Smart Home Intelligence - The eHome that Learns

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Abstract

A smart home (sometimes referred to as a smart house or eHome) is one that has highly advanced automatic systems. A smart home appears "intelligent" because its computer systems can monitor many aspects of daily life. Our research, presented in this paper, is based on a universal implementation model for the smart home. The "Home Intelligence" (HI) module of the smart home, offers important added-value to the intelligent behavior of the smart-home environment. The HI creates an integrated environment in which the Artificial Intelligence (AI) mechanism can infer and suitably react according to changing conditions and events. By identifying abnormal or unexpected events and, when necessary alerting the home's occupants, the AI module can provide an immediate automatic response if desired. Because of the complexity of the systems, their diverse areas of control and supervision, the variety of information technologies and learning mechanisms, and the reasoning capabilities used in updating the information system, developers, suppliers and users must cooperate. Cooperation will be expressed by agreeing to anonymously transfer information from the client to the developer through the suppliers. The transferred information will include characteristics of abnormal events, which have actually occurred in reality (true life scenarios), and the responses of the smart home. This information is then analyzed and used for AI learning and to improve the system's reasoning mechanisms. Collecting information from a large number of clients will allow for faster learning and updating of the home intelligence system. A simulation system was developed in order to illustrate the HI module. The simulation illustrates the learning and the reasoning processes as well as demonstrates the smart home's responses to abnormal events.

Keywords: *Smart-home, Standardization, Universal Model, Artificial Intelligence, Home Intelligence*

1. Introduction

1.1. What is a Smart Home?[1]

A smart home (sometimes referred to as a smart house or eHome) is one that has highly advanced automatic systems for controlling lighting and temperature, multi-media equipment for monitoring and activating security apparatus (alarms and alerts) associated with windows and doors and many other functions. A smart home appears "intelligent" because its computer systems can monitor many aspects of daily life. For example, the refrigerator may be able to inventory its own contents, suggest menus, recommend healthy alternatives, and order

[1] http://architecture.about.com/od/buildyourhous1/g/smarthouse.htm

groceries. The smart home systems might even take care of cleaning the cat's litter box and watering the plants.
The idea of a smart home sometimes seems like something from Hollywood. Indeed, a 1999 movie Smart House presents the comical antics of an American family that wins a "house of the future", complete with an android maid who wreaks havoc. Other films show a science fiction vision of smart home technology that, for the most part, seems rather improbable. However, smart home technology is real and is becoming increasingly sophisticated and today coded signals are being sent through the home's wiring to switches and outlets programmed to operate appliances and electronic devices in every part of the house. And increasingly home automation is proving to be especially useful for elderly and disabled persons who wish to live independently.

1.2. Universal Implementation Model for the Smart Home

Our research is based on a universal implementation model for the smart home [1]. The proposed smart-home architecture, described in detail in [1], comprises four modules (Figure 1):

- Central Management Unit (CMU)
- User Interface (UI)
- Home Equipment and Appliances Interface (HEAI)
- External Communication Interface (ECI)

Figure 1: The smart home model architecture

The CMU components include (Figure 2):

- Operating System (SHOS - Smart Home Operating System)
- The Smart-Home Database (SHDB)
- AI (Artificial Intelligence) Engine - Home Intelligence (HI)
- Application Services (AS)

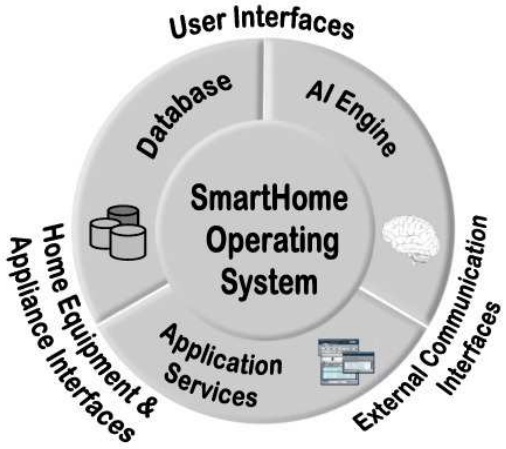

Figure 2: CMU components

In this paper, we analyze and discuss some aspects of developing and implementing the AI-engine module of the central management unit (CMU) – the Home Intelligence (HI) module.

