Smart Environment: Using a Multi-Agent System to Manage Users and Spaces Preferences Conflicts

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Abstract. People in this new technological era of Internet of Things (IoT), search for comfort and all that can simplify its quotidian life. This paper proposes a smart environment, to help achieve this purpose. The problem/challenge, which aims to overcome, can be defined in general terms as a contribute to create intelligent environments capable of adapting to the user's comfort needs/preferences, in an automatic, transparent, and non-invasive way, whether these environments are for domestic, professional, or public use. We propose the use of a multi-agent system to achieves the user's preferences management as well any preferences conflicts, that naturally exists. In this way the space smartly adapts to the present user preferences, in a transparent and noninvasive way. With this solution is also supports user's mobility, between different spaces and at different time. Making it a full ubiquitous solution, and consequently an Ambient Intelligence (AmI) solution. It has been developed a complete specification of an architecture that supports the proposed solution. The multi-agent system is fully developed, tested, and validated with the presented results.

Keywords: smart-environment, AmI, multi-agent, IoT, conflicts

1 Introduction

In a new technological development era, in which people are increasingly looking for comfort and ease, especially in carrying out their daily tasks. It is imperative that technological solutions move in this direction, and meet the resolution of people's problems and difficulties. Thus, the problem identified in this project is the difficulty in adjusting the different spaces that different users frequent throughout their daily lives [9][10].

We know the slowness, which involves the process of daily adjusting the different spaces we frequent to our preferences, from the domestic to the professional space, as well the different leisure spaces that we frequent daily from cafes, restaurants, gyms, among others. In addition to the different spaces, we also have the different preferences that each space has, and that any user likes to customize, from the temperature, brightness, luminance, sound volume, music playlist, among others.

Let us imagine users who, every time they leave their house, need to adjust the blinds, space temperature, turn off the lighting and sound, and for example turn on the alarm. In addition, doing a similar process when the user returns home. Let us now add the different users that may be part of the same home, and this is how this project problem is defined.

This problem is seen with great interest, as it will bring a significant improvement in people's lives, and is not limited to any isolated group, but to each and every human being, who as unique characteristic has their personal preferences for comfort.

In addition to being interesting, this problem is also challenging. In particular, the difficulty of identifying different users is well known, in addition to the management of their preferences, which will naturally result in conflicts, and we must also think about different concepts such as the mobility of users, their disparity in habits, among others.

Considering the Ambient Intelligence (AmI) field and this paper scope, it is possible to evidence that there are different issues to be addressed.

Thus, the following questions elucidation it is intended to approach the research problem:

- How can we characterize an environment ?
- How human comfort is defined ?
- What are the human preference's set ?
- Can we automatically detect user preference's ?
- Is it possible to solve/minimize user comfort preference´s conflicts ?
- Can human comfort be measured ?

Considering all this questions, they have been materialized and define the proposed research hypothesis as:

Smart Spaces as a transparent, non-intrusive, and safe way, to promote the satisfaction and comfort of users, according to the preferences of each individual.

The solution proposal involves an architecture definition using low cost hardware, combined with different communication technologies, thus allowing the information exchange. Along with a multi-agent solution that allows reaching the different proposed objectives.

2 Materials and Methods

2.1 Multi-Agent System

Artificial Intelligence field continues with an exponential growth rate, and multi-agent systems have been used to solve several situations, related to Ambient Intelligence (AmI).

Ambient Intelligence is an ubiquitous, electronic and intelligent environment, recognized by different technologies/systems interconnection, in order to carry out different daily tasks in a transparent and autonomous way for the user [5] [14].

Focusing on Belief-Desire-Intention cognitive model, which allows the creation of intelligent agents capable of making decisions based on beliefs and perceptions, desires and intentions that the agent may have at a given moment [4].

Jason is a framework for multi-agent system development, which has an interpreter for the *Java* developed *AgentSpeak* language, which implements the Belief-Desire-Intention model previously mentioned.

