THE MODELLING OF A MULTI-AGENT SYSTEM FOR A DOMOTICS PLATFORM

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Abstract: The smart house is an environment in which several systems interact autonomously performing tasks that in regular houses are done by their occupants. This work presents two aspects of the development of a smart house project. The first is a multi-agent architecture to control the house and the second is an identification system. The multi-agent architecture uses a simple agent communication infrastructure that facilitates the implementation of distributed agents in an agents' society, combining MaSE (Multi-Agent System Engineering) and UML (Unified Modelling Language). The identification system uses a pervasive footstep sensor and a neural network, which are able to identify the occupants by their gait patterns, even in the presence of variations.

Keywords: smart house, pervasive computing, footstep sensor, multi-agent systems, neural network, domotics.

1. INTRODUCTION

This work presents two aspects of the development of a smart house project. The first is a multi-agent architecture to control the house and the second is the identification system.

In the Multi-Agent System (MAS) for the smart house, the agents are grouped in a society and can communicate with each other using agents' identification and messages written in KQML (Labrou and Finin, 1997). In this project, the MAS uses the SACI tool (Simple Agent Communication Infrastructure) (Hubner and Sichman, 2003) that facilitates the implementation of the distributed agents in the agents' society. Among the available services in SACI, the projects uses the "yellow pages service", where the agents inform their abilities for a facilitator.

This work develops an identification and adaptation system for the smart house, based on a multi-agent methodology that facilitates the construction of multi-agent systems. Among several methodologies, this work combines MaSE (DeLoach, 2001; DeLoach *et al.*, 2001; Dam and Winikoff, 2003) and UML (Unified Modeling Language). This methodology has a software called AgentTool (DeLoach and Jacobs, 2001) used in the diagrams construction.

In this first proposal of the MAS for the smart house, the agents are reactive. In this paper we present a variation of the footstep sensor presented in (Rosa *et al.*, 2004). In an identification system, when a person enters a room, a footstep sensor is activated. This event starts the data acquisition by the sensor, the data collected is sent to an *id algorithm* in order to determine the person's gait pattern. Using an ART 2 (Adaptive Resonance Theory) (Carpenter and Grossberg, 1997) neural network, the id algorithm identifies a resident based on the gait pattern.

2. DESCRIPTION OF THE MAS

The smart house of this work has the following functionalities: identify occupants, adjust the temperature and luminosity of a room according to an occupant's preferences, control the energy consumption and maintains a security system.

The occupants' identification system is based on footstep data. This system is composed by a footstep sensor associated to a digital acquisition system. A neural network makes the occupants' identification in agreement with the data of the occupants' footstep. Footstep sensors are scattered on the house floor in a pervasive form. The identification system is set when a person enters or leaves a certain room. Two typical results are generated by the identification system when a person enters the room: the person is classified either as an identified or a non identified occupant.

The treatment of the non identified occupant is according to a security mode defined for the house. Three security modes are defined: red, green and yellow. For the green mode, the non identified occupant become treated as a new occupant; for the yellow mode, as a visitor; and for the red, as an intruder. The security mode is modified when an occupant, contacts the security company. The green security mode is applical for the house to recognize its occupants. The yellow mode is used in a normal situation for the house, where yet not recognized people are considered visitors. The red mode is the higher security, all the strange people in the house are considered intruders.

The temperature and luminosity preferences of the occupant are stored by the system indexed for each room, and for defined time intervals along the day. The gathering of this information is made by observation of the occupant modifications in the temperature and luminosity of each room, along the day. The temperature and luminosity preferences are not stored for the visitors and intruders.

The temperature and luminosity of a room are adjusted by the system, as an agreement of the preferences of the group of occupants that are in the room. For this, an average of the temperature and luminosity preferences values registered by the system for the occupants in the referred room is used. An occupant has higher priority then a visitor or intruder, for the adjustment of the temperature and luminosity of a room.

When there are no occupants in a room and a visitor enters the room, temperature and luminosity standard values are used to adjust the room. This visitor can modify the temperature and luminosity values, but this is not registered by the system. In the entrance of other visitors nothing is modified. In the entrance of a occupant, if he has defined the room preferences in the time interval, the room becomes adapted by the occupant's preferences, otherwise the visitor's preferences are maintained.

