Human Behavior Analysis in Ubiquitous Environments for Energy Efficiency Improvement*

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Abstract. The goal of this paper is to discover human habits using the received sensors data-streams, in order to improve the energy efficiency. We propose a multi-agent architecture and a formalism to describe scenarios in ubiquitous environments based on a wireless sensors network. We have used sensor data and simulations about a four person family, to validate our prototype.

Keywords: sensors network, ubiquitos environment, scenario recognition, multi-agent system, pattern recognition, energy efficiency.

1 Introduction

Ubiquitos spaces are intelligent systems which use sensors networks to understand the environment [8]. Based on the gathered sensor data, intelligent systems take some decisions in order to improve one or several aspects of the ubuiquitos space. We use in our study as a ubiquitos environment a house. The goal is to discover the people habits and the correlation between these habits and the energy consumption. Using wireless sensor networks, we can obtain data-streams, which describe different aspects of the environment and the interactions between the people and devices/appliances or other objects.

First, we must understand what happens in the house. To achieve this goal we have defined a formalism to describe all the actions and the events, the Human Behavior Scenario Description Language (HBSDL). An intelligent agent analyses the sensors' data-stream and builds scenarios. Other approaches for activity recognition use image recognition [6], neural networks [5], Hidden Markov Model [7] and others data mining [3] or statistical techniques. Our model is based on decision-trees and a set of constraints. Second, we discover patterns in the behavior of house residents. A pattern recognition agent is used in order to process and analyse the HBSDL scenarios. We analyse the habits which have associated a significant energy consumption.

In the next section of the paper we present our approach to scenarios formalisation and the activities recognition process. After we outline the pattern recognition process over scenarios time-series and the system multi-agent architecture. We conclude the paper with discussions about the results and with the important fields of the future work.

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2 System Architecture and Principles

Human Behavior Scenarios Description Language. The purpose is to describe the human behavior over large periods of time and for that, we use scenarios (a list of actions linked together). The goal is to describe the human interactions with devices and appliances. There are three categories of actions:

(i) Instant-actions (the person spent less than one minute to perform that action), such as: wake up, goes to bed, turns on, etc.
(ii) Long time exclusive actions (the person can perform at a certain moment only one action, with a significant time interval), such as: uses toilet, uses sink, etc.
(iii) Long time non-exclusive actions (the person can perform at a certain moment that action and also others action), such as: watching TV, uses washing-machine, etc.

