A Panoramic Study of Fall Detection Technologies

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Abstract

Falls are a major risk of injury for elderly aged 65 or over, blind people, people with balance disorder and leg weakness. In this regard, assistive technology which aims to identify fall events at real time can reduce the rate of impairments and mortality. This study offer a literature research reference value for bioengineers for further research. Much of the past and the current fall detection research, the vital signals features and the way features are extracted and fed to a classifier are introduced. The study concludes with an assessment of the current technologies highlighting their critical limitations along with suggestions for future research direction in this rapidly developing field of study.

Keywords: *Fall detection, elderly monitoring, accelerometer, tilt, gyroscope, vision-based, ambience-base, pressure sensor, SVM, KNN, classification.*

1. Introduction

As per the World Health Organization [1], there are about 28-35% of people aged 65 or over. In this age group, falling is the most common ones of life threatening events that can occur, which is leading to a high incidence of impairments to the health and lifestyle of elderly people.

In particular, falls not only a health problem, causing accidental death or physical injury such as hip fractures, but also a social and psychological issue in that it may cause people who have experienced fall previously, fear another fall and drown into inactivity and social isolation [2] [3].

Furthermore, when elderly helplessly fall without getting any prompt assistance and help, thus that will brings out large medical care costs. In this regard, new assistive technology for fall detection and continuous monitoring is needed in order to have a major benefit of the treatment on fall injury outcomes. The objective of the assistive technology is to alert the related personnel who might help faller as early as possible to receive timely treatment.

The attempts to distinguish unintentional fall from other fall related daily activities as bending and lying is difficult due to a configuration of the human body. Therefore, a need for valid and reliable measuring techniques has motivated researchers to propose different methods to detect the unintentional falls.

Much of the current fall detection is ranging from wearable devices for automatic evaluation of fall by analyzing different biological signals to context-aware systems that assist to alert of the fall event and help patient to recover.

In the following sections, we glance at a variety of fall detection and monitoring methods. Then, we conclude our paper in section V, and highlight some directions for future research.

2. Related Works

Different technologies have been employed for automatic fall detections that can be broadly grouped in three main categories: wearable, ambience and vision-based devices [4].

Since different activities of daily living have similarities to fall events, like lying, most related studies share the same objective, which is developing technique capable of distinguishing between unintentional fall and other fall -related daily activities. Therefore, the general framework for fall detection approaches based on processed and classified data which is collected from sensors. The data form varies according to sensor used; it could be pressure signals, images and acceleration signals, etc [5].

The performance of the detection method is measured in two statistical indicators, Sensitivity (*Se*) and Specificity (*Sp*). The sensitivity of a test is the ability of a detector to successfully detect falls, whereas the specificity is the ability of a detector to successfully detect other daily movements.

In the following sections, we investigate some of the most relevant fall detection methods in the different categories with respect to performance measures, technique used, hardware used in the implementation, weaknesses and strengths.

3. Wearable Devices

Nowadays, much of the current fall detection techniques are being done on providing wearable devices attaching to the human body that monitor those experiencing fall during the day. This approach based on using different movement sensors such as accelerometer, tilt and gyroscope. These sensors could be inserted in accessories and worn as a necklace, watch or belt, and their data transmitted wirelessly to a computer or a mobile. Recently, various proposed techniques have been used the embedded accelerometer of a smart phone to act as a fall detector for the user.

In using a wearable sensors based analysis to detect fall in [6] there has been effective use of tri-axial accelerometer, gyroscope, and Bluetooth that integrated together in motion sensor board and attached to a custom vest worn by the elderly in order to capture the reluctant acceleration and angular velocity of activities of daily living in real time. The stream data is then sent to a smart phone, which runs the proposed technique based on sliding window and the kNN algorithm. Meanwhile, the sliding window is used to take the last seen N elements of the varying reluctant acceleration and angular velocity stream data, and then kNN algorithm is used as a predictive tool for fall detection over stream data. At last, the algorithm's identification results achieved sensitivity of 94% and specificity of 99%.

