Multimodal Analysis for Behavioural Recognition in Tele-assistance Applications

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Abstract: The paper proposes an approach for behavioural recognition in which the individual conditions are recognized using a multimodal analysis method. This approach is an extension of our previously defined multimodal analysis method for biometrics; in this case the target application is the accurate recognition of human behaviour in smart home environments, with main focus in the home tele-assistance integrated services for elderly people. The proposed multimodal analysis method uses a hierarchical approach for data classification together with a fusion rule to combine the matching scores for several behavioural patterns. The approach novelty is given by the hierarchical classification design which provides an optimal performance-cost trade-off for the behavioural recognition system. This optimization could be done at run-time in practical applications.

1 INTRODUCTION

At the European level there are serious concerns about the population ageing. According to Ageing Report (EC, 2012) the every 3rd European citizen will be over 65 years old till 2060. The working people vs. the 'inactive' others ratio is expected to increase from 4:1 currently to 2:1 until 2060.

The population ageing deals with the following issues:

- ✓ The elderly people are more likely prone to various chronic diseases and mobility limitations, often with concurrent mental and cognitive disorders (Boulos2009);
- ✓ The typical expectations of elderly people to have an independent and active life at their homes or within their communities. The distance between home and the care office center is a critical issue for elderly people who choose for home care.

These people represent unique medical cases, as subjects with various individual needs that should be managed; the special focus is on the highest important challenges of diseases prevention and lifestyle management to timely clinical care and follow ups.

The European Comission has stated 3 directions of action (EC, 2007):

a) well ageing at working place or extending the working activities;
b) well ageing within the community;
c) well ageing at home.

Within this general framework there are ongoing concerns to find out efficient solutions supporting medical care and continuous assistance for elderly individuals at their home, with costs reduction too.

During the last few years a lot of real advances was achieved in the home assistance electronic services implementation; these services are supported through the exponential development of ICT technologies, enabling the improvement of the elderly individuals life.

The home integrated tele-assistance systems have an important position in this direction.

The tele-assistance integrated services represent all the management, technical and economic processes supporting and providing the assistance services for people, especially at their homes; these activities are performed using a platform containing various networked devices, together with custom software applications (Pușcoci, 2012).

A citizen-oriented services paradigm which responds to his/her real needs becomes the central pillar for the tele-assistance integrated services development in order to meet several target objectives, as shown in Figure 1 (Pușcoci, 2012).

The tele-assistance integrated services

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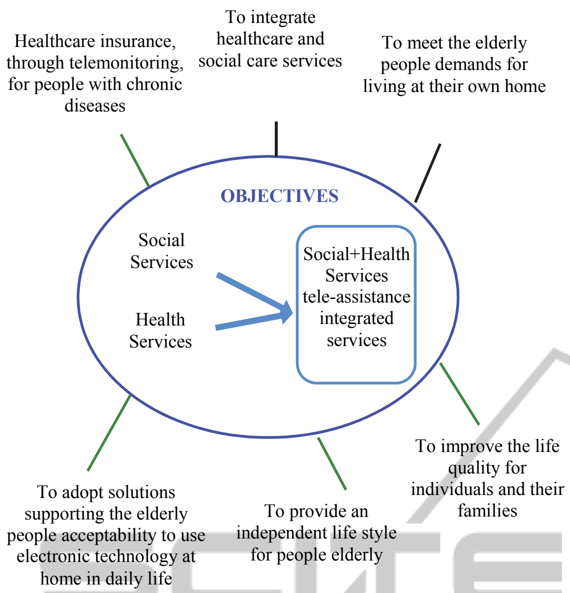

Figure 1: The tele-assistance integrated services target objectives.

development should be done within a framework containing the following main elements, according to (Reem, 2012):

✓ *Monitoring Services*: remote measurement and monitoring services. These services are used to send real-time physiological information about the patient's condition through communications (wired or wirelesss) lines and even over Internet. Finally these monitoring services allow physicians to adjust therapy to meet the patient's changing needs.

✓ *Activity recognition :* the psychophysical skills identification for patients or elderly people in order to optimally adjust the therapy actions.

✓ *Behavior detection:* the measurement and detection of behavioral changes in patients' typical profile.

