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Enhancing Human Fall Detection with Wearable Sensors: Exploring Artificial Intelligence through Approximate Entropy

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Abstract:
Falls among individuals living alone at home pose significant health risks, particularly for older adults, presenting a substantial challenge in healthcare. Detecting anomalies in their Activities of Daily Living (ADL) is crucial for proactive healthcare management, aiding in the early identification of potential issues and enhancing the quality of life for this demographic. Numerous studies have explored anomaly detection in ADL using various sensor types. Therefore, there is a pressing need to develop a precise system capable of accurately detecting human falls during ADLs within a home environment. This research specifically focuses on identifying and distinguishing human falls in ADLs by leveraging data collected from wearable sensors. This paper introduces a novel model employing the Approximate Entropy (ApEn) measure for detecting human falls during ADLs within home settings, achieving a notably high level of accuracy. The effectiveness of this proposed Approximate Entropy method is assessed using the publicly available URFD dataset. The experimental outcomes demonstrate that the entropy measures proposed exhibit promise in accurately detecting and distinguishing human falls from other activities. Comparative analyses with alternative techniques further corroborate the efficacy of the proposed Approximate Entropy.

Keywords: Detection of people falls, Approximate entropy, recognition of human activity, wearable sensors, activities of daily living (ADL).

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تحسين اكتشاف السقوط البشري باستخدام أجهزة الاستشعار القابلة للارتداء: استخدام الذكاء الاصطناعي من خلال الانتروبيا التقريبية

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الملخص
يشكل السقوط بين الأفراد الذين يعيشون بمفردهم في المنزل مخاطر صحية كبيرة، خاصة بالنسبة لكبار السن، مما يمثل تحديًا كبيرًا في مجال الرعاية الصحية. يعد اكتشاف الحالات الحرجة في أنشطة الحياة اليومية (*ADL*) أمرًا بالغ الأهمية لإدارة الرعاية الصحية الاستباقية، مما يساعد في التحديد المبكر للمشكلات المحتملة وتحسين نوعية الحياة لهذه الفئة العمرية. ساهمت العديد من الدراسات في الكشف عن الحالات المعرضة للمخاطر اثناء القيام بالأنشطة الروتينية اليومية والحد من عواقبها الوخيمة، وذلك باستخدام أجهزة الاستشعار المختلفة. ولذلك، هناك حاجة ملحة لتطوير نظام دقيق قادر على الكشف الدقيق عن حالات السقوط البشرية أثناء القيام بالأنشطة اليومية داخل البيئة المنزلية. يركز هذا البحث بشكل خاص على تحديد وتمييز السقوط البشري في أثناء القيام بالأنشطة اليومية من خلال الاستفادة من البيانات التي يتم تجميعها من أجهزة الاستشعار القابلة للارتداء. تقدم هذه الورقة نموذجًا جديدًا يستخدم مقياس الإنتروبيا التقريبي (*ApEn*) للكشف عن حالات السقوط البشرية أثناء القيام بالأنشطة اليومية داخل المنزل، مما يحقق مستوى عالٍ من الدقة بشكل ملحوظ. يتم تقييم فعالية طريقة الإنتروبيا التقريبية المقترحة باستخدام مجموعة بيانات *URFD* المتاحة لعامة الناس. توضح النتائج التجريبية أن مقاييس الإنتروبيا المقترحة تبشر بالخير في الكشف الدقيق عن حالات سقوط الإنسان وتمييزها عن الأنشطة الأخرى، كما تؤكد التحليلات المقارنة مع التقنيات الأخرى فعالية الإنتروبيا التقريبية المقترحة.

الكلمات المفتاحية: اكتشاف حالات السقوط البشرية، مقاييس الإنتروبيا، تمييز الأنشطة البشرية، أجهزة الاستشعار القابلة للارتداء، أنشطة الحياة اليومية.

Introduction

Generally, the people of seniors aged 60 years old and more in developed countries is expected to be around 1.9 billion by the year of 2050 [1]. This will gradually affect on the cost of healthcare sector of older people [2]. Moreover, researchers have indicated that the population of older people who live alone at home is globally increasing [3], which leads to more expenses in healthcare. Researchers also have demonstrated 30% of old people above 65% suffer from one fall in each year at least [4], and 47% of fallen people would not be able to get back up without help from other people [5].

