APPLYING MULTI-AGENT SYSTEM IN A CONTEXT AWARE SMART HOME

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ABSTRACT. *The goal of this project is to create a context aware home that utilizes multi-agent system to monitor and execute appropriate actions based on the current state of the house. There are two main intelligent features introduced in this project architecture to facilitate the multi-agent system in a smart home environment. The first feature learns and adapts the movements and actions of the occupants. The second feature predicts events engaged by the occupants. The effectiveness of the integration on smart home is documented and presented using a simulation application of the technology in a working smart home environment. The proposed architecture expands from the conversion of passive sensors into smart devices by adding processing and analytical capabilities from the software integration.*

KEYWORDS. Smart home, Intelligent agent, Context-awareness, Multi-agent.

INTRODUCTION

The notion of context-aware computing seeks to resolve the problem of needing explicit input and greater complexity by giving the computer system various means of knowing the context in which the system is being used at that time. In order to develop such intelligent and complicated systems, it must be designed with multiple sensing modalities to interpret, compute, and implement proactive presentations of services and information to the user, and store information about the context for future references.

In order to be helpful to the user, a context-aware system needs to acquire and utilize information about the context of a device to provide services that are appropriate to the particular people, place, time and events (Moran and Dourish, 2001). Occasionally, activity context categories describe specific activities associated with an alarm event. Examples of such activity categories include intrusion, access, property damage, and property removal.

Another key aspect is that the application should be able to query context information they are interested in and some sensors should be able to provide context information, such as aggregated context information to other devices. Additional parameters for context might include user preferences and history of interaction (Lieberman and Selker, 2000). Context-aware interfaces seek to move much of the interaction into the background, thereby becoming transparent to the user (Svanaes, 2001).

Smart home are often the ideal solution for individuals with different needs and abilities. This is because a smart home can provide an environment that is constantly monitored to ensure the individual is safe, automate specific tasks that an individual is unable to perform, provide a safe and secure environment, alert helpers should the occupant be in difficulties, enable and empower the user, facilitate in the rehabilitation of individuals.

Alternatively, smart home is seen as an intelligent agent that perceives its environment through the use of sensors, and can act upon the environment through the use of actuators. Sensors that included are motion sensor, magnetic sensor, vibration sensor, floor sensor, smoke sensor and so forth. The home has certain overall goals, such as minimizing the cost of maintaining the home and maximizing the comfort of its inhabitants (Rao and Cook, 2004).

Smart home research has focused on developing ubiquitous computing solutions, which aim to adjust to the inhabitants' needs according to the information collected from the inhabitants, the computational system and the context. Ubiquitous computing enables invisibility of the computational technology and provides the user with “natural” interaction techniques, such as speech (Kidd, 1999).

Most of the smart home designs elaborate on home automation and promote safe-guard on dependent occupants. The system's control comes with a set of predefined static rules without the capabilities of self-learning and makes prediction based on a detected event by the system automatically. With such limited intelligent resources, the system is unable to adapt the continuous changes of society daily living pattern.

In order for the system to suit with various household living patterns, self-learning is essential to be integrated into the smart home technology. Learning and adaptation process is the concept that is defined as the type of service it provides to the house inhabitants by providing comforts, security and entertainment. Data collected during learning process can benefit the accuracy of prediction result for future events.

To address the main concerns on daily absence by leaving maid, children or elderly at home alone, the primary aim of this research is to focus on providing house owner comforts and security services for context-aware computing environments that can adapt to track the presence of individuals in control area. In addition, it also produces a simple and cost-effective means of introducing a better interactive and intelligent system to enhance existing smart home technology.

This paper focuses on the creation of a simulated environment that acts as an intelligent agent, perceiving the state of the home through sensors. The agent's goal is a function that maximizes comfort and productivity of its inhabitants and minimizes operation cost. In order to achieve this goal, the house must be able to predict and make assumption, learn and adapt to its inhabitants. The main objective is to predict the behavior of the observed agent based on given predefined setting and historical collected data. In the context of cognitive assistance, these predictions are used to identify the various ways a smart home observer agent may help its occupant. An important assumption underlying this approach is that the observed agent is rational. The remainder of this paper is organized in the following manner. Section 2 describes related research projects that have been carried out. Section 3 describes the agent's decision making algorithm. Section 4 presents the results obtained, and a discussion based on the simulated application runs. Section 5 provides a conclusion, drawing together concepts learned through the research and experimentation performed.

