Image and Vision Computing 27 (2009) 153–166

Contents lists available at ScienceDirect

Image and Vision Computing

journal homepage: www.elsevier.com/locate/imavis

Automated detection of unusual events on stairs

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ARTICLE INFO

Article history:
Received 22 February 2007
Accepted 10 April 2008

Keywords:
Human motion analysis
Hidden Markov model
Gait analysis
Anomaly detection
Event recognition
Bayesian tracking
Particle filter
Automated video analysis
Machine learning
Biomedical analysis
Stairs

ABSTRACT

This paper presents a method for automatically detecting unusual human events on stairs from video data. The motivation is to provide a tool for biomedical researchers to rapidly find the events of interest within large quantities of video data. Our system identifies potential sequences containing anomalies, and reduces the amount of data that needs to be searched by a human. We compute two sets of features from a video of a person descending a stairwell. The first set of features are the foot positions and velocities. We track both feet using a mixed state particle filter with an appearance model based on histograms of oriented gradients. We compute expected (most likely) foot positions given the state of the filter at each frame. The second set of features are the parameters of the mean optical flow over a foreground region. Our final classification system inputs these two sets of features into a hidden Markov model (HMM) to analyse the spatio-temporal progression of the stair descent. A single HMM is trained on sequences of normal stair use, and a threshold on sequence likelihoods is used to detect unusual events in new data. We demonstrate our system on a data set with five people descending a set of stairs in a laboratory environment. We show how our system can successfully detect nearly all anomalous events, with a low false positive rate. We discuss limitations and suggest improvements to the system.

1. Introduction

Stairs have long been the subject of study for architects and designers [1], who attempt to build more ergonomic and safe stairs for different public and private situations. Increasingly, stairs have become a subject of interest for biomedical researchers, who realise that, even with perfect design, stairs are inherently difficult for humans to navigate and their use will always lead to accidents. The US Consumer Product Safety Commission estimates that in 2005 alone over one million people received hospital treatment in US due to stair related injuries [2]. Older adults are particularly susceptible to accidents on stairs due to their reduced mobility and weaker musculoskeletal systems. This is of special concern to the growing population of elderly people who wish to age in their homes. Falls in general are the leading cause of accidental mortality and morbidity among the elderly population [3,4] and stairs are a significant cause of falls [1]. In fact, in the United States, the Netherlands and the United Kingdom, steps and stairs are the single most dangerous element in the home [1].

Biomedical researchers study the ways in which adverse events happen on stairs, and aim to identify and predict the causes of these events. One of the major hurdles involved in such research is the gathering of real stair data. Aside from the ethical difficulties of recording stair usage in public or private spaces, there is a technical difficulty imposed by the rarity of adverse events. It is estimated that on public staircases, a slip, stumble, trip, or other loss of balance not resulting in a fall occurs once in 2222 stair uses, while minor accidents such as falls occur only once in 63,000 stair uses [5]. It is hypothesized that the labour intensive process of manually identifying unusual events in stair video data can be avoided with an automated system which is proposed herein.

It is assumed that the system will have access to a database of stair events on a particular set of stairs, where each stair event consists of a single person entering the stairwell and descending the stairs. A stair event (or descent) is considered to be of two types, normal and anomalous. In a normal stair event, the person descends the stairs with no problems, correctly placing their feet on steps without any loss of balance. We consider an *anomalous* event to be one in which the person misses a step at some point in the stair event. More obvious abnormal events, such as a person falling down the stairs, will not be considered. A person can miss a step either by completely overstepping, or by catching their heel on the nosing of a step and slipping off onto the next lower step (a slip). These are the most common anomalous events and account for a combined 65% of all "gait incidents" on stairs [1] (followed by stumbles (17%), balance loss(10%), other (8%)). The primary goal of our system is to filter a large database, removing a large fraction

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doi:10.1016/j.imavis.2008.04.021

of stair events which are sure not to contain anomalies. The remaining data could be forwarded to a human for final analysis. Therefore, while our system should miss as few anomalous events as possible, we can afford a reasonable amount of false positive anomalous events. It is assumed that only a single person is descending the stairs at a time, a limitation that could be overcome with multiple target tracking (such as by using the Bramble system [6]). We only look at descents, as these present a significantly higher risk for adverse events (75% of stair falls causing injury occur during descent [7]), and are of most interest to biomedical researchers and stairwell designers.

