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Detecting and exploring deviating behaviour of smart home residents

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ABSTRACT

A system for detecting deviating human behaviour in a smart home environment is the long-term goal of this work. Clearly, such systems will be very important in ambient assisted living services. A new approach to modelling human behaviour patterns is suggested in this paper. The approach reveals promising results in unsupervised modelling of human behaviour and detection of deviations by using such a model. Human behaviour/activity in a short time interval is represented in a novel fashion by responses of simple non-intrusive sensors. Deviating behaviour is revealed through data clustering and analysis of associations between clusters and data vectors representing adjacent time intervals (analysing transitions between clusters). To obtain clusters of human behaviour patterns, first, a random forest is trained without using beforehand defined teacher signals. Then information collected in the random forest data proximity matrix is mapped onto the 2D space and data clusters are revealed there by agglomerative clustering. Transitions between clusters are modelled by the third order Markov chain.

Three types of deviations are considered: deviation in time, deviation in space and deviation in the transition between clusters of similar behaviour patterns.

The proposed modelling approach does not make any assumptions about the position, type, and relationship of sensors but is nevertheless able to successfully create and use a model for deviation detection–this is claimed as a significant result in the area of expert and intelligent systems. Results show that spatial and temporal deviations can be revealed through analysis of a 2D map of high dimensional data. It is demonstrated that such a map is stable in terms of the number of clusters formed. We show that the data clusters can be understood/explored by finding the most important variables and by analysing the structure of the most representative tree.

1. Introduction

The world population is predicted to increase to approximately 9.3 billions in the year 2050 (Statistics Sweden, 2013). According to Bloom and Canning (2004), the proportion of people older than 60 will near quadruple in the year 2050. This will cause rapidly increasing costs of healthcare, see Dini and Goldring (2008). One solution to this challenge is through technological development aiming at reducing the costs of home-based healthcare. One of the technological challenges is to develop a system for anomaly detection in a home environment. This paper suggests a new approach for human behaviour modelling as well as detection of deviations using such type of models.

In Sweden, the number of elderly receiving home-based healthcare service is steadily increasing (The National Board of Health & Welfare, 2012). The home healthcare management in the municipality of Halmstad, Sweden, provides a service which includes nightly supervision carried out by home-care patrol teams, the so called *night patrol*. A visit in the home of the elderly usually includes assuring that the person is still at home, in bed and is sleeping. Interventions involving traditional care such as diapering, giving medication, toileting, and repositioning in bed also occur during the night. For a visit based purely on supervision, the state of the individual is evaluated, where most of the times the person sleeps. For each person there could be up to three visits per night. Each visit only gives a current state of the beneficiaries situation, therefore a step towards continuous monitoring capable of discovering situations requiring immediate help is needed.

The following two services are of particularly importance. Firstly, detection of sudden changes in the human behaviour, e.g. a resident prepares to leave the home in the middle of the night

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or when a sudden fall occurs on the way to the bathroom. Another case is when the resident is lying in bed irregularly or without breathing. Such a service could provide additional information before and after each visit and could point out which individual needs an urgent assistance. The suggested approach targets these sudden changes in behaviour by using a learnt model to continuously assess in-home events. This paper also suggests a way to explore deviations by analysing the clusters of behaviour patterns to which the deviating pattern is related. Secondly, detection of long-term behaviour change would provide caregivers with important information on various aspects of health and upcoming problems. Such information would be of great help when assessing the independence and behaviour of beneficiaries. These services could enable people to remain independent at their own homes and live longer with a higher quality of life. Implementation of the services is assumed to make use of simple sensors such as switches which are distributed across the own home of the elderly person.

Ambient assisted living (AAL) and *smart environments* (Cook & Das, 2004) are two keywords reflecting research in this area. Smart environments often make use of sensors such as switches, motion detectors and electromechanical sensors, which do not, to the same extent as cameras, breach the privacy of individuals. Because of the large variety of sensor types and settings, information processing approaches, floor plan of the homes, and individual behaviours, finding a reasonably robust and economically efficient solution to the problem, is a difficult task.

Anomalies (unexpected behaviour) can be divided into *point anomalies* and *contextual anomalies* (Chandola, Banerjee, & Kumar, 2009). A point-anomaly, i.e. a sudden change not depending on a specific context, such as time or space, is rarely seen in smart homes. It is intuitive that both temporal and spatial variations of readings from sensors, such as magnetic switches installed in various parts of a kitchen (in cabinets, fridge, microwave oven, coffee maker etc.) exist. Therefore, anomalies very often need to be assessed in relation to both temporal and spatial aspects which makes the task of developing services rather challenging. Moreover, variations in an activity itself (e.g. different ways to prepare a meal), interrupted and interleaved activities and the fact that behaviour is usually characterized by a complex sequence of patterns (Rashidi & Cook, 2013) makes the data difficult to interpret.