1.3. OPM -Object-Process Methodology

Object-process methodology (OPM) [2] is a comprehensive and novel approach to systems engineering. Integrating function, structure and behavior in a single, unifying model, OPM significantly extends the system modeling capabilities of current object-oriented methods. Founded on a precise generic ontology and combining graphics with natural language, OPM is applicable to virtually any business, engineering or science domain. Relieved from technical issues, system architects can use OPM to engage in the creative design of complex systems. Figures 3 and 4 illustrate the use of OPCAT, a software product that supports OPM-based conceptual modeling (**www.opcat.com**), to describe the functionality of some components of the smart home, sometimes referred to as the eHome.

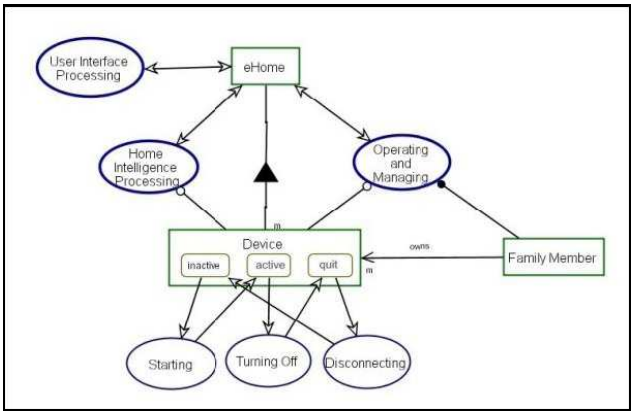

Figure 3. Object-Process Diagram (OPD) of eHome's_CMU (Central Management Unit)

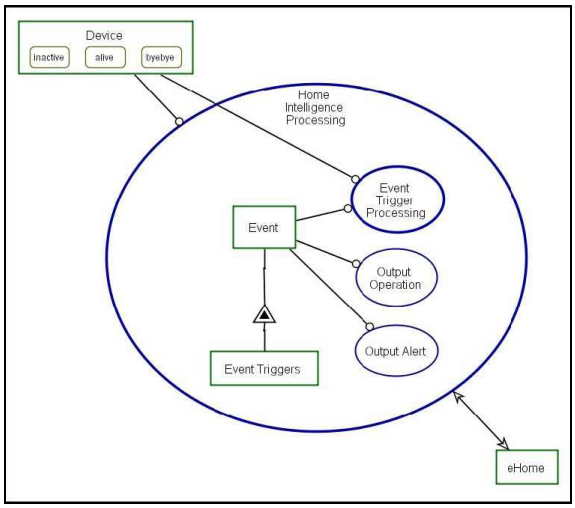

Figure 4. OPD of eHome's_HI (Home Intelligence)

2. Home Intelligence (HI) - The Artificial Intelligence (AI) Engine

The HI offers important added-value to the intelligent behavior of the smart-home environment. Instead of a group of sophisticated appliances and devices, the HI creates an integrated environment in which the AI mechanism can infer and suitably react according to changing conditions and events. By identifying abnormal or unexpected events and, when necessary alerting the home's occupants, the HI module can provide an immediate automatic response if desired. Several scenarios are presented below that illustrate abnormal events and some of the smart home's suitable responses.
Events describe and define the behavior of the intelligent home. Events might be related to security, health, convenience or any other practical issue. The HI module will enable centralized management and monitoring of all events, leveraging main alerts and obtaining input from several devices at the same time. For example, an alert could be initiated if, when the front door is locked and the house is presumably empty, a window is suddenly opened. The events are implemented as software modules either by pre-programming or by the HI module's AI learning and reasoning capabilities.

An event can be defined as a set of properties and functions (the object-oriented approach):

- Event Name: a description of the event
- Input Devices: devices inside the eHome that trigger an event by a combination of their current status and measured values
- Event Triggers: functions that return TRUE when a trigger is invoked
- Output Operation: a function with the desired output operation
- Output Alert: if an event requires an alert, Output Alert describes the alert.