The assisted person's behaviour recognition represents a novel decision support for the tele-assistance systems. It requires for a lot of software and hardware developments in order to implement reliable solutions with optimal accuracy vs. cost-effectiveness trade-off.

The papers proposes an approach for behavioural recognition in which the individual conditions are recognized using a multimodal analysis method.

This approach is an extension of our previous work for biometric data. In this case the target application is the accurate recognition of the human behaviour in smart home environments, with main focus on the home tele-assistance integrated services of elderly people.

2 RELATED WORKS ABOUT ACTIVITY RECOGNITION

The tele-assistance integrated services should be implemented using ICT technologies, within a smart environment/smart home which allows to develop home applications. This approach aims the assisted persons to perform their daily activities and to benefit from a set of telemonitoring and emergency actions services.

The tele-assistance integrated services implementation is a challenging task because the only remote monitoring of some medical or environmental parameters does not efficiently approach the home elderly people care and assistance.

The related works about telemonitoring, tele-assistance and ambient assisted living applications include a lot of published solutions and methods for home people daily activities recognition and human behaviour recognition.

In (Rodrigo, 2009) the authors developed a feature selection method for Human Activity Recognition. They used a large feature set as descriptors for the human activities and also applied Best First Search and Genetic Algorithms for the optimal feature subset selection to maximize the accuracy of a Hidden Markov Model generated from those features. The approach was compared against other published techniques for human activities classification using video sensors. The optimal feature selection is justified by the fact that sensor data are typically noisy; the best attributes should be retrieved before the classifier traning. All the features were generated from image sequences.

In (Young-Seol Lee, 2011) a 3D accelerometers-based activity recognition method was proposed. The authors developed an activity recognition system for smartphones in which the uncertain time-series acceleration signal was processed using hierarchical Hidden Markov Models. The model was designed in respect to the typical resources constraints of the mobile devices (memory storage and computational power). The overall proposed hierarchical probabilistic model for humans activitivies recognition combined 2 different probabilistic models, a continuous HMM and a discrete HMM. This hierarchical approach for probabilistic models seems to be more reliable if the patterns could be divided into smaller units. The data acceleration from a 3-axis accelerometer on a smartphone is initially transferred to a low-level HMM for human actions classification. Then a high-level HMM is applied to identify the human actions.

In (Ugur Toreyin, 2008) the authors approached the falling person detection. A safe and active life for elderly people could be supported in a home environment with sound, passive infrared (PIR) and vibration sensors. In their approach the falls detection is based on the simultaneous analysis of signals produced by sound, PIR, and vibration sensors. The classification is done by training Hidden Markov models (HMM) for regular and abnormal actions of elderly people. The final decision resulted from the fusion of HMMs decisions. The classifier was trained according to the possible human states.

(Zouba, 2009) defined a method for home elderly people activity recognition using a multisensor approach with video cameras and environmental sensors. The authors applied a high-level (event) fusion with a combination of video and environment events. They used heterogeneous sensor data for the home elderly people activities recognition. This task is performed with a data fusion method, according to the application requirements.

In (Oliver Brdiczka, 2008), the authors approached learning and recognition of human behavioral patterns given multimodal data from a smart home environment. The proposed method general goal was to achieve a high-level contextual model for human behavior. The work was mainly related by the problem of automatically human behavior recognition in a smart home environment. The human behavioral patterns were learned and recognized using a multimodal data processing approach for video and audio information in a smart home.

In (Rim, 2012) the authors focused on a major challenge of context-aware computing and intelligent environments: the acquisition and modelling of heterogeneous context data. The key issues are the various granularity degrees for the human activities. The authors considered that ontology-based activity models are able to support interoperable multilevel activity recognition. They applied probabilistic description logics (DLs) for multilevel activities identification in smart environments.

3 MULTIMODAL METHOD FOR THE BEHAVIOURS RECOGNITION

In our opinion the behavioural analysis of the home-assisted person is a suitable way to get meaningful information about his/her state. It allows to develop prevention programmes for risk situations; these should enable medical and social actions for early solving of the detected problems.

In our approach the designed system includes one or several sensors networks which are deployed at the assisted person home. The resulting sensor data are provided as input set for a multimodal processing and analysis module. The further processed data are used then to generate a specific behavioural pattern for each end-user.

