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A context-aware approach for long-term behavioural change detection and abnormality prediction in ambient assisted living

Abdur Rahim Mohammad Forkan [a,b,*], Ibrahim Khalil [a,b], Zahir Tari [a], Sebti Foufou [c,d], Abdelaziz Bouras [c,e]

[a] School of Computer Science and IT, RMIT University, Melbourne, Victoria, Australia
[b] National ICT Australia (NICTA), Victoria Research Lab, Melbourne, Victoria, Australia
[c] Computer Science and Engineering, College of Engineering, Qatar University, Qatar
[d] Le2i Lab, University of Burgundy, Dijon, France
[e] DISP, Université Lumière Lyon 2, Lyon, France

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ABSTRACT

This research aims to describe pattern recognition models for detecting behavioural and health-related changes in a patient who is monitored continuously in an assisted living environment. The early anticipation of anomalies can improve the rate of disease prevention. Here we present different learning techniques for predicting abnormalities and behavioural trends in various user contexts. In this paper we described a Hidden Markov Model based approach for detecting abnormalities in daily activities, a process of identifying irregularity in routine behaviours from statistical histories and an exponential smoothing technique to predict future changes in various vital signs. The outcomes of these different models are then fused using a fuzzy rule-based model for making the final guess and sending an accurate context-aware alert to the health-care service providers. We demonstrated the proposed techniques by evaluating some case studies for different patient scenarios in ambient assisted living.

1. Introduction

In the field of healthcare monitoring [1,2] and smart-home technology [3], the availability of a system capable of automatically detecting future behaviour or abnormality is remarkably attractive for many applications. The long-term historical information of human physical activities [4], daily behaviours and physiological data are valuable for long-term assessment of behaviour and health. A context-aware assisted living system consists of heterogeneous sensors and devices generating large amounts of context information every day [5]. A major challenge to such context-aware technology is to convert this huge amount of information into a knowledge base using appropriate machine learning models so that the system becomes competent enough to accurately sense eventual change.

Traditional home-based context-aware remote monitoring systems use different techniques such as rule-based reasoning [6–8], probabilistic model [9], data mining [10,11], sensor-network based decision support [12] and video-based monitoring [13] which can detect abnormalities only when they occur in an ongoing situation. Such systems have no options to utilize long term situational data for modelling each user state individually and predict future anomalies ahead of time. In this work, we have improved the effectiveness of such remote monitoring systems by extending the functionalities for predicting future trends. Therefore, it can alert a remote health-care service provider about the incoming changes before the situation becomes critical. This kind of system is also very helpful for early detection of symptoms [14] and chronic disease prevention.

Chronic diseases [15] are major illnesses especially in older adults, and is increasingly becoming a part of life. These diseases are the main cause of many deaths in Australia and other western countries. Major reasons for chronic illness include an irregular lifestyle, improper diet, and congenital genetic problems [16].

* Corresponding author at: Building-14, Level-10, Room-06, RMIT University, City Campus, 414-418 Swanston Street, Melbourne, VIC 3001, Australia. Tel.: +61 450 354 402.
E-mail addresses: abdur.forkan@rmit.edu.au, AbdurRahimMohammad.Forkan@nicta.com.au (A.R.M. Forkan), ibrahim.khalil@rmit.edu.au (I. Khalil), zahir.tari@rmit.edu.au (Z. Tari), sfoufou@qu.edu.qa (S. Foufou), abdelaziz.bouras@qu.edu.qa (A. Bouras).

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Modern remote monitoring technologies utilize body sensors [17] which continuously monitor different physiological parameters of the user. The most recently observed information is sent to the healthcare professionals or doctors. Doctors observe the current medical condition and activities of the user and provide a diagnosis based on the information provided by the monitoring system. However, that system can only notify at the stage when any chronic disease attains a mature state in the patient. That is, these systems cannot detect a sudden attack of chronic disease. Some systems can detect certain chronic diseases such as cardiovascular illness or, diabetes, but they only make a decision based on a single context observation (e.g. ECG, blood sugar) [18]. This kind of system suffers from high false alert rates because they do not consider the effect of other related contexts (e.g. user activity, time of blood sugar measurement) and context histories. If a single context has any growing trend of abnormality then in most cases the final prediction cannot be made without checking the status of other contexts (e.g. an increasing trend of heart rate is normal when a user exercises). In summary, existing context-aware monitoring technologies are insufficient and not intelligent enough to predict future change.