RELATED WORKS

There are a number of research projects that actively explore the possibilities offered by technology associated with the smart home.

The Assistive Home is a new approach to independent living. The Assistive Home allows the integrated control via a centralized control center or via the electrical items focusing on accessibility and usability for people with disabilities. It consists of features which can be controlled directly via switches or centralized via an environmental control system (Nussbaum and Miesenberger, 2004). The Aware Home is a focused research program, whose goal is to develop the requisite technologies to create a home environment that can both perceive and assist its occupants. The scope of the projects carried out within this program range from fundamental technical development to cognitive and ethnological studies that assess the most appropriate and compelling technological strategies (Kidd, 1999.).

Ambient Assisted Living consists of technologies that address user needs by focusing on the safety and protection of the personal environment and the stimulation and enabling of older adults to maintain an active lifestyle. The aim of the adaptive house experiment is to explore the concept of a home which programs itself, freeing the inhabitants from the need to carry out this task. The researchers point out that the software for an automated home must be programmed for a particular family and home and updated in line with changes in their lifestyle (Mozer, 1998).

Ubiquitous Computing Environments is developed in a home environment that will comprise numerous computationally enhanced artifacts that are autonomous, but interconnected via an invisible web of network-based services. The approach is to enable end users to make their own applications by linking such artifacts, which are treated as reusable components. A key requirement to achieve this is the availability of editing tools that meet the needs of different classes of users (Mavrommati, Kameas and Markopoulos, 2004).

THE SMART HOME

This study will be tested in a simulated environment with a house plan displayed for vision purposes. This research focuses mainly on the software that provides the infrastructure for intelligent monitoring of movement within a house. The floor plan used in the simulation system includes kitchen, dining room, balcony, outside of the main door, inside the main door, living room, hall, bedrooms and toilets. These will cover the average size of the house in an existing housing area in the actual scenario.

The context-awareness for smart home proposed in this paper uses the multi-agent system, to represent context and shared knowledge among agents. That is, agents interoperate and work together to provide the mentioned location-aware services to the inhabitants of the smart home.

The system provides a necessary infrastructure for each agent's interaction to take place. The infrastructure includes protocols for the agents to communicate and protocols for the agents to interact. Communication protocols enable the agents to exchange and understand messages with each other effectively. Interaction protocols enable agents to have conversations, which for the purposes are structured exchanges of messages. As an example, a communication protocol might specify the types of messages that can be exchanged between agents: capture (Sense) a course of action, accept (Learn) a course of action, reject (Alert) a course of action, and evaluate (Predict) a course of action.

Agents are often characterized as autonomous, intelligent, and robust. The realization of these traits generally requires much complexity, leading to large, monolithic software components. This centralization is problematic for many reasons: it creates a bottleneck in resource access, it produces a single point of failure, and it makes it difficult to reuse particular agent characteristics in other contexts (Coen, 1994).

An alternative approach to designing agents is characterized by what is known as multi-agent systems (MAS). Agents in multi-agent system perform individually specialized, simple tasks, but they connect together in a web of intercommunication to cooperatively perform complex activities. According to Minsky (Minsky, 1986), a complex system can be decomposed into a lot of little agents accomplishing a task with reduced complexity, but collaborating in such a form that the final system is smart. This is obtained when a complex system is divided into several agents specialized on a concrete task and they cooperate to solve a major task (Vlassis, 2003).

An agent system will be able to provide better assistance to its users. In this section, it focuses on constructing a representation for context and using that representation to understand user needs and expectations. In the simulation, we presume motion sensors have been installed at all the corners of the house. Areas include kitchen, dining room, living room, corridor, bedrooms, toilets and front doors. We rely on sensors for motion and enhanced device controllers for device state detection. In short, we collect information about the current state of the area and the occupants within to be delivered to the agent for risk analysis.

Foremost, this research presumes all the agents are able to identify individual occupants and other house members. For the sub-agent to correctly react to a user's action, it needs to situate that action within its context. Knowing what task the user is currently performing can help do so. The agent's task is to observe user actions, predict and analyze the risk of the task. The agent recognizes the ongoing task within the area and presents an organized method to structure area reactions.

Super-agent acts as an intelligent processor to evaluate on all kinds of scenarios sub-agents whereas sub-agent acts as a data collection bridge between sensor device and intelligent processor as shown in Figure 1. This allow super-agent to distribute event detection task to each relevant agent in order to improve its processing power more efficiently without interrupted by heavy loaded process.

