Chapter 8
Multilinear Modeling for Robust Identity Recognition from Gait

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ABSTRACT

Human identification from gait is a challenging task in realistic surveillance scenarios in which people walking along arbitrary directions are viewed by a single camera. However, viewpoint is only one of the many covariate factors limiting the efficacy of gait recognition as a reliable biometric. In this chapter, we address the problem of robust identity recognition in the framework of multilinear models. Bilinear models, in particular, allow us to classify the "content" of human motions of unknown "style" (covariate factor). We illustrate a three-layer scheme in which image sequences are first mapped to observation vectors of fixed dimension using Markov modeling, to be later classified by an asymmetric bilinear model. We show tests on the CMU Mobo database that prove that bilinear separation outperforms other common approaches, allowing robust view- and action-invariant identity recognition. Finally, we give an overview of the available tensor factorization techniques, and outline their potential applications to gait recognition. The design of algorithms insensitive to multiple covariate factors is in sight.

INTRODUCTION

Biometrics has received growing attention in the last decade, as automatic identification systems for surveillance and security have started to enjoy widespread diffusion. Biometrics such as face, iris, or fingerprint recognition, in particular, have been employed. They suffer, however, from two major limitations: they cannot be used at a distance, and require user cooperation. Such assumptions are not practical in real-world scenarios, e.g. surveillance of public areas.

Interestingly, psychological studies show that people are capable of recognizing their friends just from the way they walk, even when their "gait" is poorly represented by point light display (Cutting & Kozlowski, 1977). Gait has several advantages over other biometrics, as it can be measured at a

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distance, is difficult to disguise or occlude, and can be identified even in low-resolution images. Most importantly gait recognition is *non-cooperative* in nature. The person to identify can move freely in the surveyed environment, and is possibly unaware of his/her identity being checked.

The problem of recognizing people from natural gait has been studied by several researchers (Gafurov, 2007; Nixon & Carter, 2006), starting from a seminal work of Niyogi and Adelson (1994). Gait analysis can also be applied to gender recognition (Li et al., 2008), as different pieces of information like gender or emotion are contained in a walking gait and can be recognized. Abnormalities of gait patterns for the diagnosis of certain diseases can also be automatically detected (Wang, 2006). Furthermore, gait and face biometrics can be easily integrated for human identity recognition (Zhou & Bhanu, 2007; Jafri & Arabnia, 2008).

Influence of Covariates

Despite its attractive features, though, gait identification is still far from being ready to be deployed in practice.

What limits the adoption of gait recognition systems in real-world scenarios is the influence of a large number of so-called covariate factors which affect appearance and dynamics of the gait. These include walking surface, lightning, camera setup (viewpoint), but also footwear and clothing, carrying conditions, time of execution, walking speed.

The correlation between those factors can be indeed very significant as pointed out in (Li et al., 2008), making gait difficult to measure and classify.

In the last few years a number of public databases have been made available and can be used as a common ground to validate the variety of algorithms that have been proposed. The USF database (Sarkar et al., 2005), for instance, was specifically designed to study the effect of covariate factors on identity classification in a realistic, outdoor context with cameras located at a distance.

View-Invariance

The most important of those covariate factors is probably viewpoint variation. In the USF database, however, experiments contemplate only two cameras at fairly close viewpoints (with a separation of some 30 degrees). Also people are viewed while walking along the opposite side of an ellipse: the resulting views are almost fronto-parallel. As a result appearance-based algorithms work well in the reported experiments concerning viewpoint variability, while one would expect them to perform poorly for widely separated views.

In a realistic setup, the person to identify steps into the surveyed area from an arbitrary direction. View-invariance (Urtasun & Fua, 2004; Yam et al., 2004; Bhanu & Han, 2002; Kale et al., 2003; Shakhnarovich et al., 2001; Johnson & Bobick, 2001) is then a crucial issue to make identification from gait suitable for real-world applications.

This problem has actually been studied in the gait ID context by many groups (Han et al., 2005). If a 3D articulated model of the moving person is available, tracking can be used as a pre-processing stage to drive recognition. Cunado et al. (1999), for instance, have used their evidence gathering technique to analyze the leg motion in both walking and running gait. Yam et al. (2004) have also worked on a similar model-based approach. Urtasun and Fua (2004) have proposed an approach to gait analysis that relies on fitting 3D temporal motion models to synchronized video sequences. Bhanu and Han (2002) have matched a 3D kinematic model to 2D silhouettes. Viewpoint invariance is achieved in (Spencer & Carter, 2002) by means of a hip/leg model, including camera elevation angle as an additional parameter.

Model-based 3D tracking, however, is a difficult task. Manual initialization of the model is often required, while optimization in a higher-