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# A cascade fusion scheme for gait and cumulative foot pressure image recognition

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ABSTRACT

Cumulative foot pressure images represent the 2D ground reaction force during one gait cycle. Biomedical and forensic studies show that humans can be distinguished by unique limb movement patterns and ground reaction force. Considering continuous gait pose images and corresponding cumulative foot pressure images, this paper presents a cascade fusion scheme to represent the potential connections between them and proposes a two-modality fusion based recognition system. The proposed scheme contains two stages: (1) given cumulative foot pressure images, canonical correlation analysis is employed to retrieve corresponding gait pose image candidates in gallery dataset; (2) pedestrian recognition is achieved via small samples matching between retrieved gait pose images and unlabeled ones. The proposed fusion recognition system is not only insensitive to slight changes of environment and the individual users, but also can be extended to multiple biometrics retrieval. Experimental results are conducted on the CASIA gait–footprint dataset, which contains cumulative foot pressure images and its corresponding gait pose image sequence from 88 subjects. Evaluation results suggest the effectiveness of the proposed scheme compared to other related approaches.



## 1. Introduction

Recent biomedical and forensic studies [1] reveal that humans can be distinguished by unique walking patterns (e.g., limb movement pattern and ground reaction force). Unique limb movement patterns seem to help to recognize individuals at distance (e.g., gait recognition [2]), while ground reaction force and its variants such as footprints are also separately utilized to identify criminals by human experts [3]. Recent walking pattern based recognition systems are not practical for many reasons due to the single camera sensor. For example, viewpoint problems in gait recognition under constrains could be avoided if we use Kinect [4]. The cumulative foot pressure image is a cumulative image-type record of ground reaction force change during one gait cycle [5]. It provides richer information to identify different walking patterns, compared to the existing 1D ground reaction force or simple 2D footprint pictures. The cumulative foot pressure image has been applied in biomedical assistant, forensic investigation, sports assistant training and custom shoes [5]. In order to address the problems in existing walking pattern recognition systems, we propose to develop a computational correlation model for cumulative foot pressure images and gait.

As far as we know, there are a few previous works proposed to develop the computational correlation model for cumulative foot pressure image and gait, although a lot of works have been proposed to study gait recognition [6–8] or the cumulative foot pressure images [5]. Multimodal biometric system [1] have been proposed to combine evidences from different sources. These sources might simultaneously come from various sensors [9], different classification algorithms [10], multiple instances for the evidence or directly from diverse biometric traits [11]. Naive feature combinations may not always improve the performance, since some components in different sources may not be complementary. Zhang et al. found that the performance of human recognition using multiple sources could be improved by reducing the redundant classes in the gallery dataset [12]. Specifically, in order to evaluate the computational correlation model we obtain, we also develop a human recognition system using gait pose images and corresponding cumulative foot pressure images without these limitations using a cascade fusion scheme.

The proposed study is necessary since it not only provides a computational correlation model but also a solution for entrance control applications. For example, in jailhouse security system or suspect identification, cumulative foot pressure images and gait pose images of the same individual can be captured at different times. Hence, cumulative foot pressure images and gait pose

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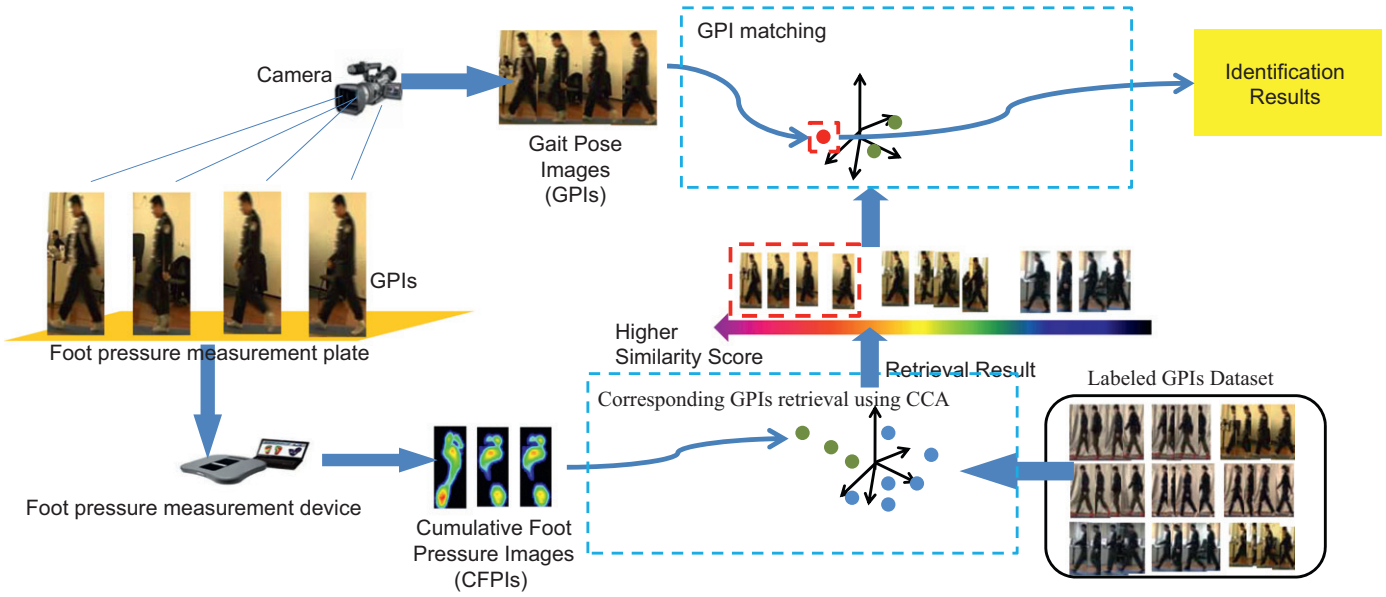