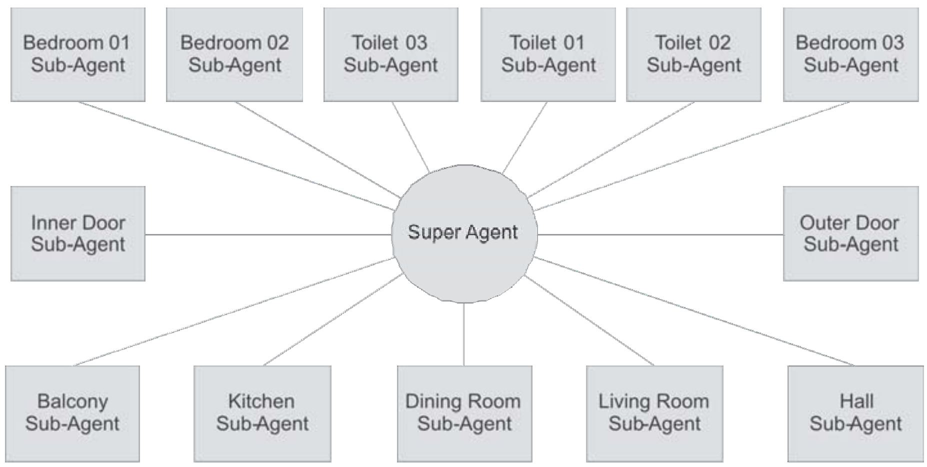

Figure 1. Overview communication diagram between agents.

The super-agent observes user actions by collecting data from other sub-agents. Given low level contextual information such as where a user is located and which device was just turned on. Therefore, the system is capable to conclude an assumption of the current task, or activity, performed in the detected area by the current users. Each event that a user performs is captured by a sub-agent within the area assigned. All the sub-agents are the subset or representative of the super-agent to monitor all sorts of events that occur in the particular area. Eventually, such event modeling can be merged to develop a context-aware application.

LEARNING AND ADAPTION

A smart home intelligent environment must be able to acquire and apply knowledge about its inhabitants in order to adapt to the inhabitants and meet the goals of comfort and efficiency. The agent needs to predict the inhabitant's next action in order to automate selected repetitive tasks for the inhabitant. The home will need to make this prediction based only on previously-seen inhabitant interaction with various devices.

Throughout the intelligent environment, the sub-agent is learning and adapting the movement pattern of the detected occupant based on the tracked data. All data collected by particular sub-agent will be stored in the database for future reference. Such event information can be shared with other agents to enhance context-aware application. Events includes movement of the occupants and device (where only light applies in the simulation) status within the house area.

When an event occurs in an area, the particular sub-agent captures the event input and compare it with the historical log for verification. If there is a similar record found in the historical log, the agent considers the event does not contain threat to the safety of the house. Ironically, if such log is not found, the sub-agent alerts the super-agent with regards to the incident and further action will be taken accordingly such as trigger an alarm.

Verification process on the historical log is based on three criteria that must be met to be considered as a safe event. Criteria includes time must fall within the range of the event, area must be the exact location and the event must be learnt, repeatedly, for thirty times. In this process, sub-agent is able to decide the outcome of the safety evaluation. To trigger an alarm, the super-agent sends the command to the sub-agent to execute the task. This process is depicted in Figure 2.

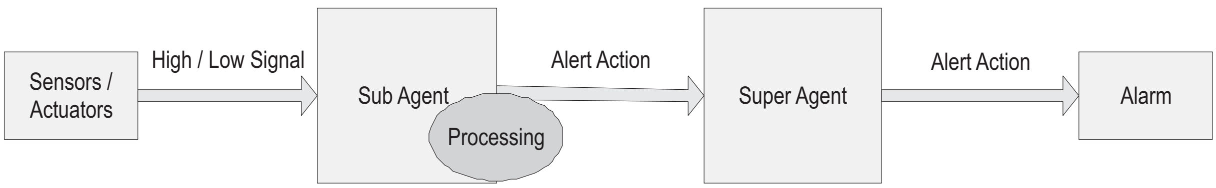

Figure 2. Learning and adaptation process diagram.