There are already different literature works that present solutions for integrating multi-agent system with Ambient Intelligence, and specifically with Smart Homes, using *Jade* [6], [3], and using *Jason* with *JaCaMo* [7], [8], [1].

Projects that use *Jason* as development language are simulated and there are no literature works on physical integration with real environments or hardware to meet ubiquitous computing.

ARGO is an architecture that facilitates ubiquitous multi agent system programming using *Jason*, independently of the field.

This work wants to introduce an autonomous Smart Home model controlled by agents using *Jason*/*ARGO*, to manage physical devices, because the developed *ARGO* agents can allow communication with several controllers like *Arduino* and *Raspberry*.

This work uses a six divisions house prototype, with lighting and heating system. To evaluate the prototype and the multi agent system, several performance tests were done, considering different parameters like the number of agents, controllers, agents speed reasoning, perception of the environment moment and information filtering, so we can explore diverse system implementation strategies [11] [12].

2.2 Assumptions

To optimize the predictions of the proposed solution, it was defined an architecture for a multi-agent system. The roles for each agent, the negotiation process to be executed, the different scenarios in which this negotiation would take place and the way to be processed were defined.

For the development of this project, the following two phases are defined:

- Local systems installation;
- Development of the Multi-agent system;

Starting, with preparation of the entire physical structure, where the local devices (*Raspberry*) with the identified network technologies, to detect the present users.

Every time an *ARGO* agent performs his reasoning cycle, the comfort preferences of each user are sent to the agent.

Next the multi-agent system must be programmed, considering the actions that must be performed to achieve the optimum comfort values for the space, then these values are sent to the actuators.

A prototype was implemented in an house, considering the multi-agent system architecture and the present comfort actuators.

For this is used a *Raspberry* at which division, namely three at the ground floor (living room/kitchen, office and bedroom), and more three on the first floor, as is detailed at section 3.

Considering the actuators, these environment have a hydraulic radiant floor heating system, and a home automation system to controls the different rooms luminosity.

We can see every detail, at a 3D model, where can be visualized the system operation, like can be seen at figure 1. It can bee seen different persons present in the space, and the local system present, the autonomous communication process between the peripherals of each user and the local system is illustrated with the arrows, and also with the central server (Cloud), which will enable to have the information for each of the agents work and to reach the values of comfort preferences to apply by in the actuators.

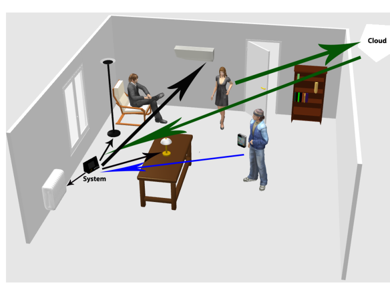

Fig. 1. System functioning in a environment.

This project proposes a model to an autonomous Smart Home, controlled through different cognitive agents, which get the information to be applied by actuators.

A six divisions house was used as prototype with different comfort features, namely temperature, luminosity, audio and video. For performance evaluation, are used the following parameters:

- Number of agents;
- Speed reasoning;
- Information filtering;
- Perception time;

Figure 2 shows the use case diagram, it can be verified the different agents functioning, namely the information received by them, and how the negotiation process is carried out, those involved in it, and how the final result of the negotiation is passed to the actuators.

At the start, the agent that representing the local system receives the information of the environment, namely the security information (maximum values of temperature, gases, and others). For each user present at the local, there will be an agent who represents him, it will receive information about the user preferences from the central system.

The negotiation result will then be used by each actuator present in the local.

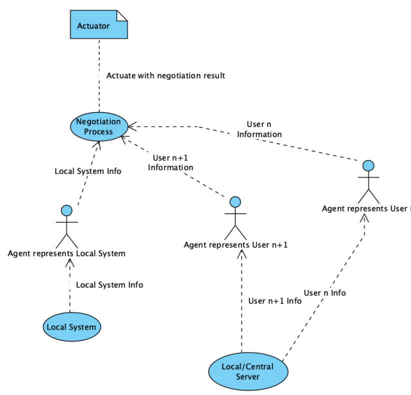

Fig. 2. Agent - Use Case diagram.

