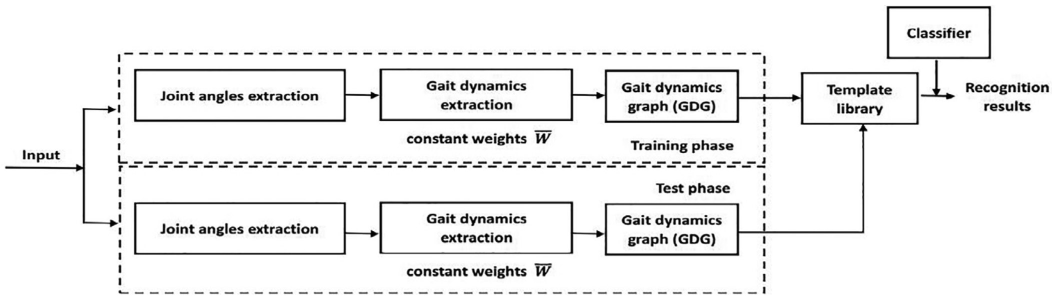

Fig. 1. Overall work flow of the proposed method.

dynamics along the phase portrait of joint angles versus angular velocities, for model-based gait recognition [8], and gait dynamics along the trajectories of silhouette width parameters, for silhouette-based gait recognition [9]. Our experiments have confirmed the feasibility of gait dynamics as an identifier of individuals. This kind of gait dynamics represents the temporal change of body poses or silhouettes between consecutive frame sequences [10]. Following this idea, in this paper, we propose a new gait data representation, gait dynamics graph (GDG), to represent the gait dynamics information and further improve the recognition rate.

1.2. Outline of the proposed method

The proposed method is schematically shown in Fig. 1. For each gait sequence, lower limbs joint angles are extracted as gait parameters, and gait system dynamics are captured by using deterministic learning algorithm. Gait dynamics graph (GDG) is then generated by plotting the extracted dynamics information into three-dimensional graphics. This kind of gait representation preserves temporal dynamics information of human walking, which does not rely on shape or silhouettes information. Both direct matching method and nonlinear dynamics analysis method can be used for GDG recognition.

1.3. Contribution of the proposed paper

In comparison with the state-of-the-art, the contributions of the proposed paper are:

1. *New gait representation*—We propose a new model-based gait representation, called gait dynamics graph (GDG) for individual identification. Unlike other gait representations, which are not embedded with any dynamics information, GDG demonstrates nonlinear gait dynamics in a new, visually intuitive manner using three-dimensional graphic representation.
2. *Improvement of recognition rate*—To further improve the recognition rate, we combine the five-link biped model and dynamical neural learning mechanism, to extract gait system dynamics and generate a simple but novel GDG representation. The generated GDG representations are embedded with more distinctive information and are relatively insensitive to the change of gallery sizes.
3. *Robustness against covariant factors*—The proposed method captures the gait system dynamics underlying shallow shape information via dynamical learning algorithm. This kind of gait dynamics preserves temporal dynamics information of human walking, which does not rely on shape or silhouettes information. Therefore, it has little sensitivity to different covariate factors and can avoid the great drop of recognition rate when the training and test sets are under different walking conditions.
4. *Experimental results*—The proposed method is tested on CASIA-B, CASIA-C, TUM GAID, OU-ISIR-A and CMU MoBo database. We have provided the recognition performance based on smallest error principle, and dynamics indexes, as well as the comparison with the state-of-the-art published results.

2. Related work

Existing gait recognition methods can be roughly divided into two different categories: model-based methods and silhouette-based methods.

The model-based methods construct motion or structural models from human walking sequences and use them to extract gait parameters for individual identification. Recent findings [11] have demonstrated that the model-based methods are able to deal with the occlusion and rotation problems to some extent. However, model construction, model fitting and feature extraction are still the main difficult tasks in model-based gait recognition methods.

The silhouette-based methods directly operate on the human silhouettes without any structural or human motion models. Gait characteristics are implicitly reflected by the holistic silhouettes extracted directly from the walking images or videos. In this sense, the data size of the time-varying signal depends on the number of frames in the gait sequence. A longer gait sequence will lead to a larger data size of the signal. That is why most of the mentioned works applied dimensional reduction technique to further reduce the data size [5].

Recently, much progress has been made in the literature for generating a new gait data representation from the gait sequences. These methods extract the silhouettes from the images and combine them over the gait-cycle to obtain a new data representation, which is used for person identification [4,5]. Compared with the time-varying signal, the gait representation can greatly reduce the data size, but still retain the distinctive information for recognition [5]. Gait energy image (GEI) [3] is one of the most commonly used data representations in gait recognition. Originally conceptualized by Bobick and Davis's Motion-Energy Image (MEI) and Motion-History Image (MHI) [12], GEI extracts human body silhouettes by using background modeling and averaged these silhouettes over the time in a gait-cycle. Whytock et al. [13] extracted skeleton information from the silhouette images using the screened Poisson equation and combined it with motion information, yielding a new gait representation, called Skeleton Variance Image (SVIM). Chen and Gao [14] investigated gait dynamics underlying a 2D polar plane silhouette description. Depth Gradient Histogram Energy Image (DGHEI) was proposed by Hofmann et al. [15] for capturing the edges and depth gradient of human silhouette from depth images. Lam et al. [5] computed the optical flow fields on extracted silhouettes and presented a new representation-Gait Flow Image (GFI). Yang et al. [11] proposed a representation called Flow Histogram Energy Image (FHEI), which computed the Histogram of Optical Flow (HOF) using the silhouette images and averaged them on a full gait cycle.