The generated model is learned by the overall tele-assistance system. The further matching against the current test sample allows to early detect the behavioural anomalies. These detected outliers are then reported to the surveillance unit (or tele-assistance dispatcher) that should be responsible for the required action in each case.

The specific behavioural model results from the various environmental and medical sensors data analysis. The achieved information should have enough relevance in order to be useful for finding out the influence of health state and living environment on the individual behaviour.

The proposed method for behaviour recognition is actually an extension of our recent works on multimodal biometric systems with hierarchical classifiers design. These biometric developments were focused on security applications for access control (Soviany, 2012), (Soviany, 2013), (Soviany, 2014). Now we extend the hierarchical classification model from the previous biometric recognition to another application concerning the human behaviour recognition.

We think about this extension actually as a kind of behavioural biometric, but with a different target instead of the typical security applications. This time the new target is the tele-assistance in smart homes environments.

Within this proposed framework we consider that the multimodal analysis is a reliable tool allowing to efficiently exploit and correlate various data concerning the individuals and their position, health state and behaviour. In this approach several different information sources could be correlated in order to accurately identify the true person's state.

The general architecture for the proposed system is depicted in figure 2 (with focus on the processing stages and decisions generation).

The multimodal analysis method for behavioural data processing is sequenced into the following basic operations:

- Behavioural data types definition;
- Thresholding;

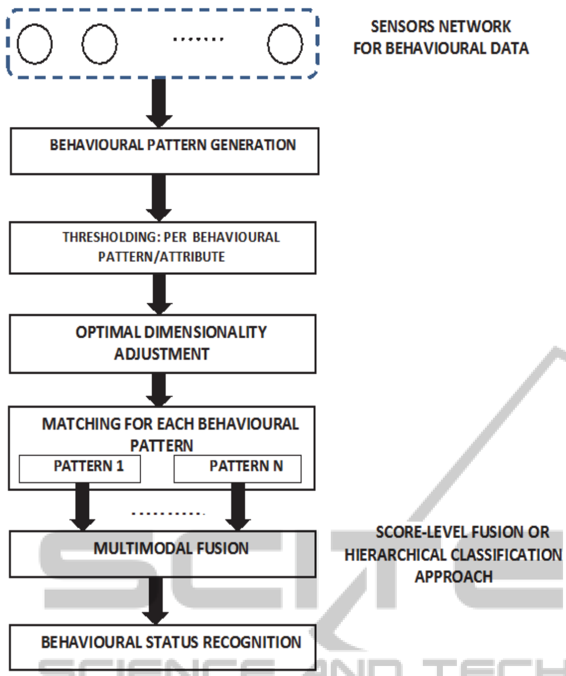

Figure 2: The general architecture for the behavioural patterns multimodal processing system.

- Dimensionality optimization;
- Matching;
- Multimodal fusion

3.1 Behavioural Data Types Definition

The behavioural data types definition is essential for the further individuals behavioural patterns generation.

A behavioural pattern for one individual subject of tele-monitoring is a set of values for certain application-specific variables, attributes or parameters; these variables are chosen just within the design stage such as to provide the best relevance for the person attitudes, movements or postures.

In the proposed approach for each person condition, state or posture we define a separate class of behavioural patterns; this definition is done according with the application specific requirements.

The sources of behavioural data are various sensors. These sensors are typically linked in wireless sensors networks with hierarchical architectures, depending on the tele-monitoring application complexity. The input data quality and behavioural patterns generation accuracy are critical factors for the overall system performance.

3.2 Thresholding

A critical issue for the suitable correlation between the individual state/posture/condition and the behavioural patterns is the relevance degree of the chosen attributes (variables, parameters). These variables are used as feature sets describing the attitudes, postures and/or other current conditions of the subject.

A detailed analysis of the behavioural features and patterns is required in order to define a set of suitable thresholds for each behavioural attribute. This thresholding supports the correlation between the person condition and his/her behavioural pattern; this could be done with suitable thresholds for each of the chosen attributes.

This thresholding-based approach provides an accurate and computational-effective classification of the current state for the monitored (assisted) subject. The classifier outputs support the decision-making step.