2.3 Framework Jason

Jason is a framework with its specific language to develop cognitive multi-agent system, and use the ARGO architecture, it is possible to bridge the gap between actuators, multi-agent system, and real world sensors.

The Belief-Desire-Intention consists in three basic constructions: beliefs, desires and intentions. Beliefs is seen as truths information for the agent, which can be internal, acquired through the relationship with other agents or the perceptions observed in the environment. Desires represents the agent motivation to achieve a specific objective and lastly the intentions are actions committed to perform by the agent.

Additionally to these, the Procedural Reasoning System (PCR) allows to build a real time reasoning system for performing complex tasks.

2.4 ARGO Architecture

ARGO is a custom Jason agent architecture to allow the programming of ubiquitous agents using several prototyping platforms.

ARGO allows the cognitive agents and a real environment (controllers) intermediation, through the *Javino* middle-ware, which communicates with different hardware (sensors/actuators). Additionally, it use the Belief-Desire-Intention on robotic platforms to generate bottlenecks in perceptions processing and also unwanted execution delays [13].

At figure 3 the complete multi-agent system architecture specification is show, the different modules are separated, to easily identify the purpose of each one, the agents containing it and its purpose are also detailed. Following at subsection 2.5 the multi-agent system schema is described.

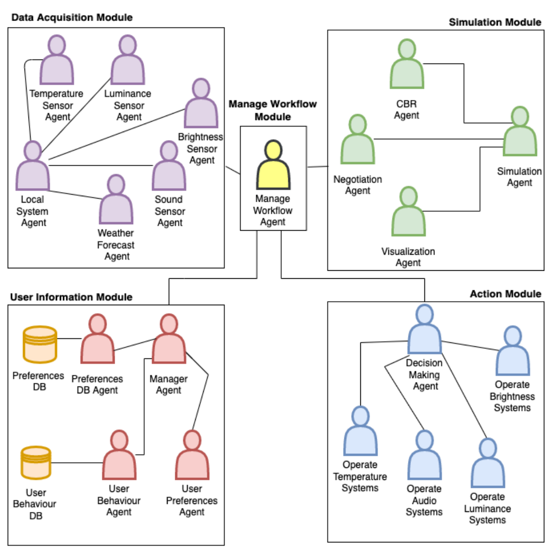

Fig. 3. Architecture of the Multi Agent system.

Next, the multi-agent system modules are fully described:

- **Data acquisition module**, includes three agents types: the sensor agents will import necessary information from the sensors (temperature, luminance, brightness, sound) for the agents operation; the weather forecast agent gets

information from a external Application Programming Interface (API); the local system agent has all the system information for each local, and obtains the present users at each period (30 minutes).
- **User information module**, this module includes an agent who will represent each user and his preferences to be used in the negotiation process.
- **Local System module**, each agent will represent a local system, which contains the location needed information, both the referred to user preferences, or local/users security (maximum/minimum temperature, CO2 safety values, and others).
- **Simulation module**, here will be the negotiation between different agents, namely users conflicts management and local systems. After the end of this process, it will be obtained the result values to apply at the environment.
- **Action module**, after the execution of the simulation process, the values to apply are obtained. These are used and sent to actuators that will use them in the different systems and actuators present.

One principal agent will represent local system, namely each specific environment, where is needed to ensure individualized comfort conditions, such as a room at an house, or a office at an building. This agent will use any existing directives for this environment, like lower/upper limits to different comfort conditions, or critical safety parameters for a given space. This agent will have a prevalence to others, because it will be the dominant for a specific environment.

Regarding the users, each one will be represented by an agent, this will receive user preferences from the local system, for the place where it is, and for the time in which it is. In this case there will be a prioritization to identify the environment supremacy user, according to the defined hierarchies, in this way increasing the negotiation process.

At the decision process, all users agents and environment agents are considered. With the different priorities for each one of them, and with this information the negotiation process begins.