This article proposes an approach to detecting and exploring short-term changes in human behaviour, where both context and variations of activities themselves are taken into consideration.

2. Related work

Anomaly detection of human behaviour in smart homes is an active field of research and is considered as one of the major technical challenges (Pavel et al., 2013). Despite the challenge there exist attempts both in research and as commercial products. A developed system by Botia, Villa, and Palma (2012), called *Necessity*, is able to capture anomalous behaviour, where an anomaly is defined as staying in a bed, or on a floor during an abnormally long time. The system, now deployed in the South–East of Spain, is based on a finite-state machine and semantic web-rules and is able to reduce the number of false alarms. To detect deviating behaviour, Jakkula and Cook (2008) utilize the temporal context by calculating the probability of an event given temporal relations to other events such as *before, contains, starts, meets* or *overlaps*. A method based on the Evolving Connectionist System was developed by Rivera-Illingworth, Callaghan, and Hagras (2005) in order to, first learn a set of activities by supervised learning, and thereafter test unseen observation to be detected as abnormal. One of the labelled activities was removed from the training set in order to test the deviation detection system. Franco, Demongeot, Villemazet, and Vuillerme (2010) developed a spatial and temporal information based technique for detecting nycthemeral shifts (i.e. temporal and spatial shifts of activities during a day) using data collected from passive infrared detectors (PIR). However, the technique does not focus on sudden changes in behaviour. Several techniques to detect deviating behaviour are based on a very limited set of parameters: in-home trajectory (Campo, Chan, Bourennane, & Estève, 2010), in-door walking speed (Hayes, Pavel, & Kaye, 2004) and inactivity profiles (Planinc & Kampel, 2013). However, such detectors cannot explain the *whole picture*.

It may seem tempting to use supervised learning for training a system to detect deviating behaviour. However, the lack of observations representing deviations is a major obstacle for a supervised learning based approach (Pavel et al., 2013). Moreover, data annotation is a very tedious process. Therefore, unsupervised learning based approaches seem more promising. According to Rashidi and Cook (2013), their *continuous, varied order, multi-threshold activity discovery* method (*COM*) can learn patterns of activities in an unsupervised fashion and is able to cope with spatial and temporal variations but also interrupted activities. The on-line learning used by *COM* is a key aspect that few researchers have approached, this is also acknowledged as an important aspect in the review by Amiribesheli, Benmansour, and Bouchachia (2015). Wen and Zhong (2015) proposed a model for activity recognition in smart environments using only a small set of labelled activities (i.e. semi-supervised learning). Their system is based on a new similarity measure for clustering sensor event sequences. However, it is unclear if the method can be extended to detect deviating human behaviour.

Another example is the PUBS system by Aztiria, Augusto, Basagoiti, Izaguirre, and Cook (2012). PUBS is able to discover frequent rules from smart home data for detecting anomalies.

Although the proposed approach concerns modelling of human behaviour and detection of potentially dangerous events the long-term goal is to develop a system able to assist caregivers in delivering and planning care by providing *situation awareness (SA)*. A system able to provide SA was developed by Foresti, Farinosi, and Vernier (2014). The system is capable of identifying areas where disasters (e.g. floods or fire) occurred by utilizing citizens social media usage as well as other stationary sensors. Similarly, the technique developed by Foresti et al. (2014) first learns a normal model from sensor data and thereafter collects, compares and classifies previously unseen data. However, deviations of human behaviour in the home may arise, not only as co-occurrence of sensor deviations as described in the application of disasters but as deviations of pattern sequences and transitions among clusters of similar patterns. These aspects are the focus of our work.

A similar approach to enable SA was taken by DAniello et al. (2015) in the form of a decision support system for shops and malls. The system was able to recognize and assess situations of interest, e.g. such as when a human shows interest for a certain product. A Neuro-Fuzzy like approach exploiting linguistic variables was used to explain situations. To deal with this issue, we focus on understanding a decision tree structure. Moreover, the system suggested by DAniello et al. (2015) takes advantage of knowledge from psychology, e.g. how *value* is perceived by the customer in order to plan a reaction to situations. Such an interdisciplinary approach, can be linked to trends seen in intelligent systems for improving health behaviour interventions – *behaviour informatics* (Pavel, Jimison, Korhonen, Gordon, & Saranummi, 2015).

Mahmoud, Lotfi, and Langensiepen (2011) and Lotfi, Langensiepen, Mahmoud, and Akhlaghinia (2012) present a clustering based technique to detect abnormal behaviour. In Mahmoud et al. (2011), abnormal observations are found by comparing sequences of binary events using the classical and the fuzzy Hamming distance measures. Lotfi et al. (2012) focus on clusters of observations using two different representations: a two-dimensional one given