2.1. Abnormal events – Identification, Response, Control and Updating of the Learning System

The smart home, based on the implementation universal model, is equipped with either a centralized or decentralized smart-home database (SHDB) [1]. This database includes

operational and periodic observation data, provided by sensors and other system devices. The database may be centralized or decentralized. In other words, some of the sensors and other devices may have a local database that is connected to the central database. This comprehensive database allows for an updated picture of what is happening in the eHome as well as a full history of events and operations.

A variety of abnormal and unexpected events may occur in the smart home: events relating to health problems; break-ins; fire; gas leaks; floods; and more. The HI module is embedded with a variety of abnormal events, information pertaining to the event's occurrence or the suspicion of such an occurrence as well as information regarding suitable responses. The HI module closely examines the smart home's database and describes abnormal situations. The module then responds in accordance with the updated response procedures by presenting suitable alerts and activating the appropriate response necessary to deal with the specific event. The system is programmed to define relevant probabilities relating to the event according to the received data and to respond accordingly. For example, when an important health problem is identified (i.e., unconsciousness or a serious injury), the system will respond. In addition to suitable alerts, the system will also call for an ambulance and convey the urgency of the situation by alerting the client's physician. In contrast, in the event of a low-level health problem, the system will only issue an alert and await a suitable human response.
Abnormal events are not common in a single individual home. Hence, in order to build a detailed AI system, one which includes a wide variety of events and suitable response procedures, it is necessary to gather data from a large number of homes. Usually, AI systems are built on learning from many events over a continuous time period. Centralizing and updating data, and building and developing the learning process may be carried out by developers and suppliers of the AI module or by specialized companies who provide this service.

2.2. Developers, Suppliers And Clients Of Artificial Intelligence Systems In Smart Homes

Because of the complexity of the systems, their diverse areas of control and supervision, the variety of information technologies and learning mechanisms, and the reasoning capabilities used in updating the information system, developers, suppliers and users must cooperate. Cooperation will be expressed by agreeing to anonymously transfer information from the client to the developer through the suppliers. The transferred information will include characteristics of abnormal events, which have actually occurred in reality (true life scenarios), and the responses of the smart home. This information is then analyzed and used for AI learning and to improve the system's reasoning mechanisms. Collecting information from a large number of clients will allow for faster learning and updating of the home intelligence system.

2.3. Learning and Updating Abnormal Events data

The AI system, which will be developed and implemented in smart homes, will comprise primary knowledge, procedures, and reasoning mechanisms. Learning from actual abnormal events will allow for the improvement of the system and an efficient and appropriate response when actual abnormal events occur. The goal of the AI module is to identify events that require a response, to understand the extent of the event's seriousness and to propose or

automatically activate a suitable response. Data gathering regarding event characteristics - observed and measured parameters, reasoning procedures, and an activated response, together with an evaluation of the desired response - will enable the creation of an events database. Analyzing and activating AI learning methods will improve reasoning procedures and the required responses towards different events. In the next section, we illustrate the implementation of the AI learning mechanism and the creation of the Home Intelligence system for the smart home.

3. A Simulation System for Illustrating the HI Module

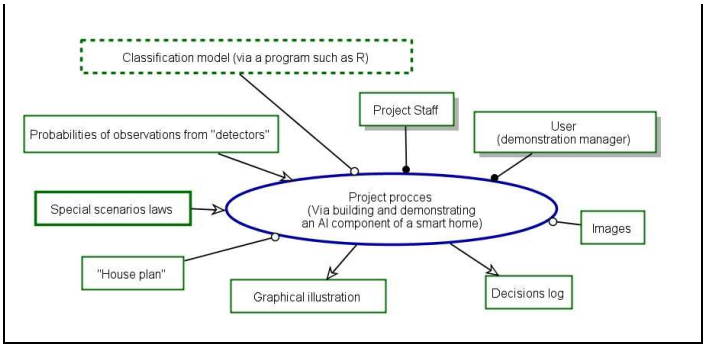

Figure 5. OPD of the Simulation System

A simulation system was developed in order to illustrate the HI module. The simulation illustrates the learning and the reasoning processes as well as demonstrates the smart home's responses to abnormal events. The simulation system was developed using R[2] software, and utilizes a CART[3] algorithm. R is a free software environment for statistical computing and graphics [3]. CART (classification and regression trees) is a set of techniques for classification and prediction [4].

