CNN-based real-time activity recognition system

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***Abstract*—Body sensors play an increasingly important role in our everyday life, they can be fundamental in terms of survival and health (think about pacemakers, bionic eye, bionic ear, etc.) or they offer us a new kinds of entertainment (such as fitness bands, sensors used in video games, etc.).**

In most cases, especially in sensors that make use of Inertial Measurement Units (IMUs), a motion recognition system is required. Depending on the application, these motions can be both little gestures or complex activity in which the entire body moves. A lot of effort has been put in find an efficient way to recognize in real time everyday activities and apply these solutions to a wide range of scenarios like first responders, assisted living rehabilitation, etc.

In this work CNN-based activity recognition systems are investigated and different architectures are tried. The goal learn a Convolutional Neural Network (CNN) capable of recognizing 11 different types of activities, showing that this type of Artificial Neural Networks (ANN) can give good predictions also with 1D data.

The resulting prediction accuracy in real-time application reveal that this architecture performs well in the learning phase but gives poor accuracy when tried on new data.

***Index Terms*—Activity recognition, Convolutional Neural Networks, Machine Learning, Real-time systems, Inertial sensors**

I. Introduction

Maximum length for the whole report is 9 pages. Abstract, introduction and related works should take max two pages.

Activity recognition systems are promising for the next-generation technologies, they will be used both for entertainment scenarios and to improve some aspects of the medical and survival sector. Existing solutions are usually implemented extracting hand-crafted features used as input for classifiers such as Support Vector Machines (SVM) [1]–[3]. This approach is consolidated and it leads to good results in terms of accuracy of the predictions, although hand-crafted features are data dependent and could not be generalized for different application domains. In the last few years a lot of effort has been put in implementing good Activity Recognition Systems (ARS) using non feature-dependent techniques to have a more general model and to reuse it in different scenarios.

This work improves the work made in [4] using a CNN-based technique to predict the proposed activities. In the original work a total of 19 features were extracted from the recorded signals, making the model strongly data-dependent. Moreover, the authors seem superficial presenting the final results. The aim of this work is to elaborate the dataset used in [4] and to learn a more general model to predict human activities in real time with a good accuracy.

Given their 2D nature, CNNs are usually applied to imaging field, such as the prediction of diseases classifying x-rays images or the recognition of object, people and animals. This work applies CNNs to 1D signals, proving that these kind of Neural Networks are not limited to 2D signals but they can have a wide range of applications. Moreover, since this approach does not require an ad-hoc dataset or a particular sensor to work, it can be applied (with some little changes) to any dataset with the same purpose.

Summing up what has been done in this work, the main contributions are reported in the following:

- a more general model CNN-based is used, to make this work reusable allowing other researchers to improve the architecture here implemented
- CNN is used in a non-typical 1D scenario, this proves the flexibility of this tool and the adaptability to a very wide range of applications
- more complete results regarding the accuracy reached in the test phase are presented, showing the behaviour of the model in situations where few data are available and these have an high variance.

The paper is structured as follows. In section II the state-of-art literature is presented, in section III are reported, at large, the main steps made by the implemented ARS to predict the activities. In section IV the signals collected in the dataset are described and the pre-processing algorithm to make them suitable for the learning framework is explained in detail. The learning framework is presented in V and the final results are commented in VI. Finally in VIII are reported the difficulty faced during the development of the system and conclusions are drawn.

II. Related Work

Activity recognition is a field evolving for more than twenty years, it started from very simple motion recognition and it gets more complex over the years. As just said, the classical approach to this problem is with a feature extraction techniques. In these solutions, ad-hoc features are extracted from the dataset, reducing the dimension of each signals from the recorded sample to a feature vector. In this way features can be classified using several classifiers to obtain an accurate prediction.

The main processing pipeline used from these solutions is reported in Fig. 1. The most used classifiers for feature extraction are Decision Trees, SVM, K-nearest neighbors and Naive Bayes although a lot of different classifiers can be used

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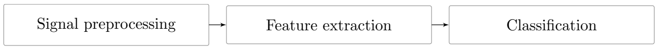

Fig. 1: Processing pipeline for feature extraction techniques

[5]. Features can be extracted either from a single sensor or from a large set of sensors, the first solution suffers an high computational complexity while the second is computational easier but certainly less portable and can create issues due to redundancy of the information. In [6] they collect data from 30 sensors positioned around the body and they classify features extracted from these data with a clustering algorithm. They chose to collect all the data in a central processing unit to perform a centralized classification. This approach suffers however an high cost and an high complexity to limit redundancy in the data. Varkey et al.'s research, uses only two accelerometer sensors placed at the wrist and ankle [7]. They collected data and they predict 6 different activity using an SVM as classifier, reaching an high accuracy.