In the scenario's description we defined and used a special language, HBSDL (Human Behavior Scenarios Description Language), with a syntax and a vocabulary similar with the English language. To assure that scenarios are accurate, we have defined a HBSDL compiler. We store the scenario for each house resident, in a different file:

```
Alice wakes up in 0#Bedroom at 08:30:20
Alice turns on light at 08:30:25
Alice turns on television at 08:31:00
Alice enters 2#Bathroom at 08:50:00
.......................................
Alice goes to bed at 22:10:00
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The activities recognition process means to have an intuition about the actions and the objectives of one or more people, using an observations set, about the person actions and the environment. Our approach uses a bidrectional process: we analyse the sensors data-streams and we analyse the context in the same time.

A flexible definition about the context takes in account: user location, his identity and preferences, the identity of other people which share the same location, the interacting objects (especially appliances), the weather, the time-moment, the temperature, etc [4]. We use a subject-centric approach of the context, based on the use of RFID [1] sensors. In this way, we know for each person where they are, at each moment.

To **represent the context** we use a matrix, with three dimensions: who, where and when. The household profile describes the household structure and the house residents: preferences, weekly schedule, sex, age, etc [1]. Using the data about house resident we can build a set of constraints. For example, if at a certain time the subject and the place is "a man in the kitchen", and we have on the same time a woman in the kitchen, using the man preferences, we build the following constraint: "the man is not cooking". We have obtained data about the household residents using a questionnaire. A large study using more than 800 households and more than 2000 people, from Romanian region of Banat, was developed in order to build a set of household profiles.

For a person p, from the room r at the moment t the context matrix element *context(p,r,t)* contains:

[1] Each person has a RFID label and in each room we have a RFID sensor which detects the identity of all the subject from that location.

(i) A scenario which describes the last actions from the moment 00:00 AM to the moment $t-1$.
(ii) A set of constraints about the actions with small probabilities to occur.
(iii) The temperature, the lightening and the movement level.
(iv) The number and the identity of other people from the same room *r*.

The analysis of sensors data-streams is used only for the sensors related with the domestic ressources consumption: electricity, gas, water. The current-cost sensor data-stream analysis provides us information about the running devices. The gas/water consumption is used to understand the cooking type or the washing type. We have defined a set of models which we use to analyse the current-cost, gas-consumption and water-consumption sensors data-streams. For each device, the model contains the average/the minimum/the maximum consumption. Also, we define the minimum/average/maximum consumption for each washing-type. The results of sensors data-streams analysis are inserted in the system knowledge base. A rule-based engine uses as input this results and the context matrix elements and provides as output the activity type as HBSDL instruction.

Human Behavior Patterns. Pattern recognition means examining input data and recognize patterns based on a priori knowledge or on statistical information extracted from the patterns. To discover patterns in scenarios (user habits) we must to "translate" the scenario from HSBDL in a numerical time-series, **the scenario time-series**. For the long time non-exclusive actions, we insert in the time-series the start-action time and the end-time action. In order to improve the energy efficiency we are interested to obtain patterns related to the long time actions. We consider a pattern in the scenario time-series, a subsequence of more than three elements. Our pattern recognition agent discovers in the scenario time-series subsequences and calculates for each subsequence the frequence and the average start-time. The context validation agent is used to check all the constraints over all the contextual data.