Much research has been done in the areas of understanding human behaviour for daily activities [1,19–21], detecting anomalies in daily behaviour, disease prediction, etc. But little work is found in the literature that focuses on the development of an integrated and intelligent change detecting model with good prediction accuracy. The context space of our context-aware system can be divided into different context domains. The best knowledge from each such domain is then extracted using well-known learning techniques. The technique is chosen based on the distribution of targeted contexts. For example, in learning what is a normal or abnormal pattern of daily activities, we have used the Hidden Markov Model (HMM) because it is a simple and efficient model for learning sequential data having temporal dependency [22,23]. The sequence of activities varies according to the individual user and the duration of each activity. For this reason, we picked HMM which is a good temporal probabilistic model for handling such uncertainties. Moreover, it was proven that HMM performs better than other learning models in such domain [24–26]. Using HMM it is possible to detect future states from current observations as well as the sequence of states from an observed sequence. The major motivations and contributions of this work are described below.

1.1. Motivations

The primary goals of our context-aware system are to learn the behavioural patterns of a patient using long-term context history, to predict future abnormalities based on gathered knowledge, to detect disease symptoms at an early stage and to help healthcare professionals in long-term diagnosis process. To accomplish these objectives we have the following motivations.

- *Develop a generic change detection framework* for a context-aware assisted living system. The framework works as an intelligent module of cloud-based context-aware middleware that not only detects abnormalities in *what is observed* but also can predict *what is going to be observed* using prior knowledge and observations.
- *Identify and develop suitable pattern recognition models* for different context domains. The selection of models depends on the distribution of context attributes in the content domain. The models will be *strong enough* to identify *future changes* in any context situation.
- *Reduce the rate of wrong predictions* of context situations as well as the number of false alerts to the monitoring systems by fusing the outcome knowledge of every trained model. All models are trained continuously to make accurate predictions.

1.2. Contributions

The main contributions of this work are as follows.

- We developed a novel change detection framework on top of generalized context-aware framework for AAL users. The framework is capable of predicting future behaviours, physiological states and disease symptoms of the user. The frameworks build the personalized knowledge-base of the user using machine learning methods, statistical analysis and mathematical prediction.
- We developed a Hidden Markov Model (HMM) based technique, which is a completely new process for detecting abnormalities in the sequence of activities of an AAL user. The developed model is also capable of finding irregular activities in a given sequence. The model is trained with a large number of samples containing normal and abnormal behaviours. We also developed a statistical method for detecting abnormalities in the routine behaviour of the user.
- We developed a forecasting technique using Holt's liner trend method for predicting the increasing or decreasing trend of different physiological parameter's of the user. The detected trend can predict the growth of several chronic diseases of the system user.
- We built a fuzzy fusion process that combines the outcomes of every well-trained model to reach final conclusion for a given situation. The process is demonstrated and validated by implementing case studies and by evaluating the performance of the individual as well as the overall framework.

1.3. Rest of the paper

The rest of this paper is organized as follows. Section 2 summarizes the related works in the area. The system methodology along with architecture is presented in Section 3. The case studies along with the experimental evaluations and the results of the proposed methodology are illustrated in Section 4. Finally, Section 5 concludes our work.

2. Related works

With the advance of wearable and wireless sensor technologies, real-time monitoring of patient's daily behaviours and physiological parameters has become more common. In an existing, remote healthcare model, the failure to perceive change in health or behaviour can create a high risk for a patient whose health condition changes rapidly, sometimes with multiple contextual effects. For understanding future changes and abnormal behaviour, a system should consider previous actions and current contextual events. Thus an approach that can understand a patient's behavioural deviation from usual lifestyle and presence of certain disease symptoms using pattern recognition and mathematical models would be of great assistance to healthcare professionals.

In the area of context-aware monitoring using wireless sensor technology most of works to date have mainly focused on understanding primitive activities or behaviours [1,19–21]. These systems only can detect some activities and are far from modelling daily life behaviour. Machine learning techniques are broadly used to detect daily behaviour, abnormality in regular activities and