When the occupant leaves the room, the system verifies if there are other occupants in the room. If it is the case, the preferences of the group of occupants' that stay in the room are recomputed, for those who have defined preferences. If there remain only visitors, the temperature and luminosity standard values are used to adapt the room. Otherwise, the air-conditional and illumination systems are turned off.

When an intruder enters the room, the police or a security company are contacted, informing the intruder location. When the intruder leaves, the room location is informed to the police or security company.

In the preservation of the room comfort, the temperature and luminosity are constantly monitored so that the system is adjusted to the influences of the external environment. The system maintains a control of the energy consumption for the equipment, used to the maintenance of the temperature and luminosity.

2.1 Multi-Agent Architecture

The MAS architecture proposed for the smart house is composed by a two layer hierarchy. The superior layer is responsible for the implementation of the functionalities available for the house. This layer is denominated service. The inferior layer is responsible for the interface among the equipments available in the rooms and the services agents in the superior layer. This layer is denominated interface. The flexibility of this multi-agent architecture, allows it to be suitable not only in a smart house, but also in hospitals, schools, offices, hotels, where similar functionalities are to be implemented.

Figure 1 shows a possible implementation of the multi-agent architecture to the smart house, where a room with its interface agent and a group of agents in the services layer are shown. The room equipments that the interface agent interacts are the footstep sensor, temperature and luminosity sensors, a dimmer (device for regulating the light intensity), a thermostat (device for regulating the temperature), an illumination system (lamps) and an air conditioner (refrigeration and heating). The service agents are described bellow:

Interface Agent: this agent performs the following tasks: (a) inform the data captured by the footstep sensor and the occupant's location in the house; (b) inform the current temperature and luminosity values; (c) modify the temperature and luminosity of the room.

Neural Network Agent: this agent receives the occupants steps data, and then uses this information to identify the resident.

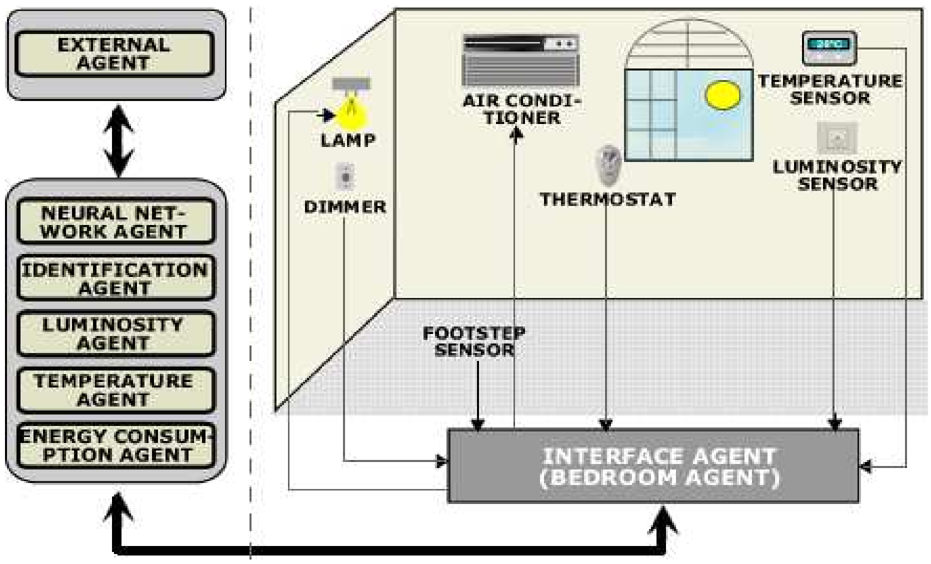

Fig. 1. Architecture MAS - Bedroom Agent.

Identification Agent: this agent performs the following tasks: (a) management of non identified occupants; (b) maintenance of the database for the identified occupants; (c) communications with the security company when an intruder enters the room; (d) solicitation of room adaptation in agreement with the preferences of its occupants.

Luminosity Agent: responsible for requests of the adjustment of the luminosity, and for information about the dimmer value to calculate the energy consumption.

Temperature Agent: responsible for requests for the adjustment of the temperature, and information of this value to compute the energy consumption.

Energy Consumption Agent: it has a function to compute the energy consumption of the rooms.