To avoid the problems of older people being fallen while they are alone at their homes, assistive technologies are used to detect falls and help them live safely [6]. Many studies have been conducted to discover the vulnerability of elderly people to falls while performing their daily routine activities, using several methods based on various types of sensors like wearable sensors. These kinds of devices are broadly used to monitor the movements of human body in order to detect falls. Therefore, study the movement of the human body allows to detect when there is an expected fall [7].

The Approximate entropy amount is utilised in several applications, to assist and show the uncertainty rate Thus, to calculate the independent rate of information with the uncertainty condition, Approximate Entropy is a beneficial measurement for human falls detection from other activities. Consequently, in this research the data gathered from wearable sensors is used to detect human falls in ADLs. It is essential to have an exact system with a capability to monitor and detect old people falls in their everyday movements. This study investigates if the proposed Approximate Entropy can be used for older people falls detection in their daily activities in a home environment.

This paper contains following: A brief review of previous associated studies for people fall detection are demonstrated in Section II. Section III shows a brief description of system framework, overview systematic and the proposed model of Approximate Entropy to detect human falls in ADLs. Section IV provides details for the dataset used, analyses the new results and provides a comparison for the achieved results from the proposed model with the existing models. Finally, all information has been provided in this paper work are summarized in Section V.

Previous work

Human falls detection during ADLs in during daily activities at home situation is still a major task for researchers lately. Different researches have been done for human fall detection in ADLs, utilising different methods, such as Hierarchical Hidden Markov Model (HHMM) [8] and Hidden Markov Model (HMM) [9]. In [9], researchers introduced a method called three X-Factor Hidden Markov Models (XHMMs), to detect people falls during home environment utilising a wearable device. The HMM is used for normal daily activities as training and a new state is added for detecting unseen falls. Two datasets, which gathered using an accelerometer and gyroscope, are used in their experiments. The achieved results show that two models of the XHMM can be used for people falls detection with an accuracy of 96.6%. An HHMM is utilised in [8] for human falls detection during daily activities using video analysis method. The HHMM was used into two layers; first layer used two states, one is for upright standing pose and the second one is for laying pose. The obtained results indicate that the suggested technique done detection rates of 98% accuracy for people falls detection in ADLs.

A study reported in [10] introduced an HMM model to detect human falls with a sensor for single motion for real-life home monitoring situations. The HMM is utilised for human falls detection built on acceleration signal data gathered from motion sensors. Both real-world data and synthetic were used to check and evaluate the suggested method. The experimental results obtained from this research indicate that when HMM is done on used datasets, a positive predictive value of 98.1% and a sensitivity of 99.2% were obtained for the first dataset used, while 78.6% positive predictive value and 100% sensitivity have been achieved from the other dataset utilised. Although the suggested method achieved the required result, there are some limitations to the study. However, the data used in this research work is a snapshot of one event, not many events from one subject over time. Likewise, in [11], the authors suggested an HMM model for human falls detection in ADLs using the publicly available RGB-D dataset. The offered system reached an accuracy of 85.56%, however, the research indicates that some further work needs to be done to improve the proposed method.

Researchers in [12], have suggested a Support Vector Machine (SVM) for detecting human fall in a home environment using data gathered from novel camera. The concept of this study focuses in detecting the moving resident at home environment and use advantages of the bounding ellipse, then SVM is applied to categorise the movements into fall and non-fall events. The proposed method is tested and evaluated using the available URFD dataset, and the suggested model can be achieved 97.1% of overall accuracy.

In [13], the researchers recommended a new method depending on a Recurrent Neural Network (RNN) to detect human falls in home environments. Their experiments have been done and evaluated depending on a dataset collected from wearable sensors and depth cameras. The achieved results from this study show that the used approach reached better results compared to the other models, with an accuracy of 98.57%. Some other methods, were not stated above, are used for human falls detection in ADLs [14]. For example, the research in [15] proposed a method based on data gathered from a depth image to detect human falls in daily activities. The focus of their research is on human fall detection during daily activities and indicating the place where the fall occurred. The obtained results from this study show that the presented method can determine human falls from other activities in a home environment by an accuracy of93.94%. Whereas the proposed method demonstrated a promising result, it is required more improvement by concentrating on using other datasets based on different daily activities.

