A Comparison of Daily Human Activity Classification Techniques for Wearable Devices

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Abstract— **We present and compare some of the most common techniques used for classifying daily human activates that are applied to signals from wearable kinematic sensors. We investigate and compare different research results reported on this topic that focus on the most common human activities, i.e., walking, running, sitting, lying and climbing up stairs. Besides comparing the considered research results in the obvious terms of classification accuracy, we also compare them with respect to the final number of features considered and the length of the windows used for feature extraction. Both of the latter characteristics have an impact on computational efficiency and delay and so affect the suitability for real-time operation of the presented techniques.**

Keywords: wearable devices, wearable sensors, classification techniques, motion analysis.

I. INTRODUCTION

In the area of modern methods of motion tracking, relevant data are the starting point for comprehensive motion analysis. Wearable motion sensors provide data that directly reflect the motion of individual body parts and can enable the development of advanced tracking and analysis procedures [1-4]. Microelectromechanical system (MEMS) motion sensors are small, light, widely affordable, and come with their own battery supply. These sensors cause minimal physical obstacles for activity performance and can provide simple, repeatable, and collectible data at any outdoor or indoor setting.

With the ongoing development in the field of body-worn sensors, their use for human motion analysis is observingly increasing. Activity classification is an important research topic in this field.

Different body-worn sensors measuring motion and various biometrical parameters are suitable for the purpose of motion analysis, among which accelerometers and gyroscopes are the most common.

In this review paper, we give attention to some of the most common classification techniques that have been reportedly applied to signals from 3D accelerometers and 3D gyroscopes for human activity classification. Our aim is to provide a quality review and present with best practices. We emphasize the problems that have been efficiently solved so far and stress the challenges that need further research attention.

Activity classification provides for modeling of user behavior. Efficient techniques can therefore enable wearable devices to be enforced to their full potential in the broader scope of motion analysis.

In this comparative study, we primarily focus on presenting different activity classification techniques and comparing them with respect to challenges they efficiently solve and the classification accuracy they achieve for the considered context. The main benefit of using body-worn sensors lies in their low-power consumption. Computationally efficient activity classification techniques not only support prolonged energy autonomy of the devices but also enable classification in real-time.

II. METHODOLOGY

Besides the complexity of human movements typical for a considered activity, the variety of performances is a mayor challenge in this field. Considering pace, intensity, body posture etc., subjects differ with respect how they perform an activity.

Intersubject variations are also common. For this reason, most of the motion classification techniques as used today are not applied directly to signals from wearable devices. Instead, time and frequency features are usually extracted from limited time sequences of acquired accelerometer and gyroscope signals. The usual time length of the considered signal window is between 1 and 5 s.

The feature set usually includes the maximum and minimum values of signals, the root mean square value, standard deviation, interquartile range, skewness, kurtosis, duration of the segment in seconds, the magnitude of the first five coefficients of the discrete Fourier transform or the dominant frequency component. For each time-window, these features are then arranged in a vector.

A feature reduction technique like principal component analysis can then be then applied to estimate along which dimensions the obtained vectors are characterized by largest variations. The dimensions with largest variations correspond to the most useful features for discriminating between the activities and providing for extracted feature reduction. These features are finally used as inputs to different activity classification algorithms.

The most commonly used classification techniques include: the least-square methods, dynamic time warping, support vector machines, the *k*-nearest neighbor algorithm, Bayesian decision making and artificial neural networks. We investigated and compared different research results reported on the topic of activity classification that focus on the most common human activities, i.e., walking, running, sitting, lying and climbing up stairs. Besides comparing the considered research results in the obvious terms of classification accuracy, we also compared them with respect to the final number of features considered and the window length. Both of the latter characteristics have an impact on computational efficiency and delay.

III. Classification Techniques

In [5], author report using 5 s long windows of signals obtained from five devices mounted on all four human extremities and the torso. The sampling frequency was set to 25 Hz. From the initial 9 signals, a total of 1170 features were obtained for each of the 5 s signal segment. This number of features was reduced to 30 using principal component analysis.

Among the seven classification techniques applied to these features to classify 19 different activities, in general, Bayesian decision making performs best with respect to accuracy and computational efficiency.

A similar analysis was reported in [6]. The authors report using 3D accelerometer and 3D gyroscope signals for classifying 13 daily activities including sitting, walking, jogging and going upstairs and downstairs at different paces.

The sampling frequency was set to 30 Hz and the window time-length was set to 2 s with a 50% overlap between consecutive windows. Among the classification techniques compared in this analysis, the k-nearest neighbor algorithm performed superior to all other methods with respect to classification accuracy.

Classification accuracy for walking at different paces was between 90.1% and 94.1%, for jogging 91.7% and for sitting 100%. Stair activity showed to be the most challenging activity, with classification accuracy ranging from as low as 52.3% to 79.4%.

High classification accuracy of a decision tree classifier was reported in [7], where a 2.5 s window with a 50% overlap was used for feature extraction. The authors here also report a significant reduction in classification accuracy when the classification techniques are trained on a younger group and tested on an older and vice versa.