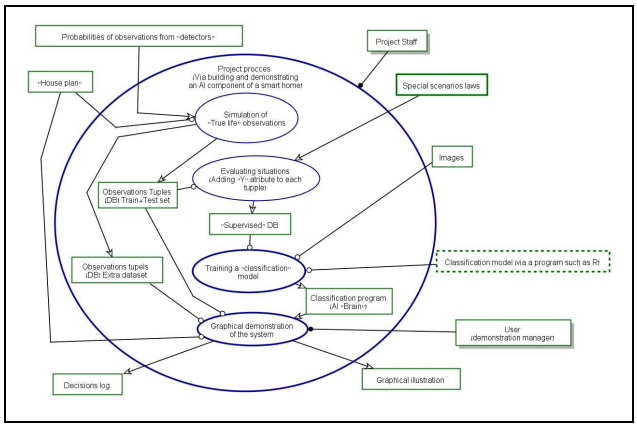

Figure 6. OPD of the Simulation Processes

[2] http://www.r-project.org/

[3] http://www.statistics.com/resources/glossary/c/cart.php; http://www.stat.wisc.edu/~loh/treeprogs/guide/wires10.pdf

In Figure 6, the OPD presents a detailed look at how the simulation is carried out. The simulation is comprised of several sub-processes:

3.1. Running the simulation and creating a database

The simulation creates a database of "real life" observations that have been received by eHome sensors. The database is divided into two parts. One part is passed through the classifier, while the second part is saved for the running stage in order to provide the classifier with new and unexpected observations.

3.2. Training Process - Data Mining model

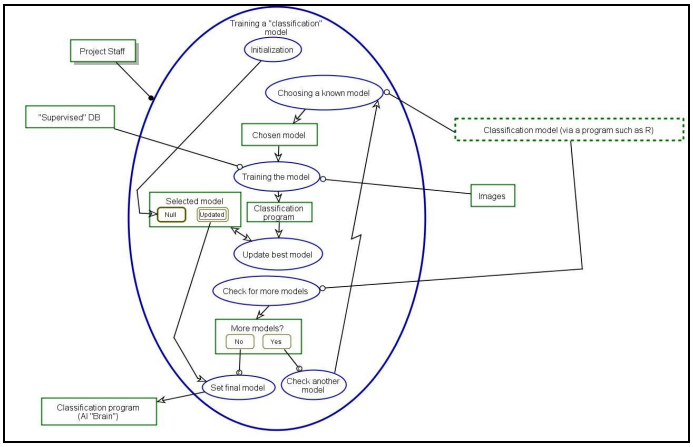

Figure 7. OPD of the Training Process

The OPD diagram in Figure 7 provides a more detailed look at how the classification training procedure is executed. This process occurs in a loop cycle each time a classification model is chosen from those available in the database. The model is trained by the R program on data that was randomly chosen from the simulation. At the end of this process, the program provides an update of the variable indicating which model provides the best classification (the model with the least classification errors). This process is based on CART. CART is a binary decision tree[4] created by dividing nodes, beginning with the root of the tree and progressing to the subsequent nodes created from the first split and continuing until conditions for stopping have been achieved. The main idea is based on choosing the right split among all possible splits. The "Gini impurity" criterion[5] was chosen for examining which split is most worthwhile. In our case, the most worthwhile split was the least "contaminated".

[4] http://en.wikipedia.org/wiki/Decision_tree_learning#General
[5] http://en.wikipedia.org/wiki/Decision_tree_learning#Gini_impurity

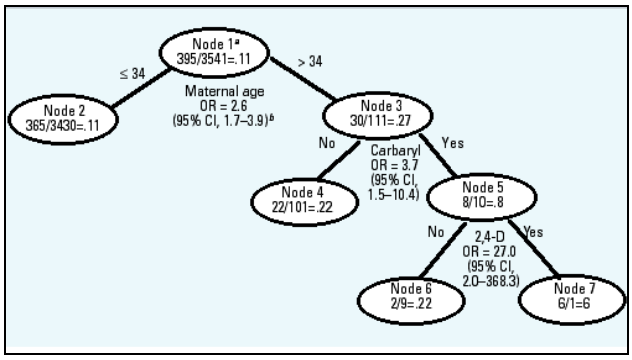

Figure 8. Stopping the Tree's Growth

Splitting of a certain node stops when the following conditions have been met (Figure 8):