2.5 Schema

Using *JADE* [2] it was been developed the multi-agent system that supports the system, and five different agent roles had been implemented:

- **Environment Agent**: Give the information of the environment status. A new agent is created for each new environment introduced into the system;
- **Sensor Agent(s)**: Have the task of retrieving the different environment conditions information, namely the temperature, brightness, or others depending of the implemented sensors at the environment;
- **Preference Agent**: Manage the preferences card, defined by each user at his personal device;
- **User Agent(s)**: Takes care of the negotiation process detailed at 2.6, in this case each user agent is associated with a single user that is at the environment;

– **Negotiation manager Agent**: Created at each environment, to do the negotiation management process between the different User Agents.

At figure 4, is the developed schema summary, where are included the five agent roles type.

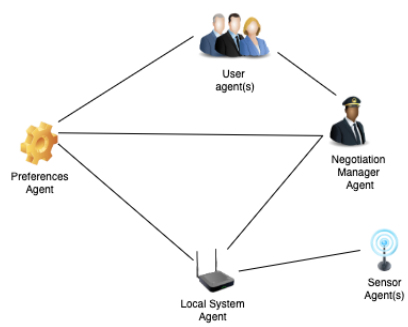

Fig. 4. Schema of the Multi-agent system.

2.6 Conflicts Management

At figure 3 the different architecture modules are represented, the local system agent that receives its information, namely the different security information (restriction values of temperature, gases, and others). And for each user present at the local, one agent will represent him, this agent will receive information about its preferences from the central system, this information will be used during the negotiation process.

At the end, the negotiation result will be passed to the different actuators that are present at each local.

For the conflict resolution we use the preferences hierarchy rules.

For the correct system functioning and to bring it as close as possible to reality. And knowing that in different environments, there are naturally different hierarchies, which have a different control level over the environment.

Thus, the hierarchies were defined, according to the tables 1, 2 and 3, for the different environments. These tables are just an example and were defined based on different principles that naturally exist, such as the differentiation between adults and children in home space. The existence of leadership at different levels and employees is based on the concept of work space. And the concept of the space owner and visitors in the different public spaces.

Of course, this kind of hierarchies can be customized on each local system, by its owner. Because naturally each space and its users have different specificities, which must be accommodated/guaranteed by this type of systems.

Regarding the family contexts, it was considered to maximize the parents elements preference value instead of the children, in a proportion of 1 to 0.75.

Other hierarchy if exists is the space preference value, it was used here a ratio of 1.5. These situations may occur in spaces with some conditioning, like kitchen's/wc's, or other with type of conditioning. All the described ratios are used for the rules, and can be seen in detail at Table 1.

In the professional context, ratio values are in the same way defined in a hierarchical way, and in this case the professional hierarchy will be used, and if exists also the space preference value. The ratios described can be seen in detail at Table 2.

Considering the public/social spaces, the value that will be predominant will be the space value, always customized by the owner of the space, with a ratio of 2. Each user will have a 0.15 ratio, considering that in these spaces is common that exist little variations, because the high people movement. The ratios described can be seen in detail at Table 3. To achieve the preference value to apply, to the different spaces it was used the following equation:

$$prefV = \frac{\sum_{user=1}^{n} \{uP * uHyP\} + (sPref * sProp)}{\sum_{user=1}^{n} \{uHyP\} + sProp} \tag{1}$$

At Equation 1, is detailed the parameters for calculate the preference value to be applied by the space actuators. Here, we have:

- n - number of users present at the space;
- uP - each user preference at the space;
- uHyP - each user hierarchy proportion;
- sPref - space preference;
- sProp - space proportion;

Table 1. Home space - User's type/ratios.

Type	Ratio
Adult	1
Child	0,75
Visitor	1
Space	1,5

As detailed before, for each system we have different constraints. At figure 5 a table constraints example is detailed, used for each agent that enters in the negotiation.