In [8] authors report that using an activity recognition framework based on compressed sensing and sparse representation theory outperforms the usually considered classification techniques including nearest neighbor, naïve Bayes and support vector machines.

The subjects were encouraged to perform these activities diversely and were not provided prior instructions on how these activities should be performed. Data was collection using a single inertial measurement unit that integrates a 3D accelerometer, a 3D gyroscope and a 3D magnetometer.

A 4 s long window was used with 50% overlap for feature extraction. Besides the common statistics used also in previous studies, the authors have included features like zero crossing rate, mean crossing rate and first-order derivative, movement intensity, eigenvalues of dominant directions and average velocity along the heading direction.

All of the obtained 110 features are then linearly combined using randomly generated coefficients.

In [9] the authors have developed a system that uses a single 3D accelerometer for classifying daily activities. The system also estimates the speed for the walking (running) labeled data features.

The classification tasks are achieved by cascading two support vector machine classifiers. The sampling frequency was set to 250 Hz and the window length to 1 s with 50% overlap.

Authors present a classification accuracy higher than 99%.

While the training is performed externally, the classification itself is performed on-line using a specially designed data acquisition and signal processing board consuming 2 W of power. Energy autonomy of the board has not been reported.

Some motion classification methods also implement the transformation of 3D acceleration values from the sensor to the reference frame, allowing accurate results regardless of the sensor orientation.

In [10], walking detection is reported. A gait segment is found when a regular sequence of eight steps is detected. Additionally, an autocorrelation-based filter is used to discard segments with reduced regularity.

3D acceleration values that belong to the obtained gait segments are then used to calculate acceleration magnitude and vertical and horizontal acceleration. These three acceleration vectors are then used as inputs to feature extraction.

A multinomial logistic regression based classification technique applied to these features was used for user identification, finally providing for a recognition rate ranging from 95% to 100%.

IV. Conclusion

From the investigations here considered, we can conclude that feature extraction and reduction from signals obtained with body-worn kinematic sensors together provide for efficient activity and/or user classification.

The techniques considered can be implemented for on-node operation. It is however important to note that, for real-time analysis the features actually considered for classification should not be repeatedly estimated during real-time operation but should be pre-defined in an offline analysis environment.

The computationally efficiency of obtaining the chosen features from the raw signals is also important. Finally, it is worth noting that residing on extracted features gives poor further possibilities for the analysis of the classified motion.

In this sense, applying a computationally efficient approach for signal-based activity classification is potentially a more reasonable choice, opening up a number of research challenges that are to be addressed in further work.

References

[1] K. Aminian, B. Najafi, "Capturing human motion using body-fixed sensors: outdoor measurement and clinical application," *Comp. Anim. Virtual Worlds*, vol. *15*, pp. 4-5, 2004.

[2] O. Tunçel, K. Altun, B. Barshan, "Classifying Human Leg Motions with Uniaxial Piezoelectric Gyroscopes," *Sensors,* vol. 9, pp. 8508-8546, 2009.

[3] D. McIlwraith, J. Pansiot, G.Z. Yang, "Wearable and ambient sensor fusion for the characterisation of human motion," *Proceedings of the 2010 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Taipei, Taiwan, 18-22 Oct. 2010,* pp. 5505-5510, 2010.

[4] G. Schall, D. Wagner, G. Reitmayr, E. Taichmann, M. Wieser, D. Schmalstieg, B. Hofmann-Wellenhof, "Global pose estimation using multi-sensor fusion for outdoor Augmented Reality," *Proceedings of the 8th IEEE International Symposium on Mixed and Augmented Reality ISMAR, Orlando, FL, USA, 19-22 Oct. 2009*, pp. 153-162, 2009.

[5] K. Altun, B. Barshan, O. Tunçel, "Comparative study on classifying human activities with miniature inertial and magnetic sensors," *Pattern recognition*, vol. 43, pp. 3605-3620, 2010.

[6] W. Wu, S. Dasgupta, E. E. Ramirez, C. Peterson, G. J. Norman, "Classification Accuracies of Physical activities Using Smartphone Motion Sensors," *Journal of Medical Internet Research*, vol. 14, 2012.

[7] M. B. Del Rosario, K. Wang, J. Wang, Y. Liu, M. Brodie, K. Delbaere, N. H. Lovell, S. R. Lord, S. J. Redmond, "A comparison of activity classification in younger and older cohorts using a smartphone," *Psychological Measurements*, vol. 35, 2014.

[8] M. Zhang, A. A. Sawchuk, "Human Daily Activity Recognition With Sparse Representation Using Wearable Sensors," *IEEE Journal of Biomedical and Health Informatics*, vol. 17, pp. 553-560, 2013.

[9] A. Mannini, A. M. Sabatini, "On-line Classification of Human activities and Estimation of Walk-Run Speed from Acceleration Data using Support Vector Machines," *Proceedings of the 33rd Annual International Conference of the IEEE EMBS, Boston, MA, 2011*.

[10] G. Cola, M. Avvenuti, A. Vecchio, "Real-Time Identification Using Gait Pattern Analysis on a Standalone Wearable Accelerometer," *The Computer Journal*, vol. 60, pp. 1173-1186, 2017.

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