RISK PREDICTION

Risk assessment involves continuous communication between the super-agent and multiple sub-agents for critical information exchange. Individual sub-agent must be aware of any single activity that is happening in its coverage area and reports the event to super-agent for risk prediction and analysis. For instance, when sub-agent detects an event occurring within its boundary, it initiates the movement tracking by records event time and period of detection. Collected information will be sent to the super-agent whenever it requests it for risk assessment purposes.

Super-agent compiles all the collected event information from the different collaborating sub-agents. Based on the event information gathered, the super-agent is able to produce an assumption on the current house environment or the detected activity. The assumption statement is made based on the criteria of who are at the scene and time of the detected event.

Assumption that is not suspicious will be ignored by the system; likewise, suspicious assumption that could jeopardize the safety of occupants will be immediately alerted to the owner of the house who is normally away from the house. Suspicious assumption includes (1) the presence of intruder in the house, (2) maid has been out of the house for too long and leaving dependent occupant at home unattended, (3) elderly has not been moving in a specific area for a period of time, (4) the maid has run away from home leaving the child home alone and so forth. The risk assessment process diagram is shown in Figure 3.

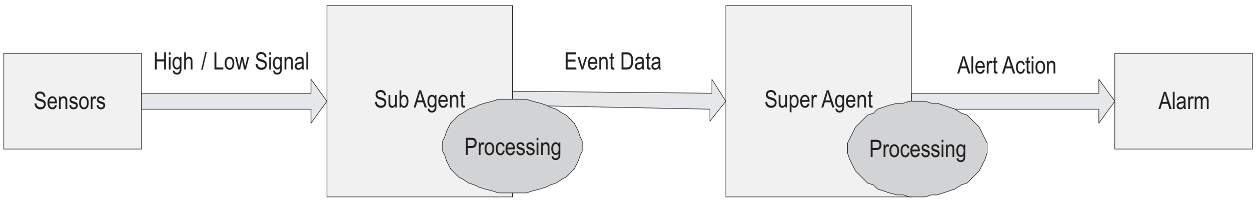

Figure 3. Risk assessment process diagram.

COMMUNICATION

Since this research is built under a simulated environment, the agents are assumed to be able to send unlimited amount of text string to each other and as often as required. Context contained in a communication transfer data from sub-agent to super-agent includes agent identification, the time of event, the status of event, location of event and sensor identification. Communication response time can be achieved within a second via memory data structure algorithm.

ANALYSIS

At a certain level in analytical model, a behavior contains a rule that, a given event action performs a reaction of assumption analysis. For instance, a maid in the kitchen, the initial perception of the sub-agent is sent to the super-agent for analysis by associating information from the other sub-agents. Method of evaluating risk analysis is based on time length, area and actors during the detection period.

A risk analysis table is formed to incorporate all kind of events that could occur during the simulation runs. The analysis table includes all possibilities of occupant's present in the house. The occupants are maid, baby, elder and intruder where these actors are shown in the simulation system.

As users go about their daily actions, the system successively records the daily routine information available to it by the sensors connected. If the user performs an action such as trigger light event and the system determines the current event is to be close enough to the historical logs in the database, then the database does not record a new entry, but rather updates the existing matched entry with a higher score. The learning system also includes adapting occupant's daily activity to suit the house environment. It tracks and learns, at the same time, from the occupant's lifestyle in order to predict for future reference. Throughout the simulation analysis modal, it constructs three types of event categories: regular event, irregular event, and automated event.

REGULAR EVENT

Regular event defines the activities that are performed under an expected environment from the system. When a current event matches one in the history log and the score is above a certain threshold, then the system is no longer needed to evaluate the risk of the event and the action is performed automatically and the score for the event in the history log is increased by one. The system will display a notice that such action has been performed. The regular event is shown in Figure 4.

