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Review of fall detection techniques: A data availability perspective

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ABSTRACT

A fall is an abnormal activity that occurs rarely; however, missing to identify falls can have serious health and safety implications on an individual. Due to the rarity of occurrence of falls, there may be insufficient or no training data available for them. Therefore, standard supervised machine learning methods may not be directly applied to handle this problem. In this paper, we present a taxonomy for the study of fall detection from the perspective of availability of fall data. The proposed taxonomy is independent of the type of sensors used and specific feature extraction/selection methods. The taxonomy identifies different categories of classification methods for the study of fall detection based on the availability of their data during training the classifiers. Then, we present a comprehensive literature review within those categories and identify the approach of treating a fall as an abnormal activity to be a plausible research direction. We conclude our paper by discussing several open research problems in the field and pointers for future research.

1. Introduction

Research in activity recognition has led to the successful realization of intelligent pervasive environments that can provide context, assistance, monitoring and analysis of a subject's activities that are usually backed up by advanced machine learning and vision algorithms [1–3]. However, a lot of this research is centred around developing techniques to identify normal Activities of Daily Living (ADL) either at an atomic level (*e.g.,* walking, running, cycling) or at a higher level (*e.g.,* preparing breakfast, washing hands). These techniques are generally applied to monitor a subject's movements, assess physical fitness and provide feedback. Though this research is useful, there can be scenarios where detection of abnormal activities become important, challenging and relevant. Missing out such abnormal activities can impose health and safety risks on an individual. Falling is one of the most common type of abnormal activity and the most studied [4,5]. In real life, most falls are caused by a sudden loss of balance due to an unexpected slip or trip, or loss of stability during movements such as turning, bending, or rising [6].

Falls are the major cause of both fatal and non-fatal injury among people and create a hindrance in living independently. According to the report by SMARTRISK [7], in Canada in 2004, falls constituted 25% of all the unintentional injuries besides transport injuries or suicides, resulting in 2225 deaths, 105,565 hospitalizations and 883,676 non-hospitalizations. The report also suggests that falls accounted for 50% of all injuries that resulted in hospitalization, and was the leading cause of permanent partial disability (47%) and total permanent disability (50%). Falls were the leading cause of overall injury costs in Canada in 2004, accounting for $ 6.2 billion or 31% of total costs besides other unintentional injuries. According to the WHO report [8], the frequency of falls increase with an increase in age and frailty. Older people living in nursing homes fall more often than those living in the community (around 30 – 50%) and 40% of them experience recurrent falls [8]. The reason is that most of the older adults living in the nursing homes are more frail and these facilities report fall incidences more accurately [9]. According to the Public Health Agency of Canada [10], older adults in Canada who were hospitalized due to a fall spent up to three weeks in the hospital, which is three times more than the average hospital stay among other age groups. Falls can impact a person both economically and psychologically. Experiencing a fall may lead to a fear of falling [5], which in turn can result in lack of mobility, social isolation, less productivity and can increase the risk of a fall.

Falls occur infrequently and diversely. The rarity of occurrence of falls lead to a lack of sufficient data for them for training the classifiers [11]. More than one type of fall may also occur and their unexpectedness make it difficult to model them in advance. Collecting fall data can be cumbersome because it may require the

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person to actually undergo a real fall which may be harmful and unsafe. Alternatively, artificial fall data can be collected in controlled laboratory settings; however, that may not be the true representative of actual falls [12]. Analyzing artificially induced fall data can be good from the perspective of understanding and developing insights into falls as an activity but it does not simplify the difficult problem of detecting falls. Moreover, the classification models built with artificial falls are more likely to suffer from over-fitting on them and may poorly generalize on actual falls. The approaches that exclusively collect fall data still suffer from their limited quantity and ethics clearances. The Centers for Disease Control and Prevention, USA [13] suggests that on an average, nursing home residents incur 2.6 falls per person per year. If an experiment is to be set up to collect real falls and assuming an activity is monitored every second by a sensor, then we get around 31.55 million normal activities per year in comparison to only 2.6 falls. The data for real falls may be collected by running long-term experiments in nursing homes or private dwelling using wearable sensors and/or video camera. However, the fall data generated from such experiments will still be skewed towards normal activities [14] and it is difficult to develop generalizable classifiers to identify falls efficiently. In addition to very few or no labelled data, the diversity and types of falls further make it difficult to model them efficiently.

Most of the previous review papers on fall detection assume sufficient data for falls, and survey methods and techniques based on different types of sensors and specific feature extraction/selection methods. We argue that since falls are rare events, standard supervised machine learning methods may not be well-posed to identify them efficiently. Keeping this view in mind, we present a taxonomy for the study of fall detection methods that depends on the availability of fall data present during training the classifiers. This taxonomy is independent of the type of sensors used to capture human activities and specific type of feature extraction/selection methods. The taxonomy envisages the problem of fall detection from a real-world perspective where falls are not abundant but the normal ADL can be easily gleaned.

