Applying Multi-Agent Systems in Prototyping: Programming Agents For Controlling a Smart Bathroom Model With Hardware Limitations

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Abstract— This paper presents a prototype using a Multi-Agent System (MAS) to manage a Smart Bathroom that has hardware limitations since it is used just one microcontroller to control all functions of the environment. In the project, the microcontroller responsible for hosting all sensors and actuators (buttons, presence sensor, valves, buzzer, pumps and others) is the ATMEGA328. For the MAS development, it was employed the Jason Framework and a customized kind of agent named ARGO, that made possible the interaction of the MAS with the prototype's sensors and actuators by controlling the microcontroller. Moreover, the prototype has certain available functions such as shower, discharge, and sink, representing water resources, and it uses payable and renewable energy resource for electric consumption. In addition, there is an emergency system to accompany the user who is inside the bathroom, aiming for his or her safety. Some performance tests were run to explore the use of embedded robotic agents with Jason and ARGO in a situation where exists a limited hardware infrastructure. The results show that using a particular strategy for programming the MAS allows the use of BDI agents in embedded systems even when there are hardware limitations.

Index Terms—Multi-Agent System, Ubiquitous Systems, Ambient Intelligence.

1 Introduction

An Ambient Intelligence (AmI) system is an environment which uses autonomous technologies, as Multi-Agent Systems (MAS), to make possible the presence of smart devices imperceptibly by people [1]. In turn, ubiquitous systems are autonomous computer programs able to interact with humans invisibly. The MAS is suitable for ubiquitous systems, because of some characteristics of agents such as having its tasks, the capability of interacting with each other, and reasoning according to perceptions, beliefs, and those agent's interactions, in favor of a common objective [2]. Many authors suggest that the MAS approach can be considered in the development of AmI applications and ubiquitous systems [3].

Jason [4] is a framework that allows the development of MAS based on the Belief Desire Intention (BDI) [5] architecture, using an AgentSpeak [6] interpreter in Java where agents can be situated in an environment, usually simulated. ARGO [7] is a customized architecture of Jason agents that provides communication with low-cost controllers, actuators, and sensors allowing to interact with the real world. ARGO is an attempt to provide an uncoupled architecture where the high-level language is programmed without being coupled to the hardware to facilitate the development and prototyping of ubiquitous MAS and AmI using Jason. One of ARGO's differential is to generalize and facilitate the construction of MAS regardless of the hardware assembled, and it is possible to use low-cost controllers, such as PIC and Arduino. Besides, praises the fact that ARGO agents can be implemented independently Of the project domain [8].

Some works use MAS mostly applied in simulated environments [9] [10]. Thereby when applying these MAS in the real world, there are no guarantees of their effectiveness since the real world is a dynamic environment which generates constant perceptual information that can compromise the MAS performance. There are some works about MAS applied in a real environment [11] [12] [13] [14], however, these works present an architecture that was structured only for a particular domain or it is not reusable. A smart home model uses ARGO agents [15] with the objective of applying and testing the performance of a MAS taking into account variables such as the number of controllers and agents in the same project, the perceptions speed, and filtering capability. It uses a prototype of a six-room home that has a set of sensors and actuators for the doors, to establish the best strategies for the implementation of such kind of system. However, when there are a few limited controllers, the response time of the MAS decreases, and it may affect the performance of the system.

The objective of this paper is to employ the agent approach in a physical and intelligent bathroom assembled with a single controller responsible for managing hydric and

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electrical resources aiming for economy and sustainability of a home model. We constructed it as a prototype composed of sensors and actuators that one or more agents can use to interact with the real world. Similarly to the Smart Home Model mentioned before, we employ Jason and ARGO for programming the MAS, where intelligent agents could control all the resources based on their beliefs and decide the actions to be taken in a near real-time situation. Besides, we also present an emergency verification process. It starts with the bathroom empty, and if somebody decided to enter, he or she is able of interacting with the devices (for example shower, sink, and discharge) pervasively. Once inside, if the person is not feeling well and the presence sensor does not capture movements, a sound would be emitted as an alert. If there is no presence after some seconds, another sound would be emitted continuously, and the door would be opened for someone to help. The prototype constructed is physically connected to only one microcontroller to explore the situation where multiple functions need to be handled by a MAS, but the hardware is limited (this situation can lead to undesirable delays).

The contributions of this work are: to provide a Smart Home Model's Bathroom applied and tested in a physical prototype; explore the use of ARGO agents for prototyping ubiquitous Multi-Agent System (uMAS); and an analysis of some strategies for programming agents which interact and control hardware devices. This work is structured as follows, in section 2 some background of MAS development can be seen; section 3 presents the uMAS approach for a bathroom in a smart home; section 4 presents the prototype of the smart bathroom; some related works are discussed in section 5, and finally, conclusion and future works are shown.