The proposed algorithm in [7] used the triaxial accelerometers worn on the chest, waist, left ankle, and right ankle, respectively from the Localization Data for Person Activity dataset of UCI database [8] [9], which is created to support such studies. As to the classifiers used, SVM and AdaBoost classifier as a cascade classifier were applied to identify falls. The optimal results were achieved on the triaxial accelerometers of waist and chest.

The peak acceleration and angular velocity in [10] were acquired by a bi-axial gyroscope sensor and accelerometer mounted on the trunk and a multi-stage thresholding-based algorithm are used to identify falls. The resultant angular velocity, angular acceleration, and trunk angle must be greater than specific thresholds to trigger the final alarm.

Recently, mobile phones are equipped with embedded accelerometers to help in fall detection. In the experiment setup in [11], the accelerometer data are collected from 8 subjects carrying mobile phone in their pockets as the subjects asked to perform various daily activities and several types of intentional falls. To recognize falls, supervised learning methods are used and the system's identification results achieved 90% success ratio.

Similarly, another recent work, iFall [12], was designed using Android smart phone with an embedded tri-axial accelerometer. Position data and several thresholds based-algorithms are used to identify falls. The threshold is adaptive to the parameters provided by the user, such as: weight, height, and level of activity. Additionally, these parameters adjust to the unique movements that a cellphone experiences. However, if a fall is detected a notification via SMS is sent to pre-specified social contacts list, in order to provide appropriate emergency help.

Nowadays, fall detection and reporting technology has been handled from another point of view, where smart solutions have been proposed a system that is intended to monitor vital signs such as temperature, blood pressure, heart rate and respiratory rate, along with abnormal movement monitoring. The proposed portable system in [13], monitors continuously a combination of accelerometer data and heart rate in order to detect both abnormal cardiovascular accelerations and patient fall.

In our previous published researches [14] [15], we studied the Electrocardiogram (ECG) signal and Arterial oxygen saturation (SpO_2) and we developed an automated classification model can recognize irregular heartbeats and SpO_2 variability. Therefore, in this regard, we are planning to use our previous works as a core along with new proposed fall detection model to build a multi parameters system and apply that as a system for automated health monitoring system.

4. Vision- based Devises

Generally, several studies have employed computer vision methods for fall detection. Camera-based surveillance system is used to detect visual fall based on various image processing techniques, such as background subtraction, posture recognition, template matching, and Skeleton extraction. The common clues used for detecting falls are: inactivity detection, Shape related features and human motion analysis.

Based on inactivity and change of shape, the study in [16], proposed approach consists of two main components: object detection and fall model. Adaptive background subtraction using Gaussian mixture model (GMM) were used to detect moving object and marked it with minimum-bounding box, and then a set of features were extracted to describe the fall model, such as vertical and horizontal gradients distribution, aspect ratio and the centroid angle to the horizontal axis of the bounding box. Human fall is confirmed when the angle value is less than 45 degree.

The study carried out by Miao Yu et al. [17] proposed fall detection by posture recognition with detection rate of 97.08%. Similarly to [16], background subtraction is the first step to extract the foreground human object, and then the recognized human posture is adjusted in an elliptical window. Extracted features from ellipse adjusting were used to distinguish different postures of the human body, such as a projection histogram along the axes of the ellipse. After features extraction, a directed acyclic graph support vector machine (DAGSVM) is used with input features to classify the human body posture. Human fall is confirmed when the ellipse is lying horizontally for specific time.

Charfi et al. [18, 19] introduced an optimized spatio-temporal human fall descriptor, named STHF, which uses several combinations of transformations of geometrical features. The extracted features, such as, width and height of human body bounding box, projection histograms and the user's trajectory, then were used for supervised SVM and Adaboost classifiers.

Also, in both [20] and [21], authors proposed a video surveillance monitoring system to detect various body posture events. Combination of best-fit approximated ellipse around the human body, normalized horizontal and vertical projection histograms of the segmented object and temporal changes of head position, were used as the features vectors fed to a MLP Neural Network [20] and k-nearest neighbor (k-NN) algorithm [21] for motion classification and fall detection. Experimental results showed a reliable recognition rate of above 90% and a stable classifier's output [21].