External Agent: responsible for calling the police or a security company when an intruder enters the a room, informing the intruder location for updating the security mode.

3. MODELING OF THE MAS

The use of an agent-oriented methodology is fundamental for the implementation of the system because of its degree of complexity. Therefore, the MaSE methodology, just the first phase, and the UML use case diagrams were used. The use case diagrams were used instead of doing the narrative description present in the methodology MaSE. In the first phase of the methodology it was developed the goal hierarchy, the sequences diagrams, the role model and a concurrent task model. As an exemple, two diagrams related to the control of the energy consumption for the room are shown. Figure 3 shows an use case diagram for the above description and its correspondent sequence diagram is shown in Figure 2.

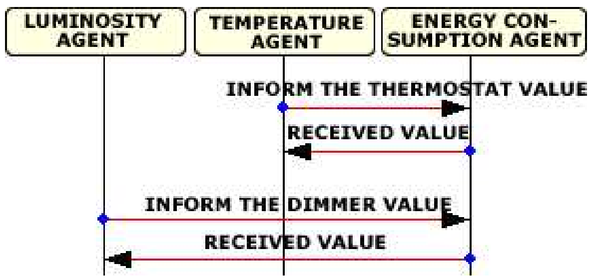

Fig. 2. Sequence Diagram - Control the Energy Consumption for the Room.

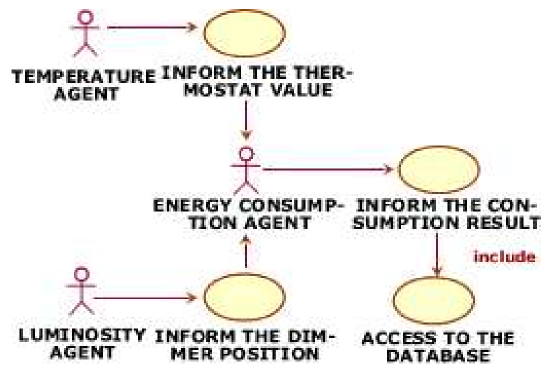

Fig. 3. Use Case Diagram - Control the Energy Consumption for the Room.

4. THE ID AGENT

All tasks accomplished by the house, described in the previous sections, are triggered after the identification of the house's residents that has just entered into a room. So, a mechanism that does it in the most natural and non-invasive way should contribute to make easier the migration from the conventional house to the smart

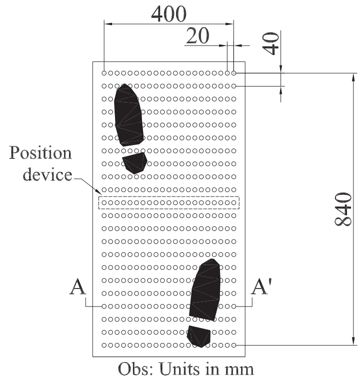

Fig. 4. Top View of the First Prototype of the Footstep Sensor.

house. To fulfill these requirements we present in this article the id agent, that is formed by the: (1) the footstep sensor; and (2) the id algorithm.

The footstep sensor presented here is a new proposal of the one in (Rosa *et al.*, 2004), that uses inexpensive materials that permit its installation all over the house, the goals of the footstep sensor are: identify the residents and track their movement. To tell the residents apart, the id agent takes into account three features that are inherent in a person's gait, these features are: f (footstep frequency), s (footstep length) and Θ (footstep opening).

4.1 The footstep sensor

Based on the points where a person stepped on the footstep sensor, the ID agent recognizes that person. This job is done thanks to a collection of *position devices* that are disposed along the sensor, this device consists of a row of coils that are connected to their left and right neighbor by a resistor, each device maps a specific y_i coordinate, and the point where the person touches will be converted into the x_i coordinate. Figure 4 shows the schematic of the first prototype built.

The top layer of the position device consists of a resistant material (in the prototype we used rubber), just below it, an aluminum strip, fed in both sides by a DC voltage source, will enable the current flow in the left and the right side of the position device through the coils, when someone steps on it. To prevent the coils from being damaged, they are installed into holes made in the shock absorber layer. Connected to the leftmost and rightmost coils of the position device there are respectively the R_e and R_d resistors, whose tension in the terminals connected to the coils are collected by an acquisition data board. Figure 5 shows all the components that had just been depicted and the configuration of the position device when someone steps on it.

