Pervasive and Mobile Computing 5 (2009) 236–252

Contents lists available at ScienceDirect

Pervasive and Mobile Computing

journal homepage: www.elsevier.com/locate/pmc

Evidential fusion of sensor data for activity recognition in smart homes

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ARTICLE INFO

Article history:
Received 6 August 2007
Received in revised form 27 February 2008
Accepted 2 May 2008
Available online 8 May 2008

Keywords:
Smart homes
Activity recognition
Context aware
Sensor fusion
Uncertainty
Evidential reasoning

ABSTRACT

Advances in technology have provided the ability to equip the home environment with a layer of technology to provide a truly 'Smart Home'. These homes offer improved living conditions and levels of independence for the population who require support with both physical and cognitive functions. At the core of the Smart Home is a collection of sensing technology which is used to monitor the behaviour of the inhabitant and their interactions with the environment. A variety of different sensors measuring light, sound, contact and motion provide sufficient multi-dimensional information about the inhabitant to support the inference of activity determination. A problem which impinges upon the success of any information analysis is the fact that sensors may not always provide reliable information due to either faults, operational tolerance levels or corrupted data. In this paper we address the fusion process of contextual information derived from uncertain sensor data. Based on a series of information handling techniques, most notably the Dempster–Shafer theory of evidence and the Equally Weighted Sum operator, evidential contextual information is represented, analysed and merged to achieve a consensus in automatically inferring activities of daily living for inhabitants in Smart Homes. Within the paper we introduce the framework within which uncertainty can be managed and demonstrate the effects that the number of sensors in conjunction with the reliability level of each sensor can have on the overall decision making process.

1. Introduction

Smart Home technology offers the prospect of significant improvements in the quality of life and level of independence for elderly or disabled people. The alternative is the reliance on a form of formal or informal care or in certain cases a form of institutionalisation may be required. The desired effect is therefore to equip with the home environment with intelligent and autonomous technology which subsequently extends the period of time a person can remain within their own home. As we are currently witnessing demographic changes resulting in an increase in the median age of the population there is not only an opportunity for a widespread uptake of Smart Homes, but also a real need to manage the additional burden on health and social care services that are a result of these demographic changes.

Smart Homes equipped with centrally managed networked devices therefore have the ability to provide a means for independent but safe living, remote but effective caring, and professional but constant health-monitoring. One of the key supporting features offered by a Smart Home is the ability to monitor the activities of daily living. By being able to recognise and monitor activities of daily living for example making a drink, bathing, dressing etc., automatic detection of changes in patterns of behaviour is possible. This information can reveal a decline in health, risks in the environment, and emergency

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doi:10.1016/j.pmcj.2008.05.002

situations that may require the assistance of caregivers. This can be considered as perhaps one of the most important areas within which Smart Homes can have the largest impact from both user and carer perspectives.

Considerable research has been devoted towards activity recognition by using multiple sensors of different types, from visual sensors like cameras [1] to sensors which provide binary 'on' or 'off' outputs such as contact switch sensors that may be used to detect for example a door being opened or closed [2]. As opposed to sensors like cameras and microphones, small and simple sensors such as switch-on, pressure sensors, and movement detectors are less invasive and ensure the privacy and comfort of inhabitants within their home.

Context-aware activity recognition in a sensorised networked environment is built on low-level sensor data detecting contexts when the inhabitant interacts with the environment. The information generated can be used to identify the activity that the inhabitant is performing. Many sensors may provide information about the inhabitant's situation simultaneously. The main problem is that data obtained from sensors have different degrees of uncertainty [3]. This uncertainty may arise for a number of reasons. The question which is to be asked is if a sensor provides a value of 'on' or 'off' how sure can we be about this measurement and how can we accommodate for any uncertainty that may exist. For example it may be the case that the sensor is faulty, it may be that it can never be 100% accurate due to the nature of what it is measuring or it may be that the overarching management system has for some reason corrupted the data. In our current work we have aimed to investigate means by which such uncertainty could be accommodated for within Smart Homes. We have focused on the deployment of anonymous binary sensors including movement detectors, contact switch sensors, and pressure mats to monitor the rudimentary activities of daily living in Smart Homes.

Among numerical reasoning mechanisms, Bayesian methods and Evidence Theory of which the Dempster–Shafer theory of evidence (DS theory) is a major constituent are commonly used to handle uncertainty. Examples of applying Bayesian methods for activity recognition have been previously reported in [2,4–6]. As a generalised probability approach DS theory has distinct features compared with Bayesian theory: representing ignorance due to the lack of information and aggregating beliefs when new evidence is accumulated. This is a useful feature which can be used within the context of Smart Homes to manage the degree of uncertainty, which, until now has not been accommodated for. In this paper, we propose an evidential approach to reasoning under uncertainty in the monitoring and management of activities of daily living. The proposed approach is based on the use of DS theory through the fusion of contextual information inferred from uncertain sensor data. Within this paper we have shown how the framework can be established, how DS theory and other tools can be employed for information management and reasoning under uncertainty and in addition have shown the ability of the framework to distinguish between the different activities of daily living. The remainder of this paper is organised as follows. Section 2 briefly introduces the typical characteristics of the sensors used in Smart Homes and informally defines context for activity recognition and establishes the activities of daily living on a practical basis. This is supplemented with the presentation of an ontology hierarchy of context-aware activities. Evidential networks of activity inference are formalised being constructed from an activity hierarchy of ontology in Section 3. In Section 4 we propose a novel approach of inferring activities from sensed contexts with uncertainty by evidential reasoning on the basis of DS theory. Section 5 details the steps of evidential inference with a Case Study of the approach and presents a series of experiments which shows the effects of sensor deployment and reliability in the differentiation of a number of activities of daily living. Section 6 describes some related work and highlights special features of our approach. Finally the paper is concluded in Section 7.

2. Smart homes for the elderly

2.1. Simple anonymous sensors

Due to the constraints of building a Smart Home, such as privacy, cost, technical installation of retro-fits and practicability, careful consideration should be given towards the selection of sensors. One particular type of sensor which has received wide spread acceptance is the anonymous binary sensor as introduced in the previous section. These sensors have been reported as being commonly deployed within home security systems and to avoid some of the constraints within the wider context of sensor deployment are the preferable choice for use in a Smart Home environment. These sensors are unable to directly identify occupants and at any given time a binary value may be obtained from them. Whenever the state of a certain context (object, movement) associated with a binary sensor is changed, the value of the sensor changes to '1' from '0' when it is in a static state. Types of binary sensors chosen in this research include movement detectors, contact switches and pressure mats. Movement detectors (passive infrared) are usually mounted in the ceilings of the home and can be used to detect user presence throughout the house. Contact switches may be installed on the doors of cupboards, the fridge, the microwave, etc. Pressure mats may be discreetly installed in objects such as chairs, sofas, beds and in some instances may be used to locate specific movements within rooms by for example placing sensors in front of the sink in the kitchen or bathroom or at the side of the bed.

2.2. Context-aware activities of daily living

The term *context* has been used broadly with a variety of meanings for context-aware applications in pervasive computing [7]. When using the term activity recognition in conjunction with Smart Home technology, we refer to contexts as any