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Model-based human gait recognition using leg and arm movements

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ABSTRACT

We have presented a model-based approach for human gait recognition, which is based on analyzing the leg and arm movements. An initial model is created based on anatomical proportions, and a posterior model is constructed upon the movements of the articulated parts of the body, using active contour models and the Hough transform. Fourier analysis is used to describe the motion patterns of the moving parts. The *k*-nearest neighbor rule applied to the phase-weighted Fourier magnitude of each segment's spectrum is used for classification. In contrast to the existing approaches, the main focus of this paper is on increasing the discrimination capability of the model through extra features produced from the motion of the arms. Experimental results indicate good performance of the proposed method. The technique has also proved to be able to reduce the adverse effects of self-occlusion, which is a common incident in human walking.

1. Introduction

In recent years, human recognition with high reliability has gained considerable importance in different applications such as access control and visual surveillance. Research has shown that this goal may be reached through biometrics. A biometric is a measure taken from a living person, which is essentially universal, unique, permanent and collectable (Jain et al., 1999). This measure can be based on physiological characteristics such as fingerprints, or some aspects of human behavior such as handwriting (Cunado et al., 2003). Physiological biometrics have been receiving more attention so far and include face, iris, retina, fingerprints, hand geometry, and voice patterns. Among all possibilities, gait is the newest (Jain et al., 1999).

Humans can recognize friends and acquaintances by the way they walk. Psychological studies support the notion that gait can be perceived by human vision as a set of unique patterns (Johannson, 1973). That is why the study of this universal and complex human activity has generated a lot of interest in various fields, especially in computer vision. It is challenging, however, to find discriminative gait features in markerless motion sequences.

Many established biometrics are obscured in various person identification applications. The face may be at low resolution or hidden with make-up or glasses, the palm could be obscured or hands may be cut off, and the ears might be covered by hair. But people need to walk; and their manner of walking is usually observable and more difficult to obscure or disguise. This feature introduces gait as a biometric. An outstanding advantage of gait is its potential for being noticeable over long distances, in contrast to other biometrics which may need high resolution images taken from a close distance. Besides, it is difficult to conceal or imitate the motions of an individual's walking. Perhaps, what makes gait an attractive biometric is its non-invasiveness, which does not involve any notification or contact with the subject.

Despite all privileges, there are limits to the use of gait. For instance, footwear, clothing or object carrying can affect it. In addition, physical conditions such as pregnancy, leg or foot injuries, or even drunkenness can change the manner of walking. Like most biometrics, gait will instinctively change with age. But a good biometric system should be able to understand the basic features of the biometric, regardless of the presence of such factors. However, representing a method to study gait as a potential biometric under limited conditions would be an initial step towards materializing a general gait recognition method.

This research investigates the potential discriminatory capability of the gait signatures obtained from different parts of the body such as legs and arms. The subject is modeled based on anatomical proportions and recognition is carried out through the *K*-nearest neighbor classifier and Fourier components of the joint angles. Special attention is paid to the movement of arms in conjunction with the movement of legs.

The rest of this paper is organized as follows: Section 2 presents current approaches to gait recognition by computer vision techniques. In order to better understand the nature of gait, an overview of the terminology and biomechanics of a person's motion is given from medical literature in Section 3. Section 4 presents the proposed algorithm. Experimental results are given in Section 5, and Section 6 concludes the paper.

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2. Previous work

Existing methods for gait recognition can be divided into two main categories: model-free and model-based approaches. Model-free approaches attempt to extract a gait description without resolving the body pose, and, hence, avoid the most complex part of this problem. These approaches typically use the subject's silhouette and its features (Phillips et al., 2002). The main advantages of these methods, compared to model-based approaches, are their simplicity and speed. However, these approaches are essentially data-driven, and, thus, the recognition rate is limited by the input data quality and noise. Occlusion and variation in clothing also affect the silhouette dynamics. Phillips et al. (2002) measured the correlation between the probe silhouette image sequences and those in a dataset, while Collins et al. (2002) applied template matching to selected key frames. Different image features are used to identify the spatial and temporal variations of human gait, such as silhouette self-similarity (BenAbdelkader et al., 2004), moments of optical flow (Little and Boyd, 1998), width of the outer contour of a silhouette (Kale et al., 2003), and generalized symmetry operators (Hayfron-Acquah et al., 2003).

Model-based approaches incorporate knowledge of the shape and dynamics of human gait into the feature extraction process, constraining the expected shape and motion of the subject to a known set of possible alternatives, which helps these approaches overcome weaknesses of the previous category. Here, gait dynamics are directly extracted by determining the joint positions, rather than inferring dynamics from other measures. However, constructing a suitable model is the main difficulty and even the source of error in these approaches. This is because applying sufficiently complex features to incorporate individual variation across the population may lead to complex models with many free parameters. However, with gait features closely related to the walking mechanics, model-based approaches have a high potential for robust feature extraction. Human-like structures are proposed in this process. Cunado et al. (2003) modeled the thighs as interlinked pendulums and used the Fourier series to extract their angular movements. Bobick and Johnson (2001) used the act of walking to derive body parameters which described the subject's body and stride. Yam et al. (2004) developed a model-based system to describe the two legs and to handle walking as well as running. This was based on evidence gathering and anatomical constraints. Zhang et al. (2007) was concerned with the change in the orientation of human limbs. Given distances normalized by the height of thorax, he represented the body posture by a set of distance measurements and the inclination of its parts.

Model-based methods seem to be more attractive and promising; but they have to deal with the complexity of models and model extraction, which is not a trivial task.

3. Biomechanics of walking

Studies and observations made regarding human identification has revealed that "A given person will perform his or her walking pattern in a fairly repeatable and characteristic way; sufficiently unique that it is possible to recognize a person at a distance by his gait" (Winter, 1990). As a matter of fact, walking uses a repetitious sequence of limb motions moving the body forward while simultaneously maintaining stability. As the body moves forward, one limb serves as a source of support while the other progresses to a new support site. The limbs then reverse their roles. A single sequence of events by one limb is called a *gait cycle* (Zhang et al., 2007). Each gait cycle is divided into two periods: a stance and a swing. *Stance* is used to describe the period during which the foot is on the ground and is subdivided into three intervals according to the sequence of floor contacts for both limbs. *Swing* is the period in which the foot is on the air. Both the start and end of stance involve a period of bilateral foot contact with the ground (double stance), while the middle portion has a period of single limb contact (single stance). The duration of a single limb support for one limb equals the swing of the other.

The relative distribution of the periods of gait within a gait cycle is 60% for the stance and 40% for the swing (Zhang et al., 2007); but the precise duration of these intervals within the gait cycle varies with a person's walking velocity.

The whole process of walking begins with the heel strike of one foot (initial contact) (right foot for example), followed by flexion of ankle to bring that foot flat on the ground, which causes the transmittal of body weight onto it (loading response). Then the left leg swings through in front of the right leg as the right heel lifts off the ground (mid stance). As the body weight moves onto the left foot (terminal stance), the supporting right knee flexes. The remainder of the right foot, which is now behind (pre-swing), lifts off the ground (initial swing) ending the stance phase with toe-off (terminal swing) (Cunado et al., 2003). Fig. 1 illustrates the described sequence.

The motion between successive points of contacts of the same foot is called *Stride*; and the motion among consecutive heel strikes of opposite feet is a *Step* (Cunado et al., 2003). It is obvious that a complete gait cycle includes two steps. Thus, human gait is a form of periodic motion, especially when one walks laterally, and can be predicted in a cycle. The motion period and gait frequency are the time taken by a step and the number of steps taken per second, respectively (Cunado et al., 2003).

Medical research has shown the uniqueness of gait, considering all movements (Zhang et al., 2007) and using markers to represent the observed movement in the form of 3D trajectories that translate into kinematic variables such as body movements and joint angles (Yoo et al., 2002). But using markers needs intrusive and expensive specialized hardware and requires

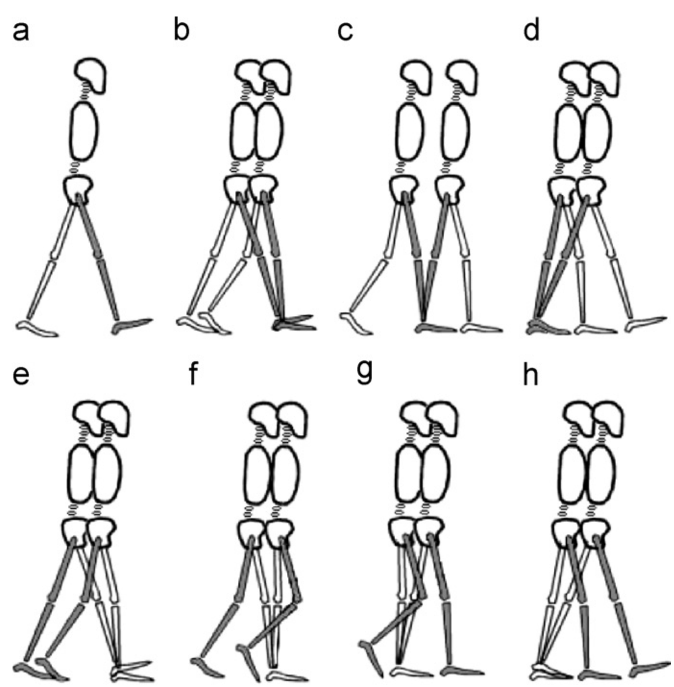

Fig. 1. Limb posture during different phases of gait (Murray et al., 1964): (a) initial contact, (b) loading response, (c) mid stance, (d) terminal stance, (e) pre-swing, (f) initial swing, (g) mid swing and (h) terminal swing.