- If the node is "pure"; that is to say, if all of the values in the node are identical
- If, at every split, we get the same value ratio
- If we have reached what the user defines as the tree's maximal "depth"

3.3. Identifying Abnormal Events in Daily Activity

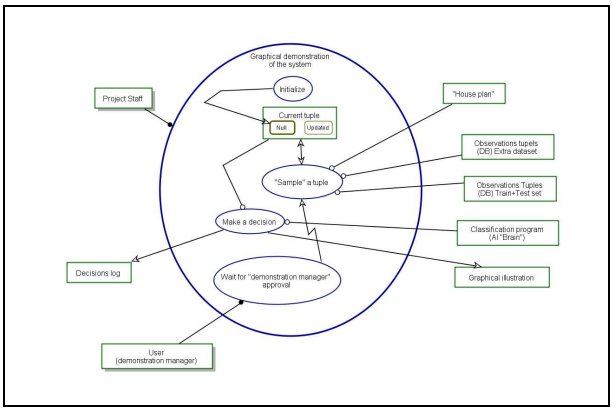

Figure 9. OPD of the system's response in daily life

In daily life, as shown in Figure 9, eHome sensors and devices accumulate data which is stored in the smart-home database (SHDB). The HI module regularly scans the SHDB and identifies abnormal events based on the classifications of the learning process. The HI module includes an appropriate response for each relevant abnormal event (Figure 10). In the next section, some scenarios of abnormal events and reactions are illustrated.

Figure 10. The simulation system's fire alarm interface

4. Examples of Scenarios and Response Procedures

Below, two examples of scenarios and response procedures of the Smart Home's HI module are described:

4.1. Fire Scenario

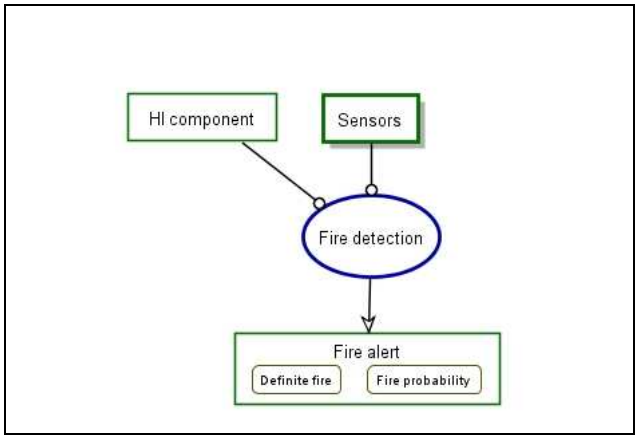

Figure 11. OPD of the HI module in the idle state (listening)

- The HI module is in the idle state (listening). It collects and analyzes data received from sensors and devices (read sensors output module [RSO]).
- The system classifies an observation as one that has deviated from the normal parameters (trigger). Smoke detectors or climate sensors report abnormal observations.
- An analysis is conducted by the sensors output analysis (SOA) module. The SOA module presents one of the three optional states: Yes, No, or Maybe.

- In the cases of Yes and Maybe, a process is activated. The system examines whether there is a fire in the home or the possibility of a fire, in which case a fire alert or possible fire alert is activated.