To be more concrete, at table 4 we see a example of temperature preference's for three users and a home space, and also each user type. With this information

Table 2. Work space - User's type/ratios.

Type	Ratio
Hier_1	(100-1)
Hier_2	(100-2)
Hier_n	(100-n)
Space	150

Table 3. Public/Social space - User's type/ratios.

Type	Ratio
User_1	0,15
User_2	0,15
User_n	0,15
Space	2

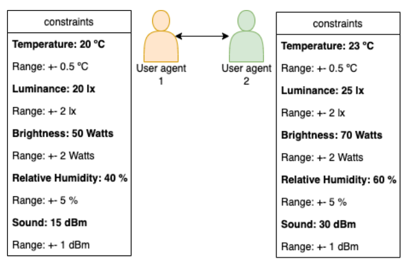

Fig. 5. Two agents constraints table.

at equation 2 we calculate the temperature preference value that will be applied at that specific home space when these three users are present.

Table 4. Example of preference value calculation - Home space.

Preference	**User A** (Adult)	**User B** (Adult)	**User C** (Child)	**Home Space**
Temperature	20	23	22	19

$$prefV = \frac{20 * 1 + 23 * 1 + 22 * 0.75 + (19 * 1.5)}{1 + 1 + 0.75 + 1.5} = 20.71 \tag{2}$$

Also in the same way, at table 5 we see a example of temperature preference's for three users and a work space, and also each user type. With this information at equation 3 we calculate the temperature preference value that will be applied at that specific work space when these three users are present.

Table 5. Example of preference value calculation - Work space.

Preference	**User A** (Hier_1)	**User B** (Hier_2)	**User C** (Hier_2)	**Work Space**
Temperature	23	21	22	18

$$prefV = \frac{23 * 99 + 21 * 98 + 22 * 98 + (18 * 150)}{99 + 98 + 98 + 150} = 20.65 \quad (3)$$

3 Characterization/Period analyzed in different smart space scenarios

For the proposed framework analysis and evaluation, different scenarios were formulated. Initially it was applied in a two floors house. In this way, it was possible to validate the domestic space concept, with a family composed of two adult users and a child, characterized in subsection 3.1. Their individual preferences were defined, and the multi-agent system system analysis was carried out during a six months period.

The workspace concept was also defined, with different local systems being installed in the partner company's offices, and also detailed in subsection 3.2.

In section 5 the two defined scenarios results, are detailed, and explained for each of the aspects analyzed.

3.1 Home Scenario

Table 6 characterizes the different users that compose the home scenario, where the username, user type and proportion used in the equation 1 are defined.

Table 6. Home Scenario - Users characterization.

Username	**Type**	**Proportion**
User1	Adult	1
User2	Adult	1
User3	Child	0,75

The entry records (samples) considered for analysis are 15420 log records for the six months in question. Each of these samples represents one user entrance/presence, recorded by the local system. We can see a average samples registered of 84,45 for each day.

3.2 Work Scenario

The three local systems (*Raspberry's*) used are putted in the company's, one at each one of the offices.

Table 7 characterizes the different users that compose the work scenario, where the username, user type and proportion used in the equation 1 are defined.

Table 7. Work Scenario - Users characterization.

Username	**Type**	**Proportion**
User10	Hier_1	(100-1)
User20	Hier_2	(100-2)
User30	Hier_2	(100-2)
User40	Hier_2	(100-2)
User50	Hier_2	(100-2)
User60	Hier_3	(100-3)

The entry records (samples) considered for analysis are 36578 log records for the six months in question. Each of these samples represents one user entrance/presence, recorded by the local system. We can see a samples average registered of 200,98 for each day.

4 Evaluation methodology

To measure satisfaction, using the comfort preferences applied by specific local system, different criteria is defined and presented at table 8. So we can identify when the applied conditions by the results of the multi-agent system, suit the different users that are on the space. Considering the inertia of the different actuators, like is mentioned above, the calculation of the preferences that will be applied in a given moment, will always be carried out using 30 minutes periods.