**Fig. 1.** Overview of pedestrian recognition using gait and cumulative foot pressure images.

images can be used to identify escaped criminal or investigate suspects noninvasively. Furthermore, the proposed cascade two-modality fusion scheme can also be employed to develop a cross-multiple-biometrics information retrieval system [13], which could allow users to retrieve the gait pose images from the person of interest given the corresponding cumulative foot pressure images.

Fig. 1 gives an overview of the propose scheme. When a person walks over the foot pressure measurement plate, cumulative foot pressure images are captured. Simultaneously or not, corresponding gait pose image sequences are captured via an off-the-shelf camera. After preprocessing and feature extraction, canonical correlation analysis (CCA) is employed to find corresponding images in the gait pose gallery dataset, given the cumulative foot pressure images. Then, pedestrian recognition is achieved via matching the unlabeled gait pose images with labeled retrieved ones. Briefly, the scheme consists of three parts:

- Feature representation for gait pose images and cumulative foot pressure images.
- Corresponding labeled gait pose image retrieval using CCA.
- Pedestrian recognition via gait pose image matching.

The remainder of this paper is organized as follows. Section 2 presents related work about gait, cumulative foot pressure and multiple evidence fusion schemes for pedestrian recognition. Section 3 illustrates the proposed cascade fusion scheme. In Section 4, feature representation for gait pose images and cumulative foot pressure images are presented. Section 5 describes the fusion based recognition system. Section 6 introduces the dataset. Section 7 reports the experiments. We draw conclusion in Section 8.

## 2. Related works

Gait recognition is potentially useful for personal identification [14]. It is quite attractive for identification purposes since its advantages are that it is completely unobtrusive, and does not involve any subject cooperation or contact. The state-of-the-art approaches in gait recognition can be divided into model-based and model-free approaches.

Model-based approaches tend to recover the underlying mathematical construction of gait with a structure motion model. The mean shapes of gait silhouettes are modeled by Wang et al. via employing procrustes analysis [15]. Bouchrika and Nixon extract crucial feature descriptions from human joints by developing a motion-based model using elliptic Fourier descriptors [16]. However, the performance of the approaches suffers from poor localization of the torso and difficult extraction of underlying models from gait sequences.

The other kind of approach is model-free one. One kind of model-free approach preserves temporal information in recognition and training states. Hidden Markov models (HMMs) are utilized to achieve gait recognition [17]. Principal component analysis (PCA) [18,19] is employed to extract statistical spatial–temporal feature descriptors of gait [20]. In this kind of approach, large-scale training samples are required for probabilistic temporal modeling approaches to obtain a good performance. Hence, the disadvantage for the approach is the high computational complexity of sequence matching during recognition and the high storage requirement of the dataset. Another kind of model-free approach converts a sequence of images into a single template. Gait recognition by averaging all the silhouettes is presented by Liu et al. [21]. Han proposed a gait energy image (GEI) to construct real and synthetic gait templates [22]. The recognition performance may degrade since the temporal information in gait sequences are discarded. Wang et al. developed a spatial-temporal walking template called chrono-gait image (CGI) to encode the temporal information via color mapping to improve the recognition rates [23]. The main drawback of these approaches is that they easily suffer from slight changes of environment such as illumination variation in probe and gallery data collections or crowded scenarios. Besides, traditional motion-based gait representation is not practical and stable in more wide application scenarios such as internet videos or image sequences from IP camera.

Recent works on action recognition started to introduce some feature descriptors like histograms of oriented gradients (HOG) to represent several action key poses [24]. Such kinds of feature descriptors have also helped to achieve state-of-the-art performance in object detection and object recognition [25]. In these tasks, they are proved to overcome environmental challenges and be able to represent objects without background priority or