The rest of the paper is outlined as follows. In Section 2, we survey the existing review papers on fall detection, present their contributions, highlight their limitations and analyze their cumulative outcomes. In Section 3, we present the proposed taxonomy for the study of fall detection methods based on the availability of fall data. Section 4 presents a comprehensive review of the current and significant research in the field of fall detection using the proposed taxonomy. In Section 5, we exclusively review research on methods that treat falls as abnormal activity or can be adapted for this task. We conclude the paper with open research questions and future direction in this field in Section 6.

2. Survey of existing literature review on fall detection

In the last decade, several review papers on fall detection are published that discuss different aspects of the fall detection problem involving various classification techniques, types of sensors and specific feature engineering methods. In this section, we survey major review papers on fall detection and highlight their focus of research, contributions and limitations.

Noury et al. [15] report a short review on fall detection with an emphasis on the physics behind a fall, methods used to detect a fall and evaluation criteria based on statistical analysis. They discuss several analytical methods to detect falls by incorporating thresholds on the velocity of sensor readings, detecting no-movements, intense inversion of the polarity of the acceleration vector resulting from impact shock and suggest that such methods will result in high false positive rates. They mention, since falls are rare, unsupervised machine learning techniques are likely to fail to identify the first fall event because it was not observed earlier. Supervised algorithms can only classify “known classes” on which they are trained and such techniques may label a rare activity, like a fall, as “Others” along with other activities *e.g.,* to stumble, to slip *etc*. Yu [16] presents a survey on approaches and principles of fall detection for elderly patients. Yu first identifies the characteristics of falls from sleeping, sitting and standing and categorize fall detection methods based on wearable, computer vision and ambient devices. These approaches were further broken down into specific techniques such as based on motion analysis, posture analysis, proximity analysis, inactivity detection, body shape and 3D head motion analysis. Yu mentions that a fall is a rare event and it is important to develop techniques to deal with such scenarios. Yu further addresses the need for generic fall detection algorithms and fusion of different sensors such as wearable and vision sensors for providing better fall detection solutions. Perry et al. [17] present a survey on real-time fall detection methods based on techniques that measure only the acceleration, techniques that combine acceleration with other methods, and techniques that do not measure acceleration. They conclude that the methods measuring acceleration are good at detecting falls. They also comment that placement of a sensor at the right position on the body can impact the accuracy of fall detection techniques.

Hijaz et al. [18] present a survey on fall detection and monitoring ADL and categorize them into vision based, ambient-sensor based and kinematic-sensor based approaches. They identify kinematic-sensor based approaches that use accelerometer and/or gyroscopes as the best among them because of its cost effectiveness, portability, robustness and reliability. Mubashir et al. [4] present another survey on fall detection methods with an emphasis on different systems for fall detection and their underlying algorithms. They categorize fall detection approaches into three main categories: wearable device based, ambience device based and vision based. Within each category they review literature on approaches using accelerometer data, posture analysis, audio and video analysis, vibrational data, spatio-temporal analysis, change of shape or posture. They conclude that wearable and ambient devices are cheap and easy to install; however, vision based devices are more robust for detecting falls. Delahoz and Labrador [19] present a review of the state-of-the-art in fall detection and fall prevention systems along with qualitative comparisons among various studies. They categorize fall detection systems based on wearable devices and external sensors that includes vision based and ambient sensors. They also discuss general aspects of machine learning based fall detection systems such as feature extraction, feature construction and feature selection. They also summarize various classification algorithms such as Decision Trees, Naive Bayes, K-Nearest Neighbour and SVM; compare their time complexities and discuss strategies for model evaluation. They further discuss several design issues for fall detection and prevention systems including obtrusiveness, occlusion, multiple people in a scene, aging, privacy, computational costs, energy consumption, presence of noise, and defining appropriate thresholds. They also present a three-level taxonomy to describe the falling risks factors associated with a fall that includes physical, psychological and environmental factors and review several fall detection methods in terms of design issues and other parameters. Schwickert et al. [20] present a systematic review of fall detection techniques using wearable sensors. One of the major focus of their survey is to determine if the prior studies on fall detection use artificially recorded falls in a laboratory environment or natural falls in real-world circumstances. They observe that around 94% studies use simulated falls. This is an important finding because it highlights the difficulty in obtaining real fall data due to their rarity. They also discuss that accelerometers along with other sensors such as gyroscopes, photo-diodes or barometric pressure sensors can help