The problem of this technique is the strong data dependence even if it gets a good accuracy.

To overcome this lack of the classical ARS, deep learning is used in several ways. In [8] an Hidden Markov Chain (HMM) is used on data collected by 8 sensors. They firstly compute feature extraction on the data collected from each sensor in a distributed manner, then feature vectors are given in input to the HMM that classify the feature vectors in the activities labels. In [9] the authors perform a matrix factorization for dimensionality reduction and deep learning algorithm to automatically learn suitable features. In this work, they reduce the dimension of the dataset using matrix factorization and they elaborate the results in a Neural Network. The output of the Neural Network (NN) is a feature vector. Finally the activity is predicted classifying the feature vector with a Softmax classifier. The accuracy is quite good since they avoid hand-crafted features, but they still rely on features extracted from data.

The key to implement an adaptable and reliable algorithm to classify human activities is the use of deep learning without extracting features at all. A comparison between three different deep learning algorithms is made in [10]. They collected data from one single sensor and they predicted activities using Decision Trees (DT), ANN and Random Forest (RF). They stated that RF performs better than the other two, with an accuracy between 75% and 90% depending on the activity.

Milenkoski et al. use instead Long Short-Term Memory (LSTM) networks, a specific type of Recurrent Neural Networks (RNN), to perform activity prediction in real time on smartphones. They learn the model using a previously collected dataset to subsequently apply it to new raw data recorded from a smartphone. The accuracy reached is variable between 50% for the most difficult activities to recognize and 100% for the easiest. The overall accuracy is 88% for the data acquired and pre-processed in laboratory and 82% for the real time prediction [11].

An interesting solution is the application of CNN in the activity recognition field. In [12] a CNN is used to predict activities using data recorded by a tri-axis accelerometer sensor. They tried to predict very specific activities such as *Fetch cup from desk* or *Pour milk into cup* using a CNN made by 3 convolutional layers, one max-pooling layer and a fully connected layer, using a Softmax function to the output of the network. This application has a recognition rate of 99.8% although is not thought for real time prediction.

The goal of the next sections of this work is to combine a CNN architecture with a real time prediction model, to prove that this approach gives results comparable or better than the ones showed in [13].

III. Processing Pipeline

The project can be divided in 3 parts: the dataset creation, the neural network creation and the real time prediction. In order to make an action recognition model it was firstly created a proper dataset. All the signals were divided in several overlapping windows and were thrown into a CNN made up with 1D convolutional layers and fully connected layers. When the NN was trained and tested, a new dataset was used in order to verify the effective robustness and generalization of the model. The main steps of the processing pipeline are reported in Fig. 2.

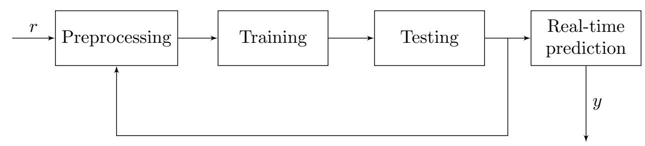

Fig. 2: Scheme of processing pipeline, r is the raw signal given in input to the preprocessing part, y is the label predicted by the prediction algorithm

IV. Signals and Dataset

A. Measurement setup

The signals the authors have worked on were provided by DLR official website [14]. We took into considerations two of the three published Matlab datasets: *ARS_DLR_Data_Set_V2.mat* and *ARS_DLR_Benchmark_Data_Set.mat*. Both of them are made up of signals recovered by a Micro Electro-Mechanical System (MEMS) based IMU (an Xsens MTx-28A53G25) composed by an accelerometer, a gyroscope and a magnetometer. These measurements systems provide informations about the inertial acceleration, the angular velocity and the magnetic field direction. At the experiment joined fourteen people and the IMU, that was positioned over the pelvic region of each one (Fig. 3), recovered signals during some ordinary motion activities like *standing*, *sitting*, *running*, *jumping*, *lying* and all the transitional phases from an activity to another.

The considered datasets are divided only because they have to be used in different ways, but they are going to be described in the same way according to their identity.