2 Ubiquitous Multi-Agent Systems

In this section, will be presented the technological background that allowed to create a uMAS applied in a smart bathroom model. The Jason framework allows creating a MAS, whereas, the ARGO customized architecture allows a MAS programmed in Jason to perceive and realize actions in the real world using controllers.

2.0.1 Jason Framework

The Jason Framework is a Java-based interpreter of AgentSpeak(L), a programming language which provides the creation of cognitive agents based on the Belief-Desire-Intention (BDI) architecture and the Procedural Reasoning System (PRS). The BDI allows creating cognitive agents based on three concepts: Beliefs, that are information acquired by others agents of the SMA, by environment's perceptions and mental notes; Desires, that are the interest and motivation to achieve a goal; and Intentions, that are deliberated actions. Furthermore, the Jason agent has a reasoning system, based on the PRS, which is a mechanism to perform the decision-making according to beliefs and perceptions. The PRS allows the agents to reason to accomplish complex tasks immersed in a dynamic environment with several agents.

Every Jason agent has a reasoning cycle, which is initialized by perceiving the environment or by another agent's messages received, and across a succession of internal events, the result is actions to be taken or messages sent. However, the Jason agent can only perceive the simulated environment and, depending on the number of perceptions processed, it can generate delays on the reasoning cycle. For this purpose, there is a customized architecture of agents that can perform a communication with the real world through the use of devices and can also filter unnecessary perceptions.

2.0.2 ARGO Agents

The ARGO is a customized architecture of Jason agents, which enables the communication between agents and controllers. The architecture uses a communication protocol named Javino for interacting with devices and can use perception filters (to improve its performance when reasoning with information from sensors). The ARGO allows creating a MAS with a heterogeneous and generic approach. Heterogeneous when considering the hardware (microcontrollers) that could be employed. For example, the microcontroller used in this work (Arduino) could be replaced for PIC; and generic when considering the applied domain. So, ARGO provides the creation of prototypes in different domains such as vehicles, robotics, and smart homes and rooms.

Javino [16] is a middleware that allows the communication between high-level languages and controllers that have a serial connection (ATMEGA in Arduino, for example). This middleware has an error identification structure that prevents loss of data in messages sent at runtime. Moreover, Javino is prepared to deal with the sending and reception of messages equally from Java to the controller, and from the controller to Java. The perception filter [17] is a mechanism that makes the agent block environment perceptions based on filters designed by the developer at design time. These perception filters (used as XML files) are named according to the name of the agent who uses the filter. Besides, the filters can be changed at runtime by the agent who owns the file.

There are two kinds of agents, the standard agent of Jason and the customized ARGO agent. The standard agent autonomously makes decisions in simulated environments. In turn, the ARGO agent has the same abilities of a standard agent, but it has the function of communicating with hardware devices (controllers). ARGO agents are programmed using 5 internal actions: *.port()*, it selects the port that the agent will access at runtime to get perceptions; *.percepts()*, which is responsible for allowing to get perceptions if the parameter is open, or not if the parameter is blocked; *.limit()*, which delimits (passing the milliseconds per parameter) the interval of time that an agent will perceive from the environment; *.act()*, which sends a message, per parameter, from the agent to the controller; and *.filter()*, which invokes the XML file of a perception filter by passing its name by parameter.

3 The MAS Approach in Home Systems

In this section, it is presented the model of our proposed intelligent bathroom. It is part of a smart home model [15] responsible of controlling its rooms using one controller to each room and the customized architecture ARGO to

percept and actuates in these environments. In turn, our objective is to employ a single controller in the Smart Home Model's Bathroom, and we aim to use ARGO agents for controlling a prototype and for saving and reusing hydric and electrical resources autonomously, showing how people can manage resources applying MAS using the bathroom. The save of resources can happen when the water used in the shower and the bathroom sink is placed on a particular box of water instead of being wasted; the rainwater is captured and placed in the second box of water; and when the solar boards capture the energy and charge some rechargeable batteries. The reuse of these resources happens when the sanitary discharge uses the water of the first or the second box of reused water mentioned before; when the shower and the bathroom sink use the rainwater in the second box mentioned; or when the electrical energy used is the energy present in the batteries.

Moreover, the proposed intelligent bathroom can also manage the security of the user inside the bathroom. In the bathroom, the person only can get in if it is empty or if someone is not feeling well inside the bathroom. A sound is emitted to report that something is wrong with the person which occupy the bathroom. Another issue is that the bathroom's door has an automatic operation in the idealized bathroom.