5. Ambience-based devices

Most ambient device based approaches analyzes fall motions bases on audio signals or ground shaking signals that is generated in the case of fall. Generally, ambience based approach use unobtrusive sound and pressure sensors, in which the human does not require wearable devices, to detect and track human body. Nevertheless, it could lead to low detection accuracy because it sense pressure of everything in the sensor deployment area.
In using sound sensing and floor vibration based analysis to detect fall events in [22], special features like mel frequency ceptral coefficients and shock response features are used. In this work, a human mimicking doll are used for human falls simulation and the results showed high sensitivity and specificity values of 97.5% and 98.6%, respectively, in differentiating fall events from other events.

In [23], an acoustic human fall detection system (FADE) was implemented based on a 3-microphone linear array to detect sounds produced above the floor level. However, to handle the environmental interference, the authors enhanced their work in [24], by replacing a linear array of microphones with an 8-microphone circular array that could provide a better 3D estimation of the sound location. Only sounds located at floor level are passed for classification procedure, while sounds above the floor level at certain height are filtered out. For the signal modeling and sound localization, algorithm called steered response power using phase transform (SRP-PHAT) is used, and the sound classification is done by mel-frequency cepstral coefficients (MFCC) together with a nearest neighbor approach. Moreover, to determine the optimal settings regarding microphones array radius and levels of background noise, many experiments are performed using a MATLAB acoustic array simulation toolbox. For a pilot dataset consisting of 55 falls and 120 non-fall sounds, the system's classification results achieved a sensitivity of 87% and a specificity of 90%.

In [25, 26] the implementation of the floor vibration based fall detector is presented. A floor surface is equipped with a special piezoelectric sensor to measure forces applied to the floor due to the object's weight pressure. For performance evaluation in [25], the tests are done using anthropomorphic dummies, however, it is planned to conduct a test with the potential human subjects.

6. Discussion

Despite the significant achievements that have been carried out on the field of providing assistive technology for elderly fall monitoring and detection in the last years, there are still many limitations and challenges need to overcome. Till now, there is no standardized approach available, due to a configuration of human body, complexity of human body movement nature, and complexity of unintentional fall pattern assessment. Typically, fall could be while standing, while walking, from chair, or from bed [27], in addition to different types of unintentional fall, such as, forward fall, backward fall, left-side fall, right-side fall, soft and hard fall.

Generally, while surveying different research approaches for technological fall detection systems, we glance at a variety of issues need to be considered for designing a robust system to assist the elderly only when there is a real fall.

First of all, the diversity of the studies designs was very high, while the methodological rigor of these studies as evaluation of detection and monitoring tests was low. Therefore, comparing among different literature studies is difficult.

As in most of the previously mentioned approaches, the authors focus only on the algorithm to be used and classification method, while shortage of such investigation like position of the detector, the way signal are acquired, the way features are calculated and processed before feeding a classifier is very clear [5]. Also, a public database with accelerometer data and videos of elderly falling is required in order to offer access to benchmark training data for investigation in this challenging field to be used by researchers to improve their used tools and mechanisms.

Second, most studies use anthropomorphic dummies or healthy young people falling as a representative to simulate real fall, while the test should take place in a real life scenario for a set of elderly patients in order to evaluate its accuracy and practicality.

Third, various proposed techniques use the embedded accelerometer of a smart phone to act as a fall detector for the user, however, smartphones cannot be overloaded with continuous sensing that depleting battery power. It is essential to manage the sleep cycle of sensing components in order to trade off the amount of power consumption.

Fourth, most of the literature visual surveillance systems lack strategies to ensure human privacy. Therefore, the way to detect totally occluded human falling is needed for a real life deployment.

Fifth, both vision and ambience based approaches require a pre-built infrastructure, which could be valuable to use them in home and hospital, but not to use them outdoor [28].

The last issue to take into consideration is the usability. The ideal system should be unobtrusive, invisible, portable, cost effective and leads to a high detection accuracy.

7. Conclusion and future works

In this survey, the most relevant studies of fall detection with their weaknesses and strengths have been described. The aim is to set a roadmap for researchers along with suggestions for future research direction.