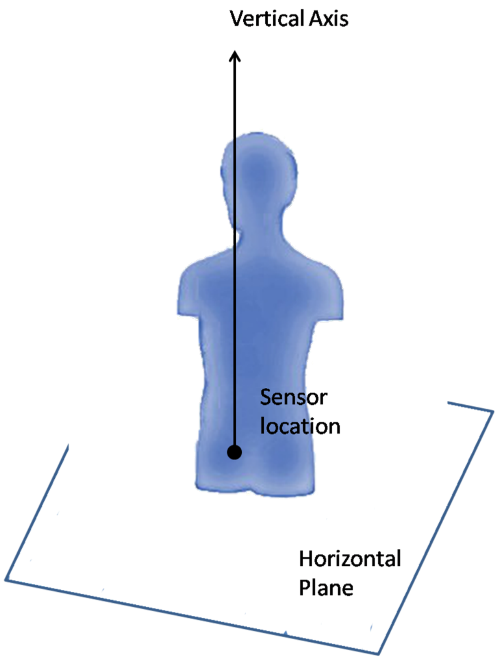

Fig. 3: Sensor position and the representation of the body frame

Both datasets are divided in activity sessions, 34 in *ARS_DLR_Data_Set_V2.mat* and 3 in *ARS_DLR_Benchmark_Data_Set.mat*, each session is a structure in turn (a sua volta) that contains: a matrix of 10 column in which the first column represents the time domain and the other ones represents the IMU records over the three sensor coordinate, a rotation matrix that has the same dimension of the first one that permits to turn to the global frame the first matrix, a vector that contains the activity labels performed during the session (see Tab. 1) and lastly a vector that indicates when each activity starts and ends.

Label	Index	Description
'RUNNING'	0	running
'WALKING'	1	walking
'JUMPING'	2	jumping
'STNDING'	3	standing
'SITTING'	4	sitting
'XLYINGX'	5	lying
'FALLING'	6	falling
'TRANSUP'	7	getting up i.e.: from sitting to standing
'TRANSDW'	8	going down i.e.: from standing to sitting
'TRNSACC'	9	accelerating
'TRNSDCC'	10	deccelerating

TABLE 1: Activities took into consideration with the associated labels

B. Signal pre-processing

The first pre-processing applied to the dataset consisted in representing the signals according to the global frame using the rotation matrix MC says: should I say more?. The dataset considered already contains pre-processed data, sampled with T = 0.01 s.

In Fig. 4, Fig. 5 and Fig. 6 is showed one of Susanna activity sessions. These figures represent the norm (see Eq. (1)) of accelerometer, gyroscope and magnetometer over the three global coordinates instead of three figures for each measurement system. This is only a convenient choose according to the visual meaningfulness of the norm. In particular in Fig. 4 the shift of the acceleration mean around 9.8 m/s is noticeable, value coherent with the gravitational constant value g.

It also emerges in each of these figures how the transitory activities from standing to sitting and vice versa can be observable due to the drastic change of the signals.

MC says: ADD LABELS ON SUSANNA FIGURES!!!