To indicate when someone is not feeling well, is necessary first to understand the logical status of the bathroom. There are six status mode: *free*, *busy*, *attention*, *wait*, *alert*, and *in help*, which constantly change (according to the perceptions of the presence sensor, door's actions, and previous status). It begins with the *free* status, which means that nobody is inside the bathroom and anyone can enter. The *wait* status happens all the times that the door's button is pressed and the person has not entered yet. The *busy* status imply that someone is inside the bathroom and this person is feeling well. When the previous status is busy, and the sensor captures no presence, the status changes immediately to attention and remains in this mode, during a certain time. While the sensor continues to identify no movements, internal sound notices are sent while the*attention* status remains the same. But, passing a certain time in the *attention* status without capturing no movements, it changes its status to *alert* (at this moment the buzzer is turned on in an external sound notice, meaning that something is not right with the person who is inside the bathroom). Finally, the *in help* status happens when someone is not feeling well inside the bathroom, and another person enters into it. It is important to remember that if, at a certain moment that the status is *attention* or *alert*, the presence sensor came back to perceive someone, the status changes to *busy*. This process can be seen in Figure 1.

4 The Prototype

In order to test the MAS approach, we developed a prototype of a smart bathroom assembled with sensors and actuators. In this section, it is explained the physical structure of this prototype, which counts with a wood structure that looks like a reduced real bathroom composed of: three boxes of water (one with rainwater and other with water bought, located on top of the part which the user access, and the last one with water already used in the shower and in the bathroom sink, below the structure); a miniature of a shower; the sanitary discharge with the bathroom sink; valves to control the water flow; electrical wires; one power supply; hoses; buttons (to turn on or turn off the shower, the sanitary discharge, the bathroom sink, the door, and the use of clean energy); three water pumps; sensors (a presence sensor and a level sensor built with a potentiometer and a styrofoam ball); buzzer; two solar boards; rechargeable batteries and; a circuit employed with an ATMEGA328 controller. The prototype can be seen in Figure 2.

An important issue to remark is the difference in the operation of the idealized door and the prototype's door: the idealized door works automatically when someone appears in front of it, and the door of the prototype works with an answer of a button pressing. The controller, mentioned before, is dedicated to one ARGO agent named *Manager*, which is responsible for capturing the perceptions from sensors and acting upon the real environment based on messages received from nine standard agents.

In this MAS, standard agents work together with ARGO agents and they are responsible for making decisions based on their beliefs, perceptions, and messages exchanged between agents. Only ARGO agents are responsible for capturing perceptions and sending them to all standard agents, and to receive messages with actions to be executed by the actuators. The standard agents are: *door*, *shower*, *discharge*, *sink*, *light*, *status*, *reservoir*, *energy* and *pump*, that, intuitively, are responsible for managing each component and the status of the bathroom, where *reservoir* and *pump* are, respectively, responsible for defining the use of adequate reservoir and to maintain perceptions of the level of the rainwater box.

The interaction among agents and between them and the environment can be seen in the Figure 3. Only the *manager* is capable of communicating with the real world (represented by the Bathroom illustration) and with all the other standard agents, and where the standard agents *light*, *status*, and *door*, can communicate not only with *manager* but also with another agent.

So, the intelligent agents, are responsible for the security and decision-making related to the economy of the bathroom resources. For this, the security and supervision actions work with a logical status mode as mentioned before. The *status* agent assumes it according to the perceptions of the presence sensor, door's action, and the previous status. With the bathroom initially empty, a user can press the button to open the door. In this case, the agent *door* opens it and the user can get in. Once inside the bathroom, if the agent *light* perceives somebody inside, the light turns on and the logical status changes from *free* to *wait*, and after a few seconds to *busy* (at this moment, if another user tries to enter, the agent *door* does not open the door). Therefore, an example of the security action happens when the status change to *attention* if the presence sensor does not identify the presence of a person inside the bathroom and after that changes to *in alert*. At this moment, the buzzer is turned on by the agent *status* [1].