Regarding to the previous work mentioned earlier, the suggested technique in this paper, based on Approximate Entropy, has not been used to detect human falls yet. Next section shows the importance of this research work.

Material and methods

The proposed Approximate Entropy method is introduced in this section for detecting human falls during the activities of daily living within home environment. First of all, a brief explanation about the Approximate Entropy approach is also presented in the fallowing section.

A. System Framework and Overview Systematic

An Approximate Entropy-based approach is considered as one of the novels employed approaches for detecting human falls in the home or work environments. In this particular experiment, data collected from wearable motion-sensing device is used. Once the anomalous in human behaviours can be defined as an abnormal behaviour, the collected data from the wearable sensors during the daily routine will be used to detect abnormal patterns, for example, fall pattern.

As it is statues in [16], any changes in an individual’s ADL patterns in a home or work environments is classified as abnormal events. Therefore, entropy measure approaches can be used as a method for indicating of the level of randomness (abnormalities). This means, entropy approaches could be accurately used to detect any abnormalities within a sample of data that is mostly presented normal pattern. Figure 1, illustrated the proposed entropy approach that aims to detect a high value of the entropy in the collected data. Thus, the human falls events have the greater acceleration (collected from the wearable sensor) than other ADL activities.

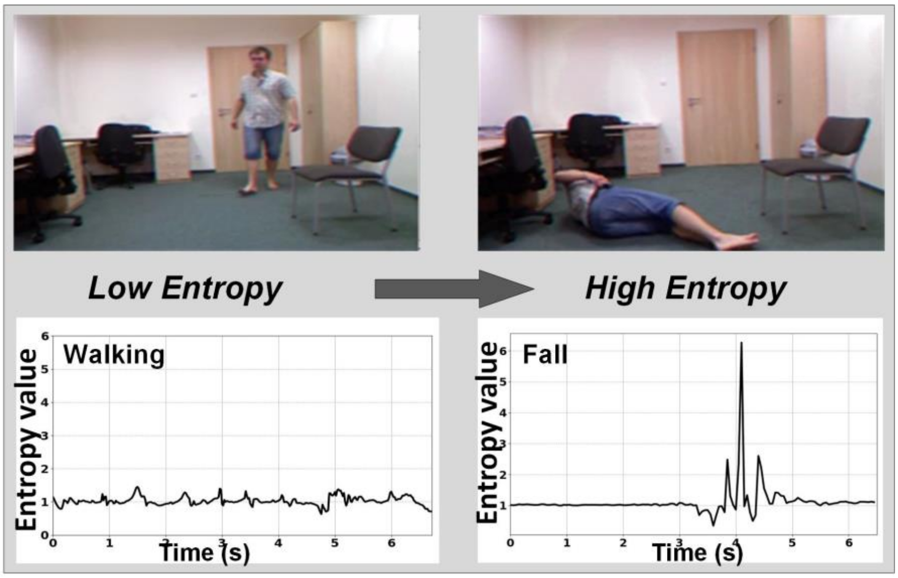

Figure 1: A framework of the proposed scenario of human fall detection within daily activities.

Figure 2, shows the proposed ApEn measure approach for detecting a human fall event. The presented ApEn contains three different stages as follows:

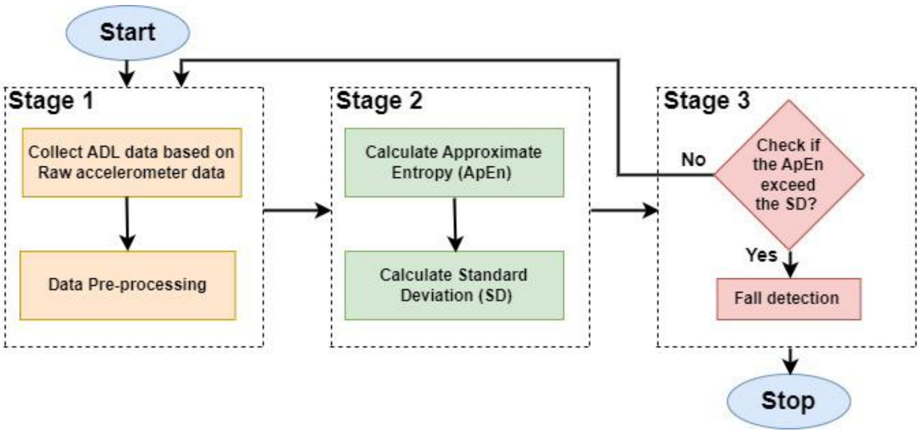

Figure 2: ApEn-based proposed approach for detecting human fall events using accelerometer data.

• Stage one, collecting the accelerometer data, which represents ADLs and pre-process it before the nest stage.

• Stage two, Employing the Approximate Entropy to the collocated and pre-processed data for detecting human falls events within the daily activities. In this stage, the standard deviation is calculated as well.

• Stage three, the calculated standard deviation will be used with the Approximate Entropy measure to identify whether if there are any fall events or not.

A. Approximate Entropy

First time the Approximate Entropy (ApEn) was introduced by the researchers in [17]. It has been used to simplify and classify the complex system concept. This means it was mainly used to differentiate the high regularity as small entropy values, and low randomness as high entropy values in any numerical data set. Following the equations used for calculating the ApEn as explained in [17]. The ApEn values can be computed for the time series length N as fellow:

$$ApEn_{(m,r,n)} = \emptyset^{m}(r) - \emptyset^{m+1}(r) \quad (1)$$

Results and discussion

To test and evaluate the proposed ApEn model for human fall detection during ADLs, a dataset collected from a wearable sensors is used. A brief explanation about the collected dataset is introduced in the following Section. All tables should be inserted in the main text article at its appropriate place.