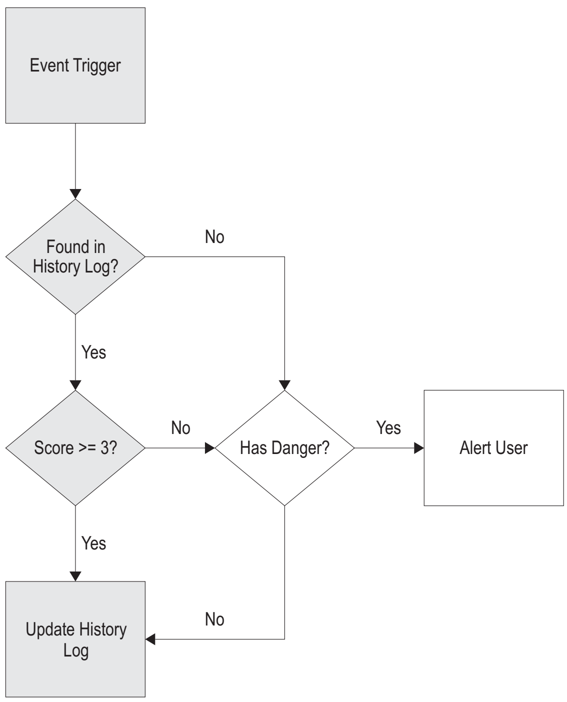

Figure 4. Regular event flow diagram.

IRREGULAR EVENT

Irregular event is an activity being performed unexpectedly from the ordinary pre-scheduled events in the system. In the simulation, when the system encounters a current event that does not match any record in the database or the threshold score does not meet thirty times, then the system will evaluate the risk of the action based on the particular location and time of the event. If the event could jeopardize the home environment, then the alarm will be triggered.

On each risk-free event, the system score is set to increment by one in the history log. This is because the system is learning new action from the user apart from the history log, and is trying to adapt to the user needs. The system continues to monitor current sensor values, comparing them with sensor values in the history log about every two second as shown in Figure 5.

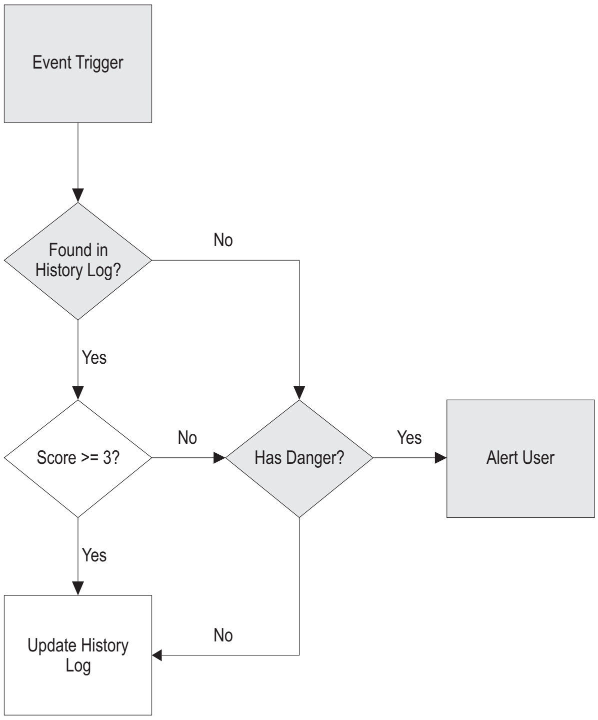

Figure 5. Irregular event flow diagram.

AUTOMATED EVENT

The goal of the decision making component in this system is to enable the home to automate basic functions in order to optimize the overall utility of the home and the comfort of the inhabitants. One important aspect of this comfort is the amount of tasks the inhabitants have to perform themselves. Prediction algorithms can anticipate future actions performed by inhabitants and could thus form a basis for automating interactions.

Automated event is an event that is performed by the system automatically based on certain criteria that has been complied. This event occurs when the system matches one in the history log based on the current time and score is above the threshold, system will perform such event automatically based on historical data provided in the database. The system will display a notice of such action has been performed.

For instance, when a historical event is matched to the current time, the system will perform the event based on the historical action captured. Due to the constraint event action under the simulated environment, the action that can be shown is turning on/off light in a particular area. The analysis of automated event is shown in Figure 6.

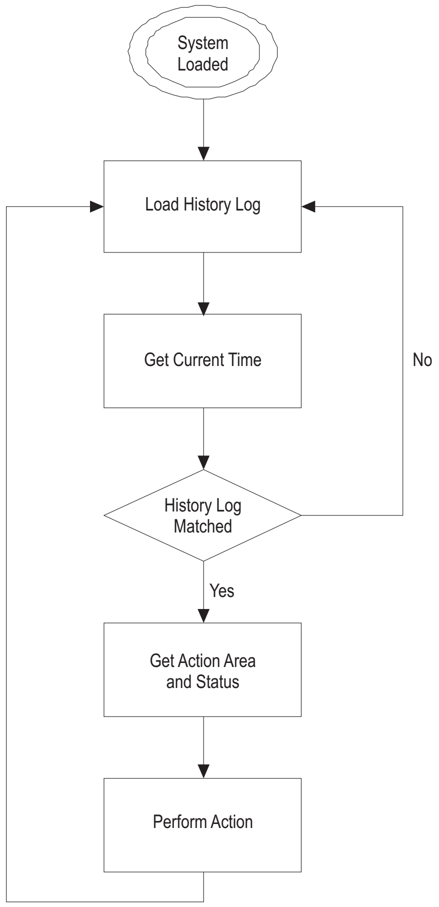

Figure 6. Automated event flow diagram.