Depending on the leftmost and rightmost pressure spots that a person applies on the sensor, a different value of tension will be obtained by the data acquisition board. Using the tension divisor principle, we obtain respectively:

$$V_{channel_n} = V_{Re} = \frac{R_e}{(R_1 + ... + R_k) + R_e} V_{dc} \quad (1)$$

$$V_{channel_{n+1}} = V_{Rd} = \frac{R_d}{(R_m + ... + R_n) + R_d} V_{dc} \quad (2)$$

Using resistors of the same value, *R*, 1 and 2 are reduced to:

$$V_{channel_n} = V_{Re} = \frac{R}{R(N_e+1)} V_{dc} = \frac{V_{dc}}{N_e+1} \quad (3)$$

$$V_{channel_{n+1}} = V_{Rd} = \frac{R}{R(N_d+1)} V_{dc} = \frac{V_{dc}}{N_d+1} \quad (4)$$

Where: N_e is the number of resistors between P_e and R_e and N_d is the number of resistor between P_d and R_d.

Considering that the d is the space between consecutive coils of the same section y_i and that k is the number of position devices of this section, the leftmost spot (x_{ie}) and the rightmost spot (x_{id}) are given by:

$$x_{ie} = N_e d \quad (5)$$

$$x_{id} = (k - 1 - N_d)d \quad (6)$$

Now, replacing the values of N_e and N_d on Equation 3 and Equation 4 respectively, the values of x_{ie} and x_{id} will be given by:

$$x_{ie}(V_{Re}, d, k) = (\frac{V_{dc}}{V_{Re}} - 1)d \quad (7)$$

$$x_{id}(V_{Rd}, d, k) = (k - \frac{V_{dc}}{V_{Rd}})d \quad (8)$$

In the next section, will be presented the id algorithm, which uses the information provided by the footstep sensor to identify the house's residents.

4.2 The id algorithm

The id algorithm uses the following data structure (x, y, T), where (x, y) are the coordinate points where the person stepped on the sensor and T is the time when that event happened. Based on these values, the first part of the algorithm calculate the following items: (1) the starting point of the right step; (2) the starting point of the left step; (3) the mean point of the right step; (4) the mean point of the left step; and (5) the footstep length. Figure 6 shows the points where the person stepped on the sensor and the points calculated by the id algorithm that are used to determine the gait pattern of the resident.

The data collected by the footstep sensor points presented in Figure 6 resulted in the gait pattern showed in Table 1.

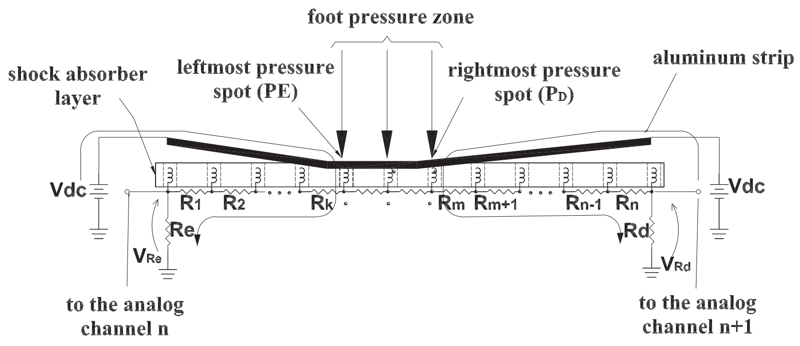

Fig. 5. View of the Position Device of the y_i Coordinate Being Stepped by a Resident.

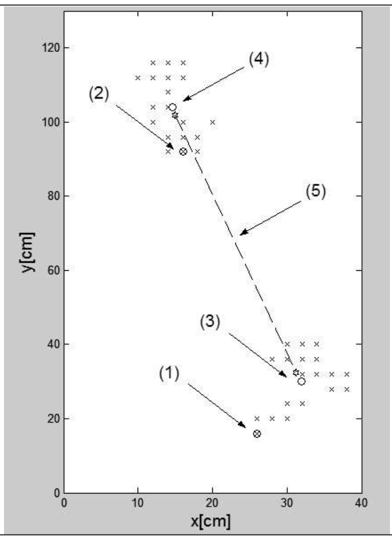

Fig. 6. View of the Position Device of the y_i Coordinate Being Stepped by a Resident.