The main drawback of the thresholding-based approach is its sensitiveness in various practical applications with different specific requirements. This is especially related by choosing the suitable thresholds for the various behavioural patterns and for their components, respectively.

On the other hand the influence of the environmental parameters on the certain individual conditions should be considered for the thresholds selection.

This is why we should also consider other additional options to provide the behavioural features relevance but only after a serious assessment of the available data according to the real application requirements.

3.3 Dimensionality Adjustment

The achieved datasets contain several values for various parameters. These values are typically grouped into certain behavioural patterns representing datapoints (or feature vectors) within a multi-dimensional space.

The resulted higher dimensionality is a significant issue for the behavioural patterns classification. A high-dimensional feature space typically requires for a lot of training samples per class to design an accurate classifier; the multi-dimensional space should be covered with many training datapoints.

On the other hand a high dimensional feature space for the behavioural patterns is not always very useful to provide the best accuracy for behaviours recognition; this is because certain attributes could have not the same relevance for the human behaviour.

Therefore the feature selection procedure is often required to optimally adjust the resulted datasets of behavioural patterns. For this step we intend to test many of the actual approaches in feature selection, either optimal (exhaustive) or suboptimal (non-exhaustive) techniques for feature selection. We will look for the best trade-off execution time vs. features optimality.

3.4 Matching

The further processing step of the behavioural patterns recognition performs their matching against the reference data. During the ongoing research we are still exploring for several design solutions, models and algorithms that should be used for the matching operation.

This operation is actually very challenging because it exhibits the highest computational complexity degree, which is mainly given by the high-dimensional feature space. This is true despite of the previous feature selection step. Another critical issue results from the intrinsic dynamic feature of the human behaviour; in this case the reliable pattern identification still remains a difficult task. In most of the actual related works HMM-based models were applied for human activity recognition with optimal results just for their applications.

However we intend to extend our works in biometric data hierarchical classification and similarity scores computation to human behaviour recognition. Therefore we consider the following design solutions for the matching operation:

- *The distance-based approach* in which a similarity ranking is directly evaluated in the multi-dimensional feature space of the behavioural patterns, just in a similar way as for the large-scale available biometric systems. We should apply various distance measures, for instance Mahalanobis distance; this is useful when it is important to optimally exploit the behavioural feature correlation as proceeded for typical biometric data. This approach is strongly dependent on the features thresholding and also exhibits a significant computational complexity;
- *the supervised or semi-supervised learning-based approach* in which a hierarchical classifier is designed and suitable trained with the available behavioural patterns. The model will classify the behavioural data in several stages, according to the classes importance. For the most critical behavioural states of an individual we will firstly apply a detection stage; a detector is a classifier which is only trained for one target class (Soviany, 2014). We previously applied this classification design solution for biometric data and the achievements proved a significant improvement in identification accuracy; this improvement was provided by the detectors design principle with one class classification approach, saving a lot of computational expenses. On the other hand there are additional issues to be considered in this case, such as the applied cross-validation procedure which is very often required to overcome certain problems of many classification systems (like overfitting).

3.5 Multimodal Fusion

The final decision concerning the real condition of the individual should result from a combination of scores or even separate decisions issued from the various behavioural pattern previously processed. Actually during the ongoing research we will evaluate several score or decision-level fusion rules. We will consider the typical rules which are already applied in most of the actual multimodal biometric systems, such as sum rule, mean rule, minimum score rule or maximum score rule; for the sum and mean rules we also consider their weighted versions.

The main challenge of this step is that not all the behavioural patterns have the same critical significance in showing the worst case of the subjects. This is why sometimes a hierarchical decision structure should be applied, while considering several priority levels for the various behavioural patterns.

4 CONCLUSIONS

We propose a multimodal approach for human behaviour recognition in which we extend our previous developments for biometric data. The behavioural recognition is performed with a hierarchical optimized classifier in which several decision stages are followed to accurately detect and recognize the real state of the assisted person.

The proposed approach allows to efficiently deal with various behavioural patterns using a multi-stage classifier, also including a one-class classification stage (detector).

Another difference between our proposal and the actual systems for behavioural recognition in smart environments is that we apply the hierarchical classifier on multiple data types, not only on images and sounds. This will be a real challenge for the ongoing research.

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