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Using automated walking gait analysis for the identification of pedestrian attributes

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ABSTRACT

Collecting microscopic pedestrian behavior and characteristics data is important for optimizing the design of pedestrian facilities for safety, efficiency, and comfortability. This paper provides a framework for the automated classification of pedestrian attributes such as age and gender based on information extracted from their walking gait behavior. The framework extends earlier work on the automated analysis of gait parameters to include analysis of the gait acceleration data which can enable the quantification of the variability, rhythmic pattern and stability of pedestrian's gait. In this framework, computer vision techniques are used for the automatic detection and tracking of pedestrians in an open environment resulting in pedestrian trajectories and the speed and acceleration dynamic profiles. A collection of gait features are then derived from those dynamic profiles and used for the classification of pedestrian attributes. The gait features include conventional gait parameters such as gait length and frequency and dynamic parameters related to gait variations and stability measures. Two different techniques are used for the classification: a supervised k-Nearest Neighbors (k-NN) algorithm and a newly developed semi-supervised spectral clustering. The classification framework is demonstrated with two case studies from Vancouver, British Columbia and Oakland, California. The results show the superiority of features sets including gait variations and stability measures over features relying only on conventional gait parameters. For gender, correct classification rates (CCR) of 80% and 94% were achieved for the Vancouver and Oakland case studies, respectively. The classification accuracy for gender was higher in the Oakland case which only considered pedestrians walking alone. Pedestrian age classification resulted in a CCR of 90% for the Oakland case study.

1. Introduction

Many road jurisdictions are making significant efforts to promote sustainable modes of transportation such as walking. Much research has gone into improving the design of pedestrian facilities to promote pedestrian safety and walkability and to accommodate various pedestrian populations. The success of these efforts will largely depend on the availability of accurate and detailed pedestrian behavior data. Therefore, pedestrian data collection is recognized as an essential phase to assemble the information necessary for sound analysis and design of pedestrian facilities. In particular, a solid understanding of walking behavior of pedestrians with varying attributes (age, gender, etc.) is required for efficient planning and design of pedestrian facilities.

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Collecting microscopic pedestrian behavior and attributes data is often conducted by manual field observations. However, the manual observation of such data is labor-intensive, time consuming, and subject to high errors. Automated collection of such data can, therefore, offer significant benefits. One important component in understanding pedestrian behavior is the analysis of spatiotemporal parameters of gait. The walking gait is considered as an important biometric measure that has advantages of being unobtrusive and accessible from a distance compared to others biometrics like face features, body shape and posture. Gait patterns contain information that can be potentially used for identifying properties such as gender and age. Gait data can be collected automatically through body mounted sensors or in a non-intrusive manner like camera based vision systems. The use of computer vision techniques for measuring gait parameters has several advantages such as capturing the natural movement of pedestrians and minimizing the risk of disturbing the behavior of observed subjects, the richness of the data that can be extracted, and the relative higher accuracy and consistency.

Recent research has focused on the use of spatio-temporal gait parameters (e.g. step length and step frequency) as the main cues used for the identification of different pedestrian attributes. Typically, as common in clinical trials, subjects' characteristic patterns are derived from a few step cycles. However, this adopted method overlooks essential gait information that may be embedded in the dynamic sequences of multiple steps during locomotion. This paper expands on earlier work on the automated analysis of gait parameters (Hediyeh et al., 2013, 2014a) to include analysis of the gait acceleration data which can enable the quantification of the variability, rhythmic pattern and stability of the pedestrian's gait. The paper provides a framework for the detailed analysis of pedestrian gait parameters and the use of these parameters for the automated identification of pedestrian attributes such as age and gender. In particular, the paper has the following objectives:

1. Expand the state of the art analysis of walking gait to include gait adaptation measures such as gait stability and variability.
2. Demonstrate the automated extraction of dynamic gait parameters using computer vision techniques.
3. Demonstrate the usefulness of the dynamic gait parameters in identifying pedestrian age and gender using two case studies.

There are several potential benefits of the presented research. Such data collection is necessary in order to derive traffic system solutions that better accommodate the needs and safety requirements of different pedestrian populations. In fact, safety issues are found to be closely related to pedestrian demographic factors. Direct applications of gender and age classification also include finding demographic characteristics for facilities such as schools, hospitals, shopping centers, and commercial and business districts. Other applications include security surveillance, shoppers' statistics, and healthcare monitoring.

The paper is organized as follows: first, previous research on gait analysis and recognition is summarized in Section 2. This is followed by a detailed description of the classification framework in Section 3. The case studies are introduced in Section 4 followed by the results in Section 5. Finally, summary and potential areas of further research are provided in Section 6.

2. Related work

2.1. Gait parameters

The analysis of gait parameters is an active research area in health and sports science where different methodologies are developed to understand how the walking mechanism changes under varying physiological, psychological and environmental conditions. Quantitative evaluation of gait parameters has been traditionally undertaken manually (Hui et al., 2007). Several studies investigated the relationship between gait parameters (stride length and walking speed) and gender (Yamasaki et al., 1991). In (Crowe et al., 1996), strong correlation was shown to exist between stride frequency and length with walking speed. All gait parameters were shown in Hui et al. (2007) to follow a normal distribution. A number of studies investigated the effect of age on gait parameters. Older people were reported to have slower walking speed and shorter step length compared to younger people (Crowe et al., 1996; Elble et al., 1991; Hageman and Blanke, 1986). Crowe et al. (1996) found that females have shorter stride length and higher stride frequency compared to males. Yamasaki et al. (1991) found that the average step length is significantly shorter for females while step frequency is significantly lower for males.

2.2. Gait variations and stability

Gait variability analysis was mainly developed in health science where the gait variability and stability have been investigated as surrogate measures for health issues and as predictors of human attributes. Discussion on variability and stability and how they are distinctive features of motion are reviewed in Li et al. (2005). Researchers have been debating what are the best measures for gait stability and variability as well as whether variability and stability are correlated (Li et al., 2005). Variability measures are proposed in Menz et al. (2003), Mizuike et al. (2009), and Sekiya and Nagasaki (1998). In Sekiya and Nagasaki (1998), the walk ratio represents the relationship between the amplitude and frequency of rhythmic leg movement during walking, and thus it is a simple index for describing temporal and spatial co-ordination (i.e. walking patterns). This suggests that deviations from the normal walk ratio during free walking may reveal a degree of abnormal walking patterns.