$$|s| = \sqrt{s_x^2 + s_y^2 + s_z^2} \tag{1}$$

MC says: problems with caption in the norm equation

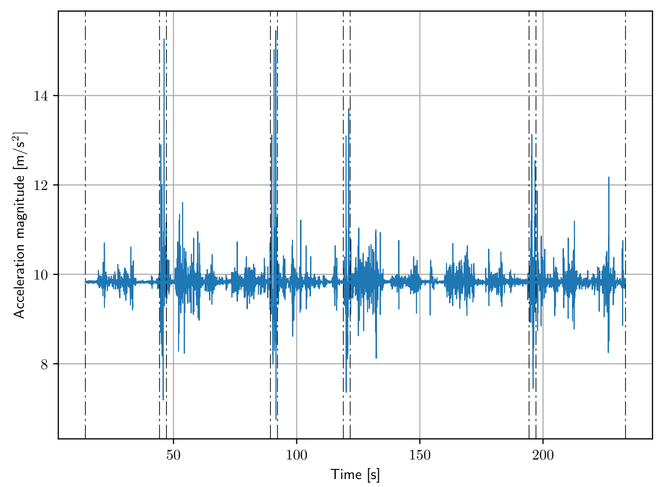

Fig. 4: Acceleration norm

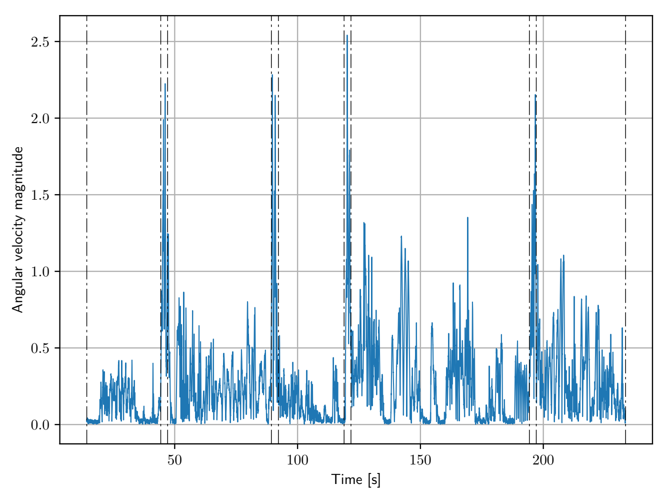

Fig. 5: Angular velocity norm

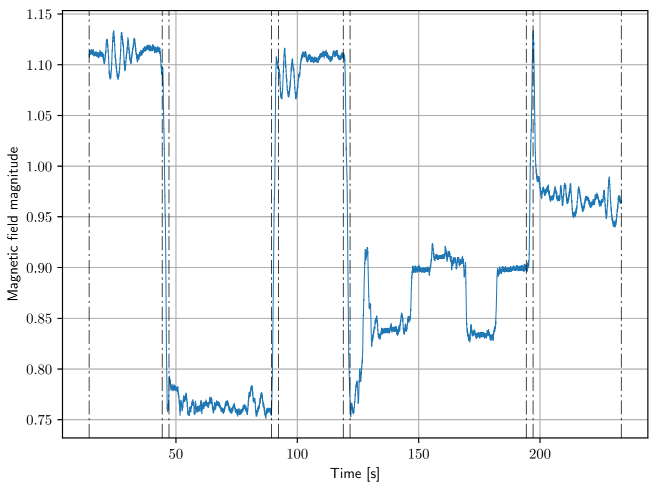

Fig. 6: Magnetic field norm

Another sort of pre-processing was made in order to fix the activity indexing of some recordings. It frequently happened to find that, considering two adjacent motion activities, the end of the previous activity and the beginning of the succeeding one were not temporarily neighboring. It happened also to find two activities temporarily overlapping: the end of the previous activity was indexed after the beginning of the second one. The authors resolved the problem removing the non indexed data and the data whose label was uncertain so as to not train the NN with wrongly labeled data.

Each session is finally represented by a long and straight matrix with nine columns (three for each measurement system) and a number of rows equals to the session duration. Due to the straight sampling time the number of rows stands at around 10^3-10^4 order of magnitude. Even if motion signals are not two dimensional signals, the peculiarity of input shape makes it suitable to be treated as a kind of image. Therefore according to the adopted strategy of *Gadaleta et al.*, the dataset was processed in order to be fit into a CNN [15].

Since the CNN needs a fixed input the authors decided to divide in patterns each session matrix and associate to them the corresponding label. The pattern length was decided equal to 27, that is the shortest activity length in the whole dataset.

Then it was taken every activity and it was divided in overlapping windows with stride equals to 3. The obtained final dataset was made by several windows associated to a specific activity. No transitional pattern from an activity to another were taken.

The last procedure attuated was a shuffle of the dataset.

V. Learning Framework

A. CNN architecture

The CNN architecture is schematically presented in Fig. 7 and in this section is going to be explained in details using the showed labeling of the layers. Because of the fixed input shape of the CNN, the dataset is composed by 322502 patterns with shape (27,9) and it was divided in two subsetsMC says: according to a common Machine Learning working iter(?): the *training set* that is constituted by the 80% of the whole patterns, the remaining part forms the *validation set*.

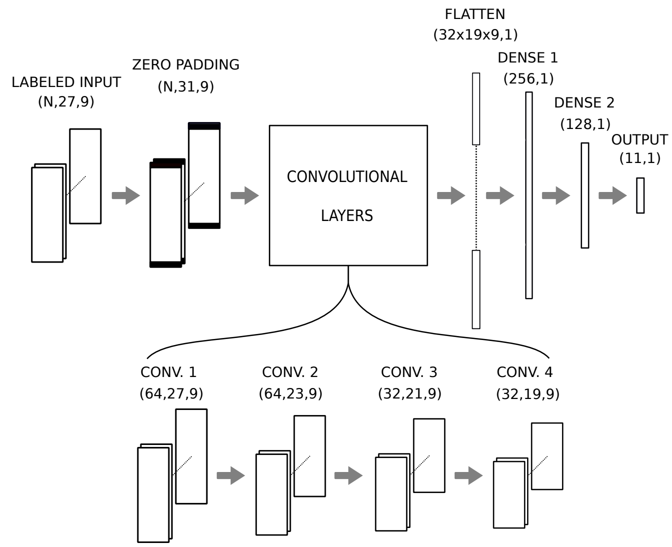

Fig. 7: CNN architecture

Due to the restrictive number of columns it was decided to learn the feature for each column separately in the convolutional layers, it was used infact 1D-CNNs, and then classify the whole pattern in the succeeding fully connected layers.