Multi-Agent Architecture. Our software protototype is a multi-agent system based on a blackboard architecture, using the JADE[2] platform. Our system uses an agent to build the context from the household profile and the RFID sensor data-stream. An ontology which describes the household is developed using the household profile. A parser analyses the XML file, which describes the household profile, and based on this data we generate as output the ontology. The communication between the agents is based on this ontology. For each current-cost/gas/water sensor data-stream, we have developed an agent which analyses it in order to recognize the model (e.g washing model, cooking model, energy-consumption model,etc). The scenarios recognition is based on a rules database which was developed in JESS (Java Expert System Shell Language) and embedded in an agent. The blackboard contains the context, the computed models, the sensor data, the scenarios and information about the household. An agent parses the scenario to discover some patterns. As a future work, we want to develop agents which compute statistics and association rules about the scenario actions.

[2] http://jade.tilab.com/

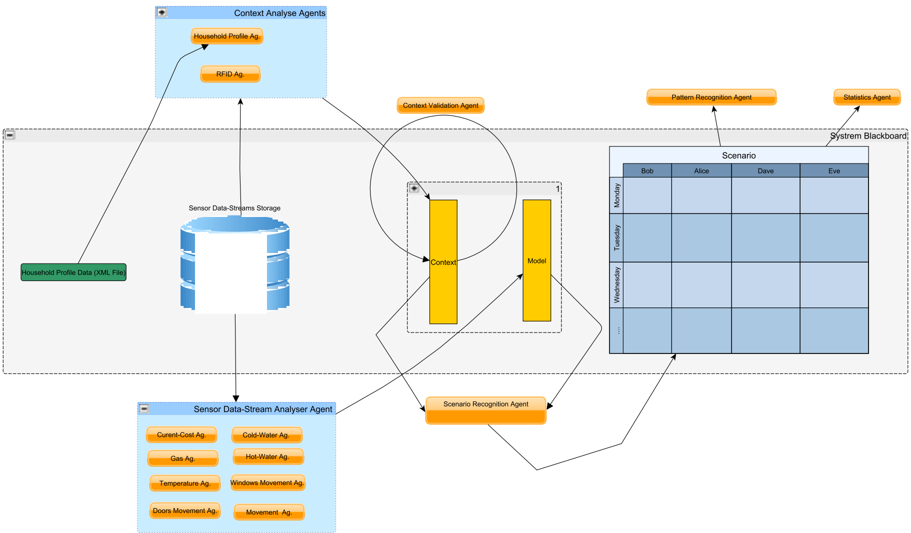

Fig. 1. The Multi-Agent Architecture

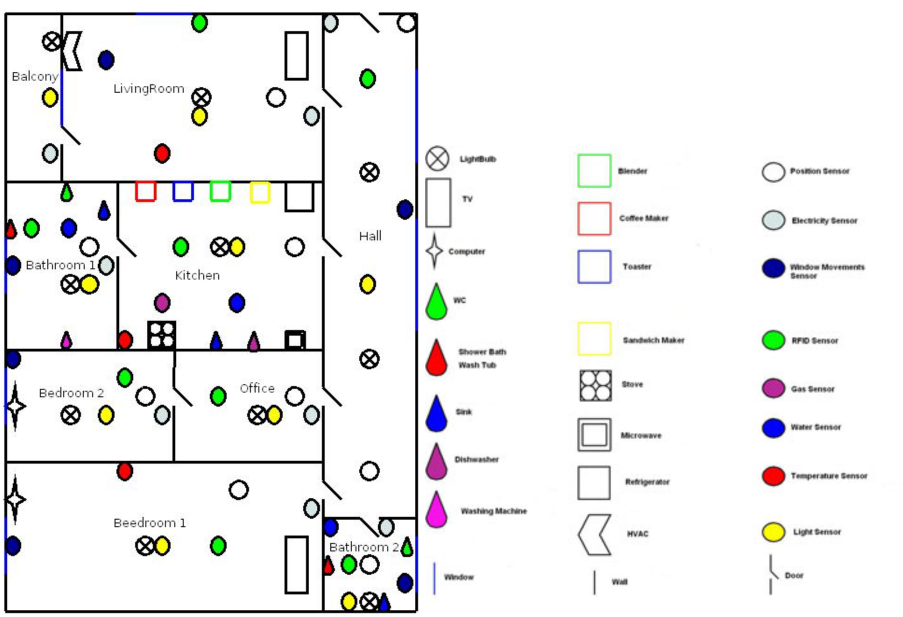

Fig. 2. House Description

3 Results and Discussions

In this section we will present an example: a family composed by four persons (Alice, Bob, Dave and Eve) which live in the house described in the figure 2 . The scenario which describes this family behavior for seven days contains 624 sentences (actions). Bob scenario's summary can be view in the figure 3. The Bob scenario is described using 164 sentences, and for each sentence the main attributes are the action, the start-time and end-time. For each action we associate a colour: dark blue for ”wakes up”, red for ”goes”, blue for ”turn on / uses *an appliance*”, gray for ”washes”, pink for ”turns off”, light green for ”exit”, yellow for ”comes”, purple for ”goes to bed”, etc. For each day of the week you can see a column which describes what actions are performed in that day. Table 1 explains the results of the scenario recognition and patterns discovering process over the scenario time-series. The recognition rate represents the similarity measure between the original scenario time-series and the recognized scenario time-series. We use the Dynamic Time Warping metric to calculate the similarity between these two time-series [2]. In our case, due to the recognition rate the original and the ”recognized” time-series can have different lengths and for this reason we use this metric. From the structural point of view Monday, Tuesday, Wednesday and Friday Bob's schedules are

Table 1. Results of habits recognition process

Scenarios	Recognition Rate	Identified Patterns	Minimum Patterns Length	Maximum Patterns Length	Total Energy Consumption
Monday.sce	0.95	4	3	5	10.003 Kwh
Tuesday.sce	0.95	4	3	5	10.340 Kwh
Wednesday.sce	0.96	5	4	5	11.152 Kwh
Thursday.sce	0.94	3	3	4	8.1100 Kwh
Friday.sce	0.92	5	3	5	10.420 Kwh
Saturday.sce	0.87	4	5	8	9.0010 Kwh
Sunday.sce	0.95	4	3	4	8.1430 Kwh

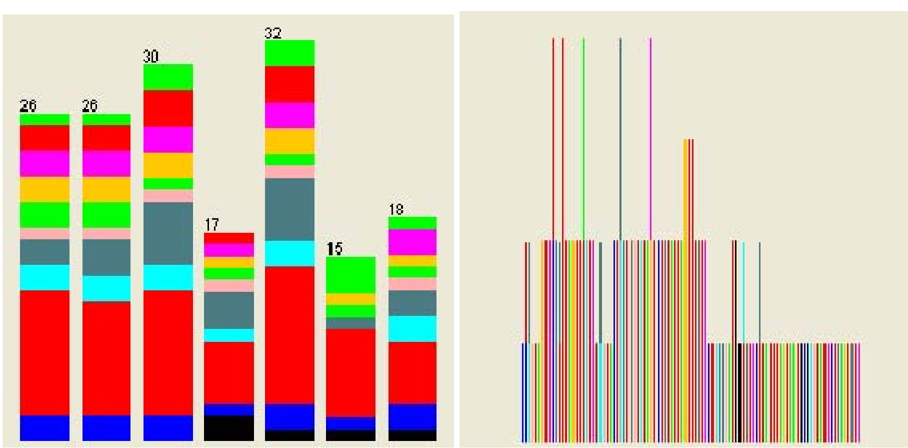

Fig. 3. Left - Bob Scenario: the seven days summary. Right- Bob Scenario: start time for all the actions.

very similar. The same patterns are discovered for all these days. The washing activities are concentrated on Saturday. On weekend the most activities are started on morning. Also, on weekends there are few activities, from the numerical point of view, but longer comparing with the other days.

4 Conclusions and Future Works

We are developing a multi-agent recommendation system for energy efficiency improvement (MARSEEI) [1]. The software prototype presented in this paper is integrated in the MARSEEI system, which is a work-in-progress. The first level of abstraction is the scenario recognition process, based on a bidirectional approach. The HBSDL language is used in order to formalise the human behavior. A second level of abstraction is developed in order to extract the user habits, from the household residents scenarios. A research about the influence of human behavior on energy consumption will be developed, for providing recommendations using these observations. We will define a **contextual model** which it will take into consideration patterns from the received data. The minimum sensor network dimension which it can be used to obtain relevant data about the household resident behavior is another important research future direction.

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