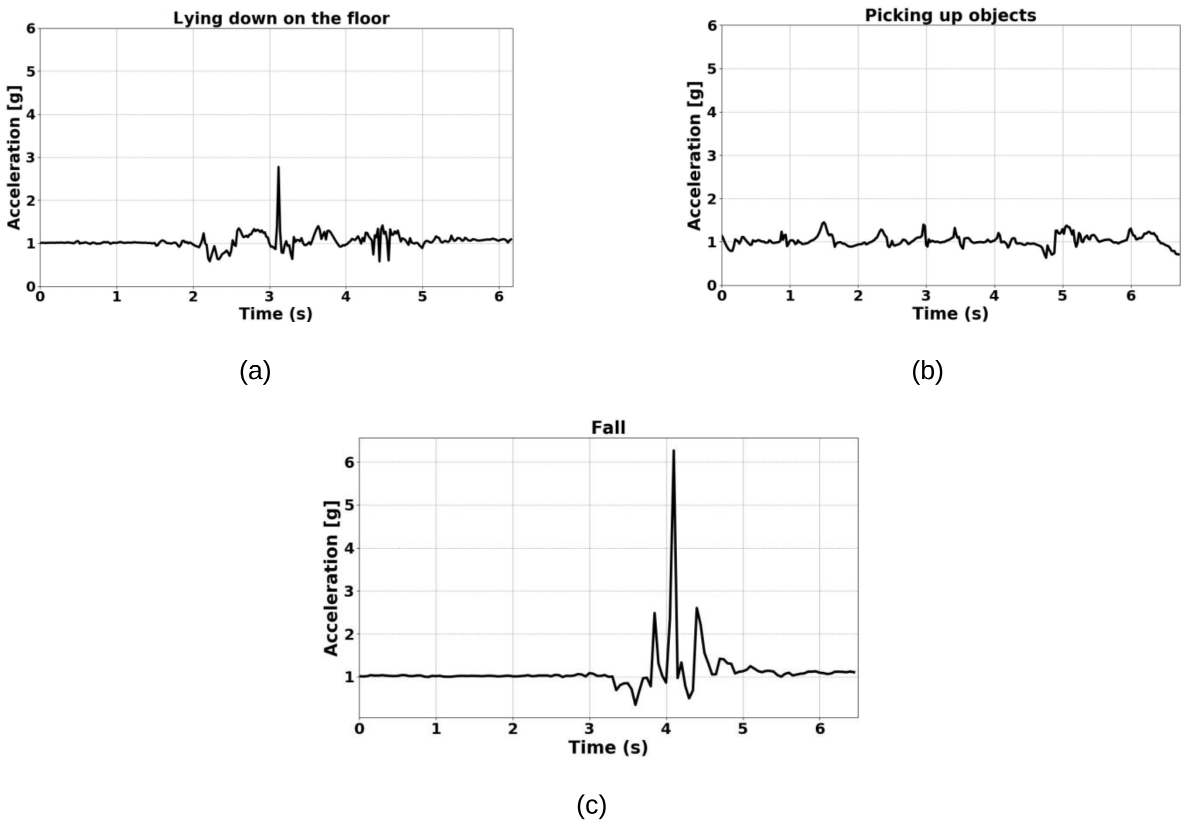

Figure 3: Different data points represent the acceleration during time; a) lying on floor activity, b) picking up any object activity and c) fall down events.

A. Data Collection

To test and evaluate the performance of the proposed ApEn measures for human fall detection, an experiment was conducted to collect the required data. The used dataset is publicly available at [18], to be utilised for research purposes. As it was explained, this data was achieved using one accelerometer sensor attached to a human body, and two cameras. After the data being collected it was fully annotated to simplify it. More than 40 ADLs was collecting during this experiment and 30 fall event was recorded and randomly distributed within the dataset. Figure 3 presents a case of acceleration data that changed its pattern during different ADLs.

As it is obviously well known, the accelerometer data has three dimensions; x-axis, y-axis, and z-axis at time t. These (x,y,z) values are used with the proposed ApEn as follows:

$$M(t) = \sqrt{A_x^2(t) + A_y^2(t) + A_z^2(t)} \quad (2)$$

Ax(t), Ay(t), and Az(t) are the collected (x,y,z) values collected from the acceleration sensor at time t. M is the input array to the proposed ApEn model. Once the output magnitude of the proposed ApEn is calculated, it will be converted to different time-based data points upon its entropy measures.

B. Experimental Setup

The explained dataset in the above Section was used to test and evaluate the proposed ApEn model. This research is aiming to clearly decide whether ApEn can detect human falls in a home environment or not. Once the ApEn values have been calculated, the acceleration magnitude points M were utilised as inputs to the ApEn measure. During this scenario, the ApEn measures were calculated every second for 60 samples per second. Thus, the vector sequence AN is containing 60 sample.

Threshold technique is widely used in many diffident relevant applications includes image processing and pattern recognition. In general, there are several threshold approaches that are easily used to differentiate between normal and abnormal events [19], [20]. In this research a threshold approach based on Standard Deviation is used. In this method of threshold, the amount of variation or dispersion within a set of values is measured as:

$$SD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2} \quad (3)$$

where xi represents the i'th value in the dataset, the average of the x-values in the dataset is presented as x in the N number of frames.

Simply, this method is utilised to decide whether there are a fall in the ADLs or not. In case if the ApEn values are higher than the upper standard deviation boundaries, that means this event is considered as a fall down. Figure 4 presents the achieved results when the ApEn measure is employed. It is clearly seen when the ApEn values are higher than the upper standard deviation boundaries, means the fall down events were accurately detected.

