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Probabilistic ontology based activity recognition in smart homes using Markov Logic Network

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ABSTRACT

Designing an activity recognition system that models various activities of an occupant is the fundamental task in creating a smart home. Activity Recognition (AR) modeling, has witnessed a comprehensive range of research, that focuses independently on probabilistic approaches and on ontology based models as well. The research presented in this paper introduces an innovative approach in AR system design that integrates probabilistic inference with the represented domain ontology. Data obtained from sensors are uncertain in nature and mapping uncertainty over ontology will not yield good accuracy in the context of AR. The proposed system augments ontology based activity recognition with probabilistic reasoning through Markov Logic Network (MLN) which is a statistical relational learning approach. The proposed system utilizes the model theoretic semantic property of description logic, to convert the represented ontology activity model to its corresponding first order rules. MLN is constructed by learning weighted first order rules that enable probabilistic reasoning within a knowledge representation framework. The experiments based on datasets obtained from smart home prototypes illustrate the effectiveness of integrating probabilistic reasoning over domain ontology and the result analysis shows enhanced recognition accuracy in comparison with existing approaches.

1. Introduction

Smart environments are enabled with intelligence, integrated into their surroundings for providing services that improve the quality of living [1]. In recent years, the research in smart environments have rapidly developed with the availability of low cost and low power sensors complemented with advances in wireless technologies and the emergence of research in fields such as Ambient Intelligence (AmI) and Ubiquitous computing. Disruptive technologies such as Internet of Things(IoT), augmented with Machine Learning paradigms revolutionized the design of smart environments [2,3].

Smart homes have found extensive applications in various socially relevant problems and as a result it is likely to have a huge impact on the future society[1]. Smart homes are designed to assist the occupant needing assistance to complete their daily routines independently without the help of a care taker [4,5]. The assistive smart home monitoring system recognizes and detects abnormality in occupant behavior and performs decision making to remotely alert the care taker during critical situations [6–8].

Activity recognition (AR) is the most important process in incorporating ambient intelligence into smart environments. It involves as a series of complex processes of activity monitoring, modeling, reasoning and decision making [2,3]. To illustrate the significance of activity recognition in the design of a smart home, let us consider a scenario - “Mary enters the Kitchen at 2:00 a.m and performs a sequence of actions using the objects kettle, stove and mug”. It is necessary for the smart home system to primarily recognize the ongoing activity in order to detect abnormality or to automate actions in the environment. In the above scenario, the ongoing activity is recognized as ‘cooking’ and it is associated with various contextual attributes (objects, space, and time). In order to integrate ambient intelligence in a smart home the fundamental task is activity recognition because, reasoning and inferences can be made only based on the ongoing activity [1,9].

The primary task in designing an activity recognition system involves the construction of an activity model that represents the occupant’s behavior and activity pattern for recognition [10]. The routine activities are the frequent activities that are repeated for a

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few days. Such routine activities referred to as Activities of Daily Living(ADL) are preferred for activity modeling for the reason that these activities help in defining normal scenarios within the smart home [2]. It is therefore essential to study the characteristics of various ADLs of the occupant of the smart home so as to model a recognition system effectively[11].

ADLs executed by the occupant are generally described as complex patterns of events. An event in a smart environment is regarded to be atomic and indivisible in nature, for example 'lying on the bed', 'sitting on a chair' etc. A simple activity is characterized by an ordered sequence of events, for example, 'preparing meal' involves the sequence 'switching on stove', 'take pan' etc. Composite activity is two or more simple activities that appear within a time interval. Composite activities vary depending on the type of inter activity relationship connecting simple activities [12]. Sequential, interleaved and concurrent are the different ways in which composite activities are defined. Thus, activity recognition system needs to model both simple and composite activities.

Majority of the ADLs are common for most of the occupants, in terms of both functions and objects involved [13]. However, certain actions differ according to the individual's preference. The common functionalities can be grouped under different granularity. For example, 'Make hot drink' is a higher level granularity of 'Make coffee' and 'Make tea'. This activity granularity presents a hierarchical ordering among activities that enhances recognition accuracy and thus is preferred in activity modeling.

Moreover, the occupant's need and preferences may change over time, for example the occupant may take bath for 20 min during summer but he might prefer to take a bath only for 10 min during winter. The activity model needs to learn these preferences and update itself by representing the latest changes in occupant's interests [2]. Therefore the activity modeling mechanism employed must be flexible enough to incorporate these variations so as to handle activity diversity and dynamics.