The choosed CNN architecture presents first of all Zero Padding at the first and last 2 rows of each pattern so the shape of the dataset pattern began (31,9).

The first 1D convolutional layer Conv1 returns 64 filters of shape (27,9) and Conv2 returns the same number fo filters with a shape of (23,9). The kernel used in these two first layers has (5,1) shape and a stride of (1,1). Conv3 and Conv4 present a kernel of size (3,1) and a stride of (1,1) instead, the outputs are both 32 filters of respecively (21,9) and (19,9) shape. Tab. 2 shows how the filters size of each convolutional layer can be mathematically calculated. After each convolutional layer was added a Batch Normalization and a "ReLu" Activation Function.

After this feature learning block follows a classification part made of three fully connected layers:to allow this passage a flattening of Conv4 output filters in necessary (see Flatten layer in Fig. 7). Then follows three fully connected layers of size respecively 256, 128 and 11. The last one is the output and presents a size equal to the number of the activity labels considered.

MC says: Lastly were added also Dropout to make the NN not to learn too specificatamente /to memorize the training dataset

MC says: model.optimizer missing

MC says: The NN was not trained with transitional patterns.

The NN was trained for 10 epochs with a batch size of 128. The optimizer used was *Adam*. Due to the

LAYER	N	K	S	OUTPUT
CONV1	31	5	1	$(31-5)/1+1=27$
CONV2	27	5	1	$(27-5)/1+1=23$
CONV3	27	3	1	$(23-3)/1+1=21$
CONV4	21	3	1	$(21-3)/1+1=19$

TABLE 2: Filters dimension along the pattern columns. N is the number of rows of the input pattern. K is the dimension of the kernel. S is the stride dimension.

VI. Results

The ARS previously described has been tried on a PC with an Intel Core i7-7700HQ microprocessor at 3.8 GHz, 8 GB of RAM, and an NVIDIA Ge-Force GTX 1050 as Graphic Card. The programming language used was Python with Keras and TensorFlow as learning framework. The most computational demanding operations was performed on the GPU using CUDA drivers. The learning part has been tried also performing all the computations on the CPU, the difference in time is dramatically: using the GPU each epoch takes about 26 seconds while using only CPU takes more than 2 minutes.

In the learning phase, the training accuracy reaches 93.75% while in the test dataset, activities are recognized the 94.6% of the times.

Once the model has been learned, the CNN is used to predict activities in real time. To assess the performance of this task, a set of predictions has been made on a raw signal recorded by the same sensor. The overall recognition rate of the real time prediction is 75.88%, precision and recall are showed in Fig. 8 and Fig. 9.

The accuracy in the prediction phase is quite low, since the dataset used was too small and had a great variance within the data. Moreover in that dataset some labels were missing.

As can be seen the accuracy is very good for longer or easy-to-recognize activities like *Running*, *Walking*, *Standing* and *Lying*, while is lower for shorter activities or activities that suffer of a big variance such as *Falling* and *Setting*.

In [13] precision and recall are plotted only for the main activities, they don't take into account the transition activities (*Up*, *Down*, *Ascending*, *Descending*). These gives a low accuracy since there are less sample in the dataset and since they can have an high variance.

VII. Summary of the project

This work has been useful to approach new machine learning tools both from a theoretical and a practical point of view, understanding the problems that one may encounter. In specific, we saw how ANN and CNN work and how can be implemented to solve a given task, we learned to use deep learning framework like Keras and TensorFlow together with advanced version control software. Moreover we improved our knowledge about Python and how to optimize it to work with big amount of data.