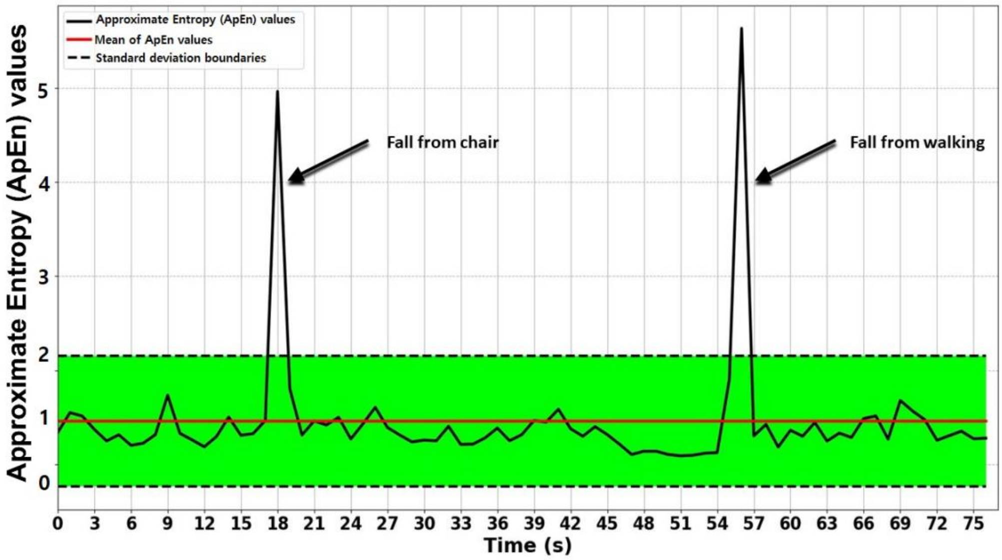

Figure 4: Results of detecting two fall events; 1) happening while falling from a chair, 2) happening during walking. These two fall events were detected using the proposed ApEn model.

C. Proposed model's

The performance of the proposed ApEn model was evaluated using a dataset containing 30 fall events and about 40 ADLs activities that captured from a real home environment. Table I, shows the proposed ApEn model indicates correctly and successfully 28 falling events out of 30 events and 37 ADLs out of 40 normal daily activities and failed to classify only 2 and 3 falling events and normal daily activities, respectively.

A confusion matrix was used to evaluate the achieved results as follows:

Table 1 The accuracy of detecting the fall down events based on the proposed ApEn model.

Events	Total	Detected	Not detected
Falls	30	28	2
Other activities	40	37	3

Table 2 Proposed ApEn model performance of for human fall detection.

Methods	Achieved Result
Sensitivity rate	98.1%
Specificity rate	96.9%
False Positive (FP)	3.1%
False Negative (FN)	1.9%
Positive Predictive (PP)	98.1%
Negative Predictive (NP)	99.3%
Accuracy (Acc)	97.2%

Table 3 Comparing the achieved results using ApEn model with the existing approaches using the same dataset.

The proposed models	Sensitivity (%)	Specificity (%)
Support Vector Machine [18]	97.2	96.6
Deep Neural Network [21]	75	92.1
ApEn-based model	98.1	96.9

• True Positive (TP): identifying the data containing fall events and correctly detected.
• False Positive (FP): identifying the data has no fall events and incorrectly detected as fall events.
• True Negative (TN): identifying the data has no fall events and is correctly detected.
• False Negative (FN): identifying the data contains fall events and incorrectly detected as not fall events.

D. Comparing the achieved results from the Proposed ApEn model with the Existing Models

As it was clearly mentioned in the previous sections, the commonly used approaches for detecting human falls events during the daily activities are: Support Vector Machine (SVM), and (Deep Neural Networks (DNNs). Therefore, the evaluation process of the proposed ApEn model will be carried out and comparing it to these mentioned approaches using the same dataset as it is shown in Table III.

Based on the compassion results presented in Table III, the proposed ApEn model is significantly accurate for detecting the fall events within human daily activities with an accurate of 98.1% sensitivity and 96.9% specificity.

Conclusion

This paper's experimental research explores the application of the ApEn measure for detecting human falls during Activities of Daily Living (ADLs) within a home environment. A unique feature, the standard deviation of the mean of ApEn values, is employed to differentiate between the presence or absence of a fall in the resident's activity. Consequently, when the ApEn measure value surpasses the upper standard deviation boundaries, the event is identified as a fall. The ApEn method demonstrates a high detection rate of 98.1% and a low false positive rate of 3.1%. With an accuracy of 97.2%, the proposed

ApEn method effectively distinguishes human falls from non-falls. The outcomes indicate superior performance compared to other approaches used for human falls detection.

This underscores the potential of the Approximate Entropy measure as a promising technique for detecting human falls during ADLs in a home environment.

Future research will involve comparing various entropy measurements to assess the overall performance of each in detecting human falls.

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