1. The video of this example running can be seen at https://youtu.be/h-xC9pk2ri4

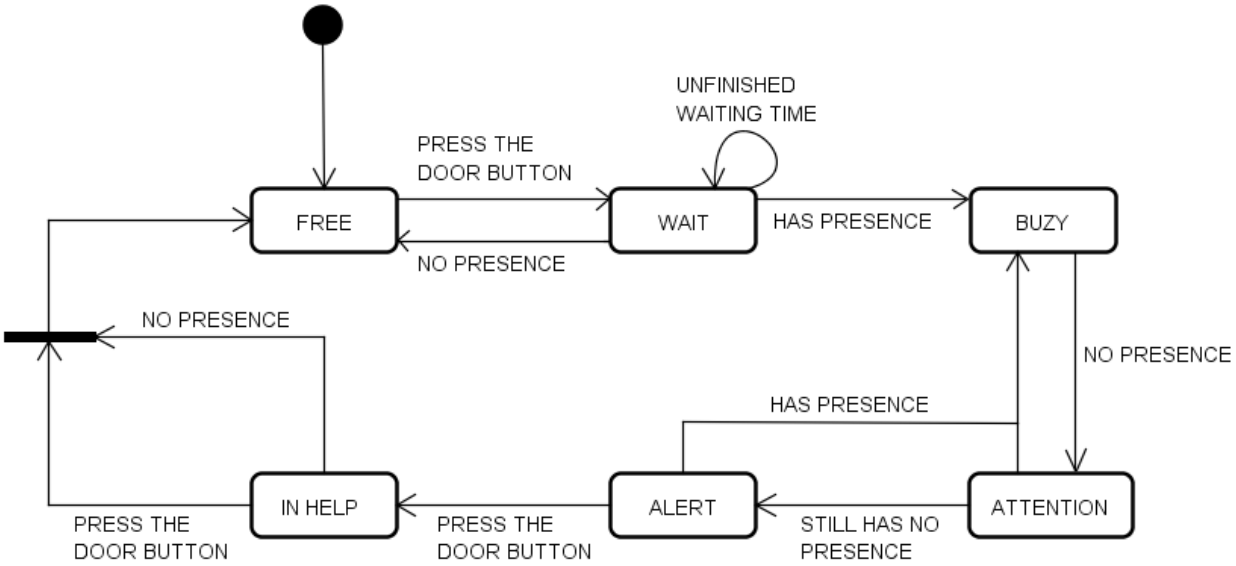

Figure 1. The logical status of the bathroom for an emergency situation.

Before continuing with the case, it is important to reinforce two things: every time that the door is open or closed, an intermediate status *wait* happens until the door is opened or closed and; that every time that is mentioned that the door is opened with the presence of someone in front of it. It means that the door button was pressed to simulate the attempt of opening the door (with the presence of someone in front of it, in this case). Therefore, when the status is *in alert*, the buzzer is turned on by the agent *status*, and anyone that appear in front of the door can make it open automatically.

Moreover, the prototype has a particular problem that is to have just one controller. This problem can cause delay by the number of requisitions done for several standard agents to just one ARGO agent and, consequently, the loss of pervasiveness expected of an AmI system. Because of this, it was necessary to perform tests to check which strategy was appropriated to use in these cases.

Besides, when the water pump and the valves, necessary to supply the components that use water are turned on, the comparisons of levels are made (with the level sensor) by agent *reservoir*. The box of water related with the water bought from some distributor is the last one to be used (being used only if the others do not have enough water for use). It is important to remember that even the shower and the bathroom sink (agents *shower* and *sink* respectively) can only receive water from the two boxes of water located on top of the prototype.

But the *discharge* agent, checks the box located below the prototype, and then, if this box is without enough water for use, it uses one of the boxes located on top. Besides, the economy of electricity happens putting the energy absorbed from the solar boards in rechargeable batteries; when it is necessary to use the electricity, a comparison circuit checks (done by agent *energy*) and if there is enough energy in the batteries and, whenever possible, it uses this one first.

Once inside the bathroom, if the person turns the shower on, at this moment, the agent *shower* checks if there is water enough in the rainwater box. If yes, the water pump related to the rainwater box and the valve related to the shower are turned on; if no, the water pump related to the bought water box and the valve related to the shower are turned on. The person can decide to use the bathroom sink too, for example. The difference between them is only the button and the agent responsible for the functioning (agent *sink*), the subsequent processes are the same as was explained before.

To use the sanitary discharge, the user presses the button but, in this time, the agent *sanitary* checks first if there is enough water in the box located below the bathroom; if yes, the water pump related to this box and the valve related to the sanitary discharge are turned on; if no, this same agent checks if there is enough water in the rainwater box; if yes, the water pump related to the rainwater box and the valve related to the sanitary discharge are turned on; if no, the water pump related to the box of bought water and the valve related to the sanitary discharge are turned on [2].

4.1 Results

We conducted some tests considering the response time of agents in each interaction with the prototype (for example, buttons and sensors). In the first test, each standard agent works along with the ARGO agent. The response time was measured considering from one to eight agents plus

2. The video of the basic functions running can be seen