EXPERIMENTAL EVALUATION

A preliminary experiment has been conducted to test the accuracy and efficiency of the simulation system in the capability of making prediction on an event and learning from occupant habitant behavior. The table shown below is a set of parameters simulated in the system to generate the prediction results on the particular event.

Table 7. Agent Prediction Test 1.

Experiment	:	Prediction Test 1
Time	:	09:00 AM
Occupant 1	:	Maid in the Kitchen.
Occupant 2	:	Baby in the Bedroom.
Assumption	:	 Maid is cooking in the kitchen and Baby is playing in the Bedroom.

Table 8. Agent Prediction Test 2.

Experiment	:	Prediction Test 2
Time	:	10:00 AM
Occupant 1	:	Maid in the Dining Room.
Occupant 2	:	Baby in the Toilet.
Assumption	:	 Maid is preparing meal in the dining room and baby is taking shower in the toilet alone.

Table 9. Agent Prediction Test 3.

Experiment	:	Prediction Test 3
Time	:	11:00 AM
Occupant 1	:	Maid is outside the house.
Occupant 2	:	Baby is in the Living Room.
Assumption	:	 *0 - 30 Minutes:* Maid is doing gardening outside and baby is left in the house.  *30 Minutes Later:* Maid is outside of the house leaving baby unattended in the house for too long.

Table 10. Agent Prediction Test 4.

Experiment	:	Prediction Test 4
Time	:	01:00 PM
Occupant 1	:	Maid in the Living Room.
Occupant 2	:	Intruder in the Living Room.
Assumption	:	 Maid has encountered the intruder in the living room.

A set of light status event has been learnt by the system in order to proof that the learning process is in working condition as shown in Figure 11 where it compares the accuracy of learning process in the system. The actual learning process is stated in column 'Actual Learnt Time' which is repeatedly trained for more than thirty times. The result of the learning process performed by the agent is displayed in column 'Automated Event Time'.

Table 11. Learning Test on Smart Home.

Area	Actual Learnt Time	Automated Event Time	Light Status
Kitchen	09:00:00	08:57:01	ON
Kitchen	11:00:00	10:57:01	OFF
Bedroom 03	15:00:00	14:57:00	ON
Bedroom 03	16:00:00	15:57:03	OFF
Toilet 03	15:00:00	14:57:04	ON
Toilet 03	15:00:00	15:57:02	OFF
Living room	12:00:00	11:57:01	ON
Living room	17:00:00	16:57:00	OFF

Based on the results on learning agent's performance, it can be observed that the agent can learn based on historical events that happen inside the house. First, it was observed that the simulation system is able to conduct assumption not only on one occupant but a few occupants simultaneously under various events. Second, the study deemed the system to present more helpful services such as security and comfort of house owner or the guardian of the dependent. Third, the simulation system is able to capture and present information and services significantly according to the events that have been learnt historically. Fourth, the multi-agent system is able to concentrate on a given monitoring task and area by making assumption based on the parameters captured on an event. Last, occupants are able to incorporate interactions with the learning and the assumptions made by the intelligent system naturally into their normal activities, at least in as far as these simulations could determine.

CONCLUSION AND FUTURE WORK

This paper presents the context-awareness smart home architecture which allows a home to act as an intelligent agent. As part of the architecture, two features are introduced that play critical roles in an adaptive and automated environment. Results from the simulation smart home application data indicate that it is capable of predicting inhabitant interactions with the home, and is able to effectively control the home based on predicted events.

By now the multi-agent system behavior is mainly reactive, and we plan on adding more intelligence to it incorporating reasoning capabilities using context information. This information will not only be location-awareness and status services but other context features like lighting, movement and risk assessment. Finally, the system intends to learn from user behavior and habits, so that the system really adapts the environment to users.

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