At table 8, are defined the values of percentage that are used to calculate the satisfaction, in the case of a manual adjustment (higher/lower) of one change rate, the value of 100% of satisfaction will be discounted by the percentage value defined for each preference. To achieve this value, was used the equation 4, considering each one of the system preferences, with this the table 8 was filled with each preference value.

$$Insatisfaction = \frac{mProp * (nClicks * cRange)}{(maxV - minV)} \tag{4}$$

To calculate each insatisfaction percentage that was discounted from the user satisfaction at each preference, we use the equation 4. This equation, is following detailed:

– mProp - metric Proportion (Value: 200);
– nClicks - number of manual adjustment clicks;
– cRange - change range;
– maxV - maximum preference value;
– minV - minimum preference value.

Considering the metric proportion we use 200, for other values, we use the correspondent preference value detailed at table 8. And the insatisfaction (%), is in this way achieved for each one of the preferences.

The insatisfaction degree calculated at table 8, represents the insatisfaction percentage value for each preference when only one manual adjustment click occurs.

Table 8. Satisfaction metrics.

Preference	**Min. value** (minV)	**Max. value** (maxV)	**Change range** (cRange)	**Insatisf. degree** (%)
Temperature	15	28	+- 0.5	7,69%
Luminance	0	40	+- 2	10%
Brightness	0	100	+- 2	4%
Relat. Humidity	20	80	+- 5	16.66%
Sound	0	30	+- 1	6,66%

With this information, next is presented two examples of insatisfaction calculation. Thus, we can verify with a simple example, for the temperature preference, in which the unsatisfied user makes a decrement change of 2ºC (4*0.5), that is, he will perform four manual adjustment clicks on the thermostat, each of the clicks will decrement 0.5 ºC. In this case, the insatisfaction equation would have the parameters identified in the equation 5, resulting in a total insatisfaction percentage of 30.77% for this example period.

So the insatisfaction, for this period will be 69.23% (100% - 30.77%).

$$Insatisfaction = \frac{200 * (4 * 0.5)}{(28 - 15)} = 30.77\% \tag{5}$$

In the same way, for the relative humidity preference, we can verify with a simple example, in which the unsatisfied user makes a decrement change of 10% (2*5), that is, he will perform two manual adjustment clicks on the thermostat, each of the clicks will decrement 5%. In this case, the insatisfaction equation would have the parameters identified in the equation 6, resulting in a total insatisfaction percentage of 33.33% for this example period.

So the insatisfaction, for this period will be 66.67% (100% - 30.33%).

$$Insatisfaction = \frac{200 * (2 * 5)}{(80 - 20)} = 33.33\% \tag{6}$$

5 Results analysis

To assess the results, the scenarios identified in section 3 were defined, and implemented. Thus, a six-month period was defined for the identified scenarios analysis, as well the users present. To verify satisfaction, equation 4 was used, and thus, the average satisfaction was calculated, for the total number of users and time period.

For the spaces characterized in section 3, information was then collected over a six months period. Thus, it was possible to carry out all the statistical analysis, in order to execute the results compilation presented below at section 5.1 and 5.2 and at tables 9 and 11.

5.1 Home Scenario

All manual changes done during the testing phase were exhaustively analyzed, and the satisfaction metric was in this case calculated, by period of time and place.

To assess the results, the scenarios identified in section 3 were defined. Also, the period definition for analyzing the identified scenarios was six months, as well the users present. To verify satisfaction, the equation 4 was used, and thus, the average satisfaction was reached, for the total number of users and time period, the results are shown at table 9. At figure 6 we can see the plot of this information.

Table 9. Home Scenario - Global Average Satisfaction - 6 Months.