During the project we encountered several problems, we tried to solve them and we found a solution or a reasonable answer. Firstly, we noticed that the number of sample for each

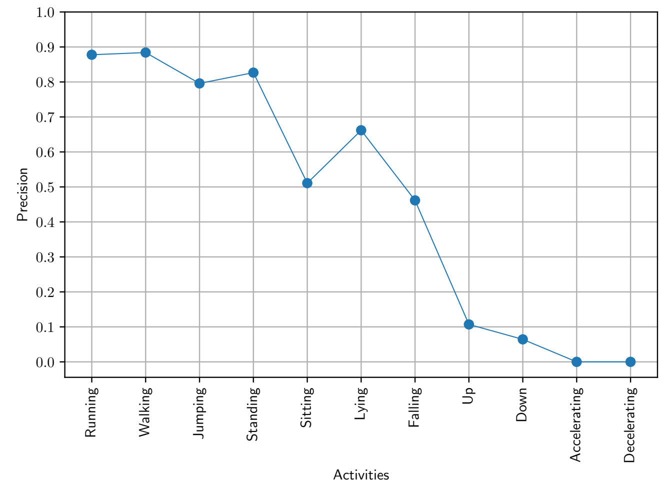

Fig. 8: Precision calculated for each activity to recognize

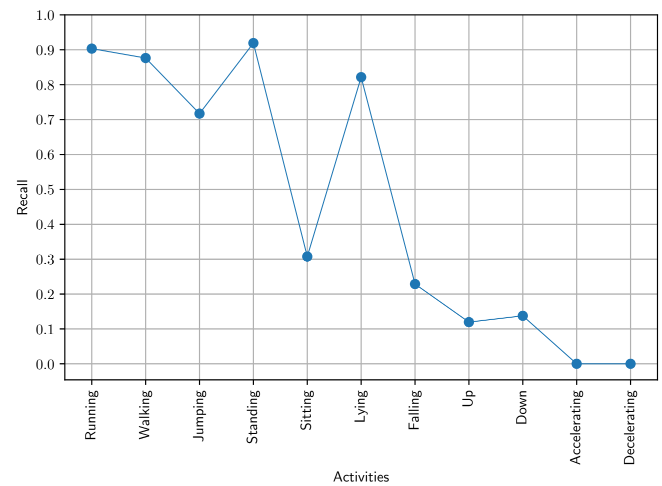

Fig. 9: Recall calculated for each activity to recognize

label is highly unbalanced, the solution we thought were to use data augmentation and to weight different each label in the CNN. We tried to implement the first solution creating new samples adding noise to the original signals. We tried with white noise with small variance but the result was a low accuracy. Maybe the solution is to estimate a good model for the noise and adding it instead of a standard white noise. In the second case we tried to weight different the classes but we can't adapt our architecture to the requirements of the apposite keras' function. Our solution has been to use a smaller stride for these activities to have more data.

In the learning phase the biggest problem was the time needed to train the network. We solved this problem installing CUDA drivers in Windows 10 and using the Graphic Card to learn the model.

In the last part, the main problem was how to elaborate the windows of the benchmark signals containing the transitions from an activity to another. Our first idea was to add to the training set some window correspondent to the transitions, and assign to them the label *TRANSIT* (i.e. *activity not recognized*), but the only result was a lower accuracy, so we decided to skip those parts when sliding other the benchmark signals.

Finally, we notice that in the benchmark dataset misses the label *TRANSDCC*, so both precision and recall has been put to zero even if these label were not present at all in the prediction phase.

VIII. Conclusions and future works

In this work, a novel approach to activity recognition has been proposed, using CNN as deep learning tool to predict automatically activities. The authors started from a dataset used originally to make activity recognition using a feature selection approach, they applied some preprocessing and they used the preprocessed data to learn the Neural Network. Then, the learned model has been applied to raw signals to show how this architecture is feasible for a real time system. Remarkable results has been obtained, an accuracy of over 94% in testing phase and an overall recognition rate of 75% in the real time prediction. Given its automatic nature, the described ARS can be used to learn other datasets, adjusting the dimension of the input and the labels to predict. In presence of a bigger amount of data, the CNN can be probably learned with more epochs without overfitting the data.

The solution proposed prove how CNN can be used in activity recognition instead of techniques based on hand-crafted features.

The ARS described can be extended to reach an higher accuracy. An improvement to the overall efficiency of the network can be to assign higher weights to the activities less frequent in the dataset, to have a more robust prediction also for those activities increasing the accuracy of the CNN. Another solution to this problem can be using a dataset with a balanced number of occurrences per label, in this case weighting differently the activities can be unnecessary. The natural continuation of this work will be to find a way to take into account also the transitions between different activities to make the prediction more robust.

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