Activities are executed under different context, for example specific locations, objects, time and situation [14]. Thus, the activity modeling approach should facilitate situation aware computing to handle spatio-temporal data through context modeling and recognition mechanisms. In smart homes, uncertainty materializes from situations that require recognizing incomplete sequences of events or those that emerge due error in sensor data [15]. The approach employed to model activity recognition should provide a means to handle uncertainty into the recognition system.

It is thus essential for any activity modeling approach to deal with the above mentioned challenges. The proposed activity recognition framework presented in this paper effectively tackles activity granularity, contextual knowledge, activity diversity through ontology model, while activity dynamics, data uncertainty are addressed through probabilistic reasoning over the represented domain ontology.

The remaining part of the paper is structured as follows: Section 2 reviews the related work on smart homes, presents various approaches for activity recognition and defines the motivation and scope of this paper. Section 3 describes the theoretical foundations of the proposed probabilistic ontology based activity modeling and recognition system. Section 4 describes the system prototype, experimental analysis and performance evaluation. Finally, Section 5 concludes the paper and outlines the future work.

2. Related work

An analysis and review of the existing Activity Recognition(AR) approaches are presented here, in-order to highlight the motivation of our proposed work. The challenges that need to be addressed in the design of a smart home were listed in the previous sections. The limitations of the existing activity recognition approaches are discussed and an appropriate solution strategy for AR modeling is proposed here.

Based on the type of sensors utilized for monitoring the occupants, the activity recognition is named as vision based or sensor based [15]. Vision based approaches make use of video cameras to monitor the occupant and the environment. Reasoning is performed over the collected video frames to recognize the ongoing activity. Though, vision based activity recognition has several advantages in modeling smart environment it has its own setbacks while being used in the design of the smart home. Privacy of occupant is a key concern in a home set up and thus cameras are not a suitable means to monitor the occupant for activity recognition.

Sensor based activity recognition employ wide varieties of sensors for activity monitoring. These sensors are either fixed on various objects in the environment or worn by the occupant [15]. The acquired data are then processed through statistical and knowledge engineering algorithms to facilitate activity recognition. The different types of sensors include wearable sensors like accelerometer, Global Positioning System (GPS) and Bio sensors [15,16]. The gesture of the occupant such as walking, running, and sitting is measured through accelerometer sensor. Global Positing System (GPS) is utilized for supervising the location of the occupant in an open mobile environment. The occupant's vital statistics like ECG, EEG, blood pressure, heart rate etc. are measured through bio sensors. The challenges in dealing with wearable sensors arises from the willingness of the occupant to put on such devices, battery existence, easiness of use and the size of device. Compared with other types of sensors, object sensors are advantageous as they can give an indirect indication of the occupant's activities [15].

Activity recognition has been broadly analyzed using Data driven and Knowledge driven approaches [15]. Data driven approach utilizes probabilistic and statistical machine learning strategies for the analysis and modeling sensor data. Knowledge driven paradigms utilize knowledge engineering and management techniques for activity modeling using domain information and artificial intelligence based reasoning techniques for inferences.

2.1. Data driven activity modeling

Data driven approaches are modeled through generative approach or discriminative approaches [9,15,16]. Probabilistic models that are used in generative approaches give a comprehensive description about the input sensor data space. Classification model is employed in discriminative approach for constructing the activity model. Naive Bayes classifier (NBC), Hidden Markov Models (HMM) and Dynamic Bayesian Networks (DBM) are most commonly used generative approaches. Support Vector Machines (SVM) and Artificial Neural Networks (ANN) are most commonly used discriminative approaches [17,18]. Data driven approach needs a huge collection of sensor data to accurately model the occupant behavior. This introduces an overhead and is termed as 'cold start problem'. Furthermore re-usability is a concern where the complete task of data collection, analysis and modeling of activity needs to be done for building an activity model for a new occupant.

2.2. Knowledge driven activity modeling

Knowledge driven approaches construct activity models as a reusable contextual model that relate objects, space and time with occupant behavior. Knowledge is extracted from domain expert or mined from web using data mining techniques. The knowledge driven model is semantically clear, follows a uniform approach for