This new system operates in five stages as shown in Fig. 2. Two types of features are computed for each frame of video: foot dynamics and overall body motion. The subject's foot positions are tracked using a mixed-state Bayesian sequential estimator with an appearance model based on histograms of oriented gradients (HOGs). Six features are derived from the locations of the feet: vertical and horizontal velocities of both feet and the vertical and horizontal distance between both feet. Body motion is computed as the mean value of the optical flow [8] over the foreground region obtained using an adaptive background subtraction technique. The resulting feature vector consisting of the tracked feet features and the mean flow features forms a time series over each stair descent. A hidden Markov model is then trained to model the statistical progression of these feature vectors over time in normal stair descents. A new stair descent is classified as normal or anomalous by computing its likelihood under the hidden Markov model and comparing it to a threshold.

2. Previous work

Relatively little work has been done to detect anomalous human motion in video. Lee and Mihailidis [9] detect the most severe anomalous motion (falls) by thresholding the diameter and velocity of a background subtracted silhouette. McKenna and Nait-Charif [10] detect deviations from models of normal activities in a home to detect unusual behaviors such as falls. Bauckhage et al. [11] estimate pose by encoding a background subtracted silhouette as a mapping onto a rectangular grid. A feature vector is generated from a concatenation of the grid representations at consecutive frames and a support vector machine is applied to perform binary classification of normal and anomalous sequences of poses. This innovative approach unfortunately requires error-free segmentations of people's silhouettes and suffers from an inability to generalize well to new subjects and gaits. The reason for this is that the class of anomalous poses and motions is simply too large and variable to model. Even with a significant amount of training data of anomalous gait it is generally easy to consider additional cases which are not represented within the training set. This is further highlighted by the fact that each person's individual gait is different and thus what is considered normal gait for one person is anomalous for another. This fact presents a major challenge to detecting anomalous events across multiple subjects. In previous work [12], we have shown that it is more challenging to detect anomalous events on stairs for a person who is not represented in the normal event training data. Medical studies have shown [13] that gait is unique across individuals. In psychological studies [14] people have been able to easily identify others by observing only their gait.

As such, a significant amount of work exists in attempting to identify people based on their gait. Niyogi and Adelson [15] detect individual gait by tracking the progression through time of skeletons fitted to background subtracted silhouettes. Little and Boyd [16] recognize people by computing periodic characteristic features of optical flow. While significant research exists into detecting individual gait [17–19] relatively little work exists on detecting anomalous gait, particularly on stairs.

There is some work on detecting anomalous behavior in video in the context of visual surveillance [20] or user modeling [21,22]. However, these approaches use coarse features such as positions and velocities of people within a scene and attempt to characterise trajectories. A larger body of computer vision research has looked into modeling the motion of the human body in fine detail. Periodic motion of walking figures is analysed in [23] by computing self-similarity of a segmented image region with itself over multiple time scales. The Fourier transform of the resulting correlations gives indications of the periodicity of the motion. The motion history (MHI) [24] is a descriptor of temporally localised image changes. However, these works do not attempt to recognise anomalous events and do not look at motion on stairs.

Little work has been done on characterising human motion on stairs. Notable exceptions are work done on motion capture data of people ascending and descending stairs, in which recovered joint angles are mapped to a subspace that can be used for synthesis [25]. However, this work does not use video and does not attempt recognition of unusual events. Human gait on staircases was analysed in [26] by fitting a skeletal model to the view-based human form, and then modeling the joint angles as a dynamical system. This was used to classify gaits such as walking, running and descending stairs, but no work was done on recognising unusual events within each of these motion types. An interesting study in [27] used a camera mounted above a side-by-side public stair-

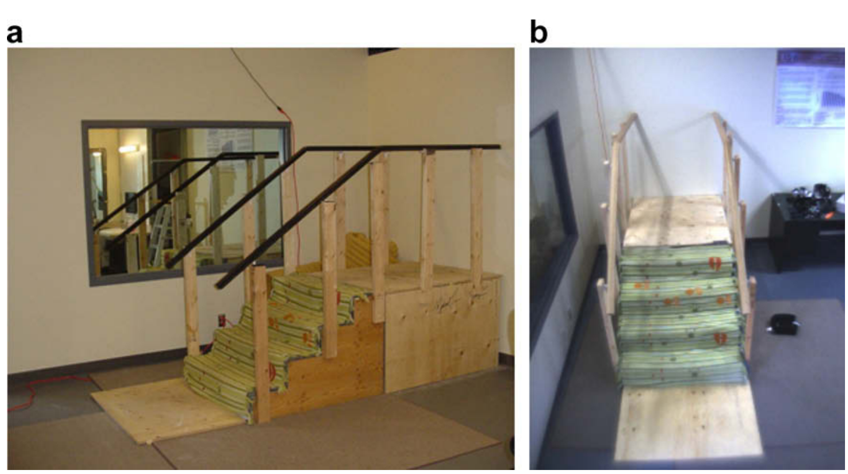

Fig. 1. The stairs (a) and the view from the overhead camera (b).