Table 1. Gait Pattern.

Feature	*Value*
footstep length - s	$61cm$
footstep frequency - f	$1.56Hz$
footstep opening - θ	$16cm$

The final step of the algorithm is to identify the resident based on the gait pattern. We want our house to have the ability to identify its inhabitants without a previous presentation of their gait pattern to the house's id agent, and most important of all, the house id agent must be able to identify them even though they present variations on their gait pattern, as people usually do during their lives. These tasks can be accomplished by the ART 2 (adaptive resonance theory) neural network (Carpenter and Grossberg, 1997). The ART 2 was chosen because its unsupervised learning algorithm permits the addition of new inhabitants to the house in real time when new gait pattern are identified, and when a person already identified by the house presents variations on the gait pattern, the art1 neural network recognizes this pattern between those patterns stored in its memory, adapting itself to this new pattern.

The vectors presented to the ART 2 neural network are classified based on their unary vector. Then, if the

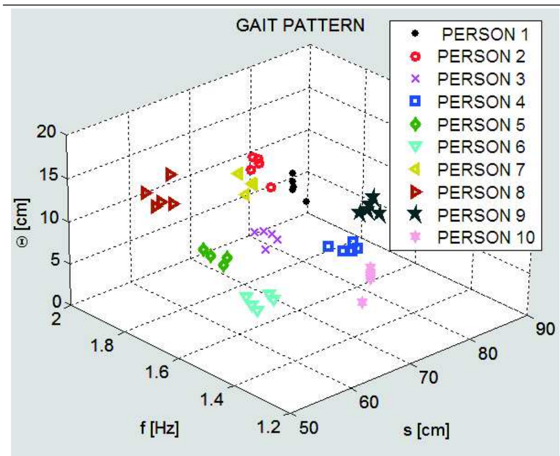

Fig. 7. Samples of Gait Pattern Collected During the Experiments With the Footstep Sensor.

angle between two vectors is smaller than a specific value, they are considered to be of the same class. But this approach leads to a problem: suppose that two gait pattern differ only by a multiplicative constant. For example, lets suppose that person 1 gait pattern is $s = 45cm$, $f = 1Hz$ and $\Theta = 10cm$; and person 2 gait pattern is $s = 90cm$, $f = 2Hz$ and $\Theta = 20cm$. As we can see, their gait pattern are very different, but using the original ART 2 algorithm, person 1 and person 2 will be classified as the same individual. To correct this problem, besides using the unary vector to classify the occupant, we also use the modulo of the gait pattern vector. With this approach, the ART 2 neural network will be able to tell person 1 and person 2 apart.

5. EXPERIMENTAL RESULTS

Using the first prototype of the footstep sensor (Figure 8), we have made twenty people walking through it (fifteen times each), in order to get their gait pattern collected. During the tests we also collect samples of people walking using different types of shoes, and the tests showed that the gait pattern keeps constant despite the type of shoes used.

In Figure 7, each group represents a set of samples of the walking patterns of several people. It can be

Fig. 8. The Footstep Sensor.

noticed, that the individuals presents very different characteristics.

Representing each gait pattern by a vector of three components $[s \;\; f \;\; \Theta]$ we used the variation of the ART 2 algorithm to classify the the individuals, achieving an accuracy of 87%. This result showed that the footstep sensor will permit the personalized action of the intelligent house and by doing improvements on the sensor construction, better results could be accomplished.

6. CONCLUSION AND FUTURE WORKS

The present project defines a modeling MAS to the smart house where the agents are purely reactive. The next step is to put cognition in some parts of the system. For example, instead of treating a group of occupants as being one, it could make an agent for each occupant in the room, that would be responsible for learning the actual occupants' preferences. The definition of the occupants' preferences could be set up by a conversation among the agents associated to each occupants.

Besides improving the footstep sensor construction, we are working on collecting a new gait feature, the sound produced by our footsteps. But collecting this feature implies having a very sensitive microphone mounted on the floor, recording all the sounds of our homes. To avoid loosing our privacy, we are analysing the frequency spectrum of different sounds that normally occur in our home, and those from our footsteps. So we will be able to project a filter that will let the microphone record only the sound which falls into the frequency produced by our footstep.

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