Time period	**Global Average**
Nr. of Days	182
Nr. of Periods	1941,33
Avg. Insatisfaction	4,88%
Avg. Satisfaction	95,12%

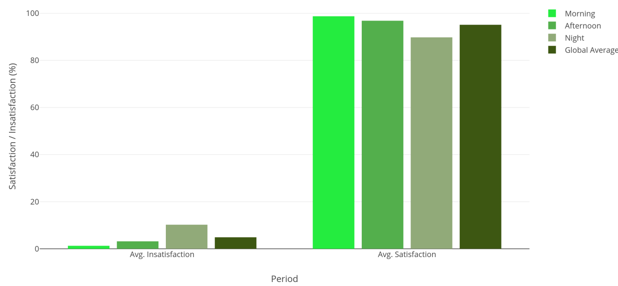

Fig. 6. Home Scenario - Global Average Satisfaction - 6 Months.

To summarize, and have a greater detail, one day was randomly selected from the period under study, and in table 10, global average for satisfaction and insatisfaction is presented.

Table 10. Home Scenario - Global Average Satisfaction - One Day.

Time period	**Global Average**
Nr. of Periods	10,67
Avg. Insatisfaction	13,33%
Avg. Satisfaction	86,67%

5.2 Work Scenario

To assess the results, the scenarios identified in section 3 were defined. Also, the period definition for analyzing the identified scenarios was six months, as well the users present. To verify satisfaction, the equation 4 was used, and thus, the average satisfaction was reached, for the total number of users and time period, the results are shown at table 11. At figure 7 we can see the plot of this information.

To summarize, and have a greater detail, one day was randomly selected from the period under study, and in table 12, average for satisfaction and insatisfaction for each one of the two periods (morning and afternoon) is presented.

Table 11. Work Scenario - Global Average Satisfaction - 6 Months.

Time period	**Morning** (8am-1pm)	**Afternoon** (1pm-7pm)	**Global Average**
Nr. of Days	182	182	182
Nr. of Periods	1820	2184	2002
Avg. Insatisfaction	5,93%	17,72%	11,83%
Avg. Satisfaction	94,07%	82,28%	88,17%

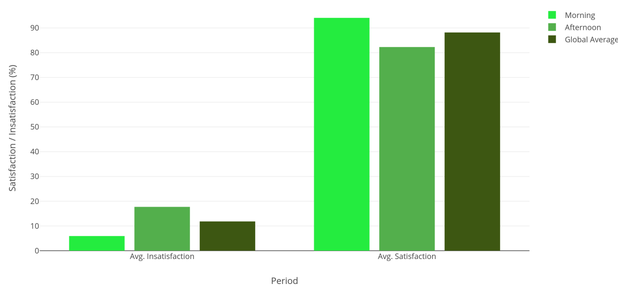

Fig. 7. Work Scenario - Global Average Satisfaction - 6 Months.

Table 12. Work Scenario - Global Average Satisfaction - One Day.

Time period	**Morning** (8am-1pm)	**Afternoon** (1pm-7pm)	**Global Average**
Nr. of Periods	10	12	11
Avg. Insatisfaction	20%	8,33%	14,17%
Avg. Satisfaction	80%	91,67%	85,83%

5.3 Discussion

Thus, as can be seen in the presented results, that are been analyzed considering the satisfaction metrics presented in table 8. It can be concluded that for both case scenarios a high degree of satisfaction was achieved, in the order of 95.12% for the home environment, and 88.17% for the work environment.

As previously mentioned, the results presented are preliminary and subject to industrial secrecy by the partner company. Therefore, all possible information is presented, considering the company's intention to patent the product developed, there are thus several restrictions on more data availability.

6 Conclusions

From this work was result, the complete architecture specification to supports the solution proposed, and to solve the presented problem. The full development of the multi-agent system was achieved, tested and validated with the presented results.

Also, the constraints specification for each one of the proposed preferences was done. And with that, the users and actuators safety was also achieved.

Using a multi-agent system containing BDI agents, created using Jason and ARGO, the development of an architecture and respective cognitive model for a Smart Home was completely done.

As main objective this project wants to verify if it is possible using low cost (~40€) hardware, like Raspberry's, the development of ubiquitous multi-agent system and this kind of architectures.

Considering the future work, more test scenarios will be tested and developed, and with these future results, this project will be improved to support other works in this field.

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