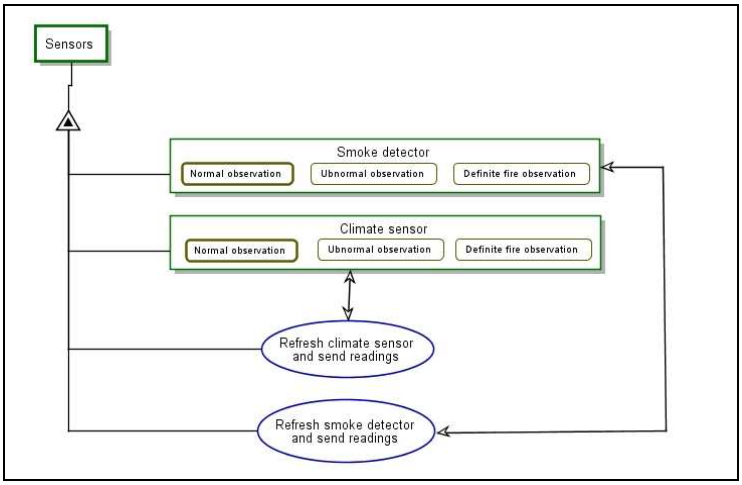

Figure 12. OPD of sensor data collection and analysis

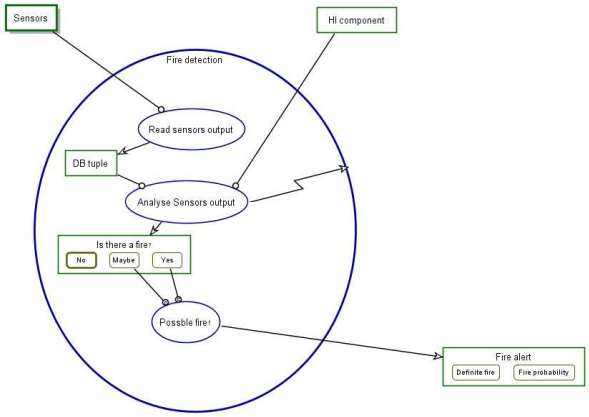

Figure 13. OPD of the sensors output analysis (SOA) module

4.2. Monitoring an elderly person's vital signs

- The HI module is in the idle state (listening). It collects and analyzes data, received from sensors and devices (read sensors output module - RSO).
- The system classifies an observation as one that has deviated from the normal parameters (trigger). Some devices or sensors report abnormal observations.
- An analysis is conducted by the SOA module. The SOA module presents a presumptive diagnosis and its probability.
- According to the diagnosis and probability, an alert is presented on the eHome displays and the displays (such as mobile phones) of other home member. If needed,

according to the diagnosis and predefined procedures, a call is made, automatically, to the physician and ambulance services.

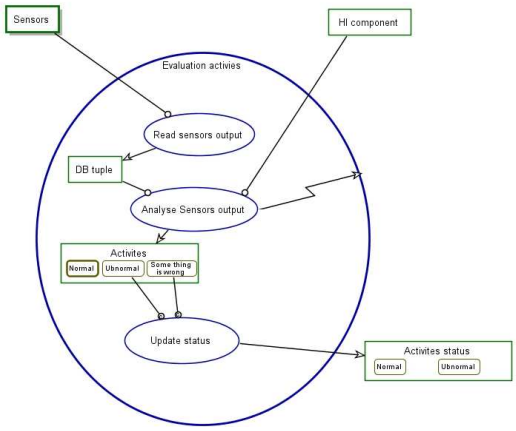

Figure 14. OPD of monitoring an elderly person's vital signs

5. Conclusions

The HI nodule, as described in the universal implementation model for the smart home, is an important added-value for the intelligent behavior of the smart-home environment. Because of the complexity of smart home systems and devices, their diverse areas of control and supervision, the variety of information technologies and learning mechanisms, and the reasoning capabilities used in updating the information system, developers, suppliers and users must cooperate. Moreover, all devices and systems must be compatible with common standards based on the universal model. Cooperation is expressed in the agreement to anonymously transfer information from the client to the developer through the suppliers. The transferred information includes characteristics of abnormal events that have actually occurred in reality and the responses of the smart home. This information can then be analyzed and used for AI learning and to improve the system's reasoning mechanisms. Collecting information from a large number of clients allows for faster learning and updating of the home intelligence system. The HI module must have an expansion capability so that it can cover an ever-increasing number of areas and events in the eHome's daily life. The cooperation mentioned above, together with the HI capabilities, will serve to support the rapid penetration of the smart home technologies to more and more households all over the world.

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Fields of resarch and interest: Information Technologies, Simulation Systems, eLearning, Medical Informatics.