The review shows the different approaches ranging from wearable devices for automatic evaluation of fall by analyzing different biological signals to context-aware systems that assist to alert of the fall event and help patient to recover. This review also provided challenges and issues need to take into account for further research. In this sense, exhaustive evaluation based on a public database, privacy violation, low detection accuracy and usability issues were discussed.

Thus, to enhance the utility of this literature, we are planning to develop a comprehensive automated health monitoring system, that fall detection using PIR sensor as one component in conjunction with our previous published works such as heart beats and arterial oxygen saturation monitoring [14, 15], in addition to other unpublished work which aims to help blind person to detect obstacle using ultrasonic sensor and Arduino microcontroller. Therefore, in this regard, we are planning to use our previous works as a core along with new proposed fall detection model to build a multi parameters system and apply that as a system for automated health monitoring system.

REFERENCES

[1] World Health Organization: Global report on falls prevention in older age.[http://www.who.int/ageing/publications/Falls_prevention7March.pdf]

[2] A. Mendulkar, R. Kale, A. Agrawal, "A Survey On Efficient Human Fall Detection System," International journal of scientific & technology research , vol. 3, no. 4, pp. 96-98, Apr. 2014.

[3] N. El-Bendary, Q. Tan, F. pivot, A. Lam, "Fall Detection and Prevention for The Elderly: A review of Trends And Challenges," International journal of smart sensing and intelligent systems, vol. 6, no. 3, June. 2013.

[4] M. Mubashir, L. Shao, L. Seed, "A survey on fall detection: principles and approaches," Neurocomputing, vol. 100, pp. 144-152, jan. 2013.

[5] R. Igual, C. Medrano, I. Plaza, "Challenges, Issues and trends in fall detection systems," BioMedical Engineering, vol. 12, no. 66, July. 2013.

[6] J. He, C. Hu, X. Wang, "A Smart Device Enabled System for Autonomous Fall Detection and Alert," International Journal of Distributed Sensor Networks, vol. 2016.

[7] W. Cheng, D. Jhan, "Triaxial Accelerometer-Based Fall Detection Method Using a Self-Constructing Cascade-AdaBoost-SVM Classifier," IEEE journal of Biomedical and Health Informatics, vol. 17, no. 2, pp. 411-419, Dec. 2012.

[8] B. Kaluza, V. Mirchevska, E. Dovgan, M. Lustrek, and M. Gams, "An agent-based approach to care in independent living," in Proc. 1st. Int. Joint Conf. Ambient Intell., Malaga, Spain, 2010, pp. 177–186.

[9] UCI Localization Data for Person Activity Database (2010). [Online].Available:http://archive.ics.uci.edu/ml/machine-learningdatabases/00196

[10] A. Bourke and G. Lyons, "A threshold-based fall-detection algorithm using a bi-axial gyroscope sensor", Medical Engineering & Physics, 30:84{90, j2006j.

[11] A. Kansiz, A. Guvensan, I. Turkmen, "Selection of Time-Domain Features for Fall Detection Based on Supervised Learning", Proceedings of the World Congress on Engineering and Computer Science, Vol II WCECS 2013, 23-25 October, 2013, San Francisco, USA.

[12] F. Sposaro and G. Tyson,"iFall: An Android Application for Fall Monitoring and Response", In Proc. Annual International Conference of the IEEE Engineering in Medicine and Biology Society, pp. 6119-6122, Minneapolis, Minnesota, USA, 3-6 Sept., 2009.

[13] G. Sannino and G.D. Pietro, "An Advanced Mobile System for Indoor Patients Monitoring", In Proc. 2nd International Conference on Networking and Information Technology (ICNIT 2011), pp. 17, Singapore, IACSIT Press, 2011.

[14] L. Almazaydeh, K. Elleithy, and M. Faezipour, "Detection of obstructive sleep apnea through ECG signal features," in Proceedings of the IEEE International Conference on Electro Information Technology (IEEE eit2012), pp. 1-6, May. 2012.

[15] L. Almazaydeh, M. Faezipour, and K. Elleithy,"A Neural Network System For Detection Of Obstructive Sleep Apnea Through SpO2Signal Features," (IJACSA) International Journal of Advanced Computer Science and Applications, vol. 3, no. 5, pp. 7-11, Jun. 2012.

[16] V. Vishwakarma, C. Mandal and S. Sural, "Automatic Detection of Human Fall in Video", Springer-Verlag 2nd International Conference on Pattern Recogni- tion and Machine Intelligence (PReMI'07), 2007.

[17] Miao Yu, Adel Rhuma, Syed Mohsen Naqvi, Liang Wang, and Jonathon Chambers,, "Posture Recognition Based Fall Detection System For Monitoring An Elderly Person In A Smart Home Environment", IEEE TRANSACTIONS ON INFORMATION TECHNOLOGY IN BIOMEDICINE, VOL. 16, NO. 6, NOVEMBER 2012.

[18] I. Charfi, J. Miteran, J. Dubois, M. Atri, and R. Tourki. "Optimized spatio-temporal descriptors for real-time fall detection: comparison of support vector machine and adaboost-based classification", Journal of Electronic Imaging, 22(4):041106–041106, 2013.

[19] I. Charfi, J. Miteran, J. Dubois, B. Heyrman, and M. Atri. "Robust spatio-temporal descriptors for real-time svm-based fall detection", In Computer Applications & Research (WSCAR), 2014 World Symposium on, pages 1–6. IEEE, 2014.

[20] H. Foroughi, B.S. Aski, and H. Pourreza, "Intelligent Video Surveillance for Monitoring Fall Detection of Elderly in Home Environments", In Proc. 11th International Conference on Computer and Information Technology (ICCIT 2008), pp. 219-224, Khulna, Bangladesh, 2008.

[21] A.H. Nasution and S. Emmanuel, "Intelligent Video Surveillance for Monitoring Elderly in Home Environments", In Proc. IEEE 9th Workshop on Multimedia Signal Processing (MMSP 2007), pp. 203-206, Greece, 2007.

[22] Y. Zigel, D. Litvak, and I. Gannot, "A Method for Automatic Fall Detection of Elderly People Using Floor Vibrations and Sound−Proof of Concept on Human Mimicking Doll Falls", IEEE Transactions on Biomedical Engineering, v. 56, issue 12, pp.2858-2867, 2009.

[23] M. Popescu, Y. Li, M. Skubic, M. Rantz, "An acoustic fall detector system that uses sound height information to reduce the false alarm rate", 30th Int. IEEE EMBS Conf., Vancouver, BC, Aug. 20-24, 2008, pp. 4628-4631.

[24] Yun Li, Zhiling Zeng, Mihail Popescu and K.C. Ho, "Acoustic Fall Detection Using a Circular Microphone Array", 32nd Annual International Conference of the IEEE EMBS Buenos Aires, Argentina, August 31 - September 4, 2010, pp. 2242-2245.

[25] M. Alwan, P.J. Rajendran, S. Kell, D. Mack, S. Dalal, M. Wolfe, R. Felder, "A Smart and Passive Floor-Vibration Based Fall Detector for Elderly," IEEE International Conference on Information & Communication Technologies (ICITA) (2006), pp. 1003–1007.

[26] L. Klack, C. Möllering, M. Ziefle, and T. Schmitz-Rode, "Future Care Floor: A sensitive floor for movement monitoring and fall detection in home environments," Second International ICST Conference, MobiHealth 2010, Ayia Napa, Cyprus, October 18-20, 2010. Revised Selected Papers, pp 211-218.

[27] X. Yu, " Approaches and principles of fall detection for elderly and patient, e-health Networking, Applications and Services",2008. HealthCom 2008. 10th International Conference on, pp. 42–47.

[28] S. Abbate, M. Avvenuti, P. Corsini, J. Light and A. Vecchio, "Monitoring of Human Movements for Fall Detection and Activities Recognition in Elderly Care Using Wireless Sensor Network: a Survey, "Wireless Sensor Networks: Application – Centric Design, Yen Kheng Tan (Ed.), InTech.