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Biometric gait identification based on a multilayer perceptron

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HIGHLIGHTS

- Novel biometric gait identification approach based on a multilayer layer perceptron.
- Identification of disordered and abnormal gait patterns is a fundamental problem.
- Development of an intelligent system to identify human activities.

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ABSTRACT

In this study, we propose a novel approach for biometric gait identification. We designed a multilayered back-propagation algorithm-based artificial neural network for gait pattern classification and we compared the results obtained with those produced using the *k*-means and *k*-nearest neighbor algorithms. A novel aspect of our feature extraction procedure was the use of a kernel-based principal components analysis because the captured real-time data exhibited significant nonlinearity. The gait data were classified into four classes: normal, crouch-2, crouch-3, and crouch-4. The proposed method achieved gait identification with very good activity recognition accuracy (ARA). The experimental results demonstrated that the proposed methodology could recognize different activities accurately in outdoor and indoor environments, while maintaining a high ARA. The identification of disordered or abnormal gait patterns was the fundamental aim of this study. Thus, we propose a method for the early detection of abnormal gait patterns, which can provide warnings about the potential development of diseases related to human walking. Furthermore, this gait-based biometric identification method can be utilized in the detection of gender, age, race, and for authentication purposes.

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0. Introduction

The human gait is considered to be a unique biometric identification tool [1] similar to a fingerprint [2]. It can be used to identify people in various security applications and to detect walking abnormalities before permanent damage occurs. The data used for pattern classification and in the analysis of different walking styles [3] can also be employed to predict the likelihood of diseases by detecting abnormalities in the gait pattern. Furthermore, the gait is a signature of human walking that can be used for personal identification [4] purposes. However, human gait synthesis is a complex phenomenon because it involves the synchronized motion of upper and lower body parts. This synchronization develops over several months of learning (for a normal child, up to one year is required before stable walking is achieved), where different parts of the brain are involved in the learning process to establish co-ordination among the nerves and muscle, i.e., the motor system and sensory organs. The mechanism of learning is almost impossible to study based on our current knowledge of human brain functioning. Thus, it is necessary to collect data and construct biped robots in digital space to operate these robots using these data. This type of research can also obtain insights into the humanoid push recovery capacity [5] as well as capturing biometric identity features related to gender, age, and race based on human locomotion [6,7]. Many previous studies have used various machine learning techniques to capture the complex nonlinear features of gait patterns [8,9]. In addition, the identification of abrupt changes in gait patterns may also provide timely warnings to facilitate enhanced security [10–13] (e.g., in a video surveillance environment) and safety (e.g., in a life-critical environment such as a patient monitoring system). In the present study, we aimed to correlate the gait with human activity recognition. Due to its inherent uniqueness, the gait research community [14–17] is actively involved in the development of gait pattern recognition techniques using various machine learning tools [18] which may help

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Table 1
Comparison of existing approaches for gait recognition.

Ref.	Method	Advantage	Disadvantage	Uses
Bobick et al. [14]	Activity recognition using temporal templates	Real time application	More than one classifier reduces the accuracy	Indoor/outdoor both
Vega et al. [15]	Spectral analysis of human motion	Higher-order spectral	Periodic detection	Differentiates between people and vehicular objects
Vega et al. [15]	View-based motion analysis	Object models are not required	Needs to reduce the combinatorial distribution	Outdoor scenario
Wang et al. [16]	Gait recognition	Locomotion human model	Insensitive to noise	Indoor scenario
Noorit et al. [17]	Model-based action recognition	Inclusion of motion texture	Poor performance during walking	Indoor environment
Iverach-Brereton et al. [24]	Relies entirely on motion in the frontal plane to propel the robot	Gait design for an ice skating humanoid robot	Classical inverted pendulum-based walking gait when using the same skates unstable	Both ice skates and inline skates

to recognize people from a distance [19]. Thus, when CCTV cameras are used as a surveillance tool, they may fail to detect potential threats due to the time gap between identification and recognition, which could be improved by using distance-based identification technique. Similar techniques can be useful in various areas such as parking lots, crowded market places, pedestrian crossings, and banks. The overall aim of classification is to discriminate among individuals based on their locomotion characteristics [20]. In contrast to conventional biometric identification techniques such as fingerprint, iris, and face recognition [21], gait recognition is unobtrusive [22] but it is also inherently nonlinear and complex. A comparison of existing approaches for gait recognition is provided in Table 1. Humanoid robots must be able to access complex social environments, so it is necessary to develop a humanoid gait that is suited to complex terrain [23]. To facilitate the development of complex robots, Iverach-Brereton et al. proposed a complex gait design method for an ice skating humanoid robot [24]. The method proposed by Iverach-Brereton et al. is a major advance in the development of sophisticated robots for uneven terrain.

Gait data may be classified using different machine learning techniques, such as artificial neural network (ANN) [25], *k*-nearest neighbor (KNN) [26], and *k*-means [27] algorithms. Studies related to locomotion may help us to understand the problems of disabled people and to develop more sophisticated advanced humanoid robots. The different types of gait patterns include jumping, running, dancing, walking, pushing, and sitting, but not all of these gait types are cyclic. In particular, jumping is considered to be coordinated and cyclic but it is not treated as locomotion. The high-dimensional feature spaces involved in gait analysis incur high computational costs, which means that the number of dimensions should be reduced. Reducing the dimensionality also improves the classification accuracy. The methods that require the least training comprise the best machine learning algorithms. Feature reduction is also important for reducing the computational costs. Let us assume that the data have the features $X(i),\ i = 1, 2, \ldots, l$ which comprise the l-dimensional feature vector $X = [X(1), X(2), \ldots, X(l)]^T \in R^l$. The two major objectives of dimensionality reduction are reducing the computational costs and generalizing the accuracy. The benefits of reduced dimensionality include less time required for training and classification, as well as minimizing the risk of overfitting. A lower dimensionality incurs reduced training costs and it improves the high-level generalizability of classification algorithms for reduced dimensionality feature vectors. Feature selection is used to select important features that still retain sufficient information for classification. Two feature selection approaches are available: the filter method and the wrapper method. Classification based on a distance measure is employed to express how well the classes are separated from each other, i.e., using filter-based classification. By contrast, instead of selecting an appropriate subset, the wrapper methods are classifier-dependent, where this method calculates the value directly based on a feature. The wrapper method measures the correctness of the algorithm, thereby determining whether it has good accuracy. However, the wrapper method is not used widely due its high computational costs, although it performs well.

The human gait involves locomotion with the support of various body parts [19]. The overall gait comprises the following stages: lift one leg with the support of the other leg on the ground and move the body forward while swinging the lifted leg until it is in front of the body [20]. The locomotion cycle moves the whole body forward when the lifted leg makes contact with the ground. Different types of activity are associated with humanoid locomotion such as walking, running, jumping, and jogging, which are all important activities in video surveillance. In our previous study, ANN was used for activity recognition [25] based on leg movements alone. The experimental results suggested that our method could be used to recognize human activities with a high level of accuracy. Human walking involves the coordination of regular periodic motions of the upper or lower body extremities, which are responsible for the unique locomotion patterns of individuals. It is considered to be very difficult to disguise the gait from recognition by a biometric identification system. In the present study, we first selected the principal features using kernel principal components analysis (PCA) and we then classified the gait data into five different types using an ANN machine learning technique [26] based on these features, i.e., normal and four types of crouch positions, where we also compared the performance obtained with different methods. The remainder of this paper is organized as follows. Section 1 highlights the the importance of this study and its benefits. Section 2 presents the techniques used for data smoothing, data correction, and analysis based on various machine learning methods. Section 3 presents the experimental results and the different patterns determined in the subjects who we tested. Section 4 describes the performance obtained using different machine learning techniques, where we designed a confusion matrix and tested other performance parameters in the analysis. Finally, we determined that ANN obtained the best gait classification performance.

0.1. Background

The main objective of gait analysis is to understand the problems of disabled and elderly subjects, as well as those using prosthetic legs [28]. In addition, the classifications obtained can be used to develop biologically inspired bipedal machines, which can operate in similar human environments [29]. In cluttered environments, pushing against obstacles is a very common phenomenon, so push recovery [5] is essential for allowing humanoid robots to mimic this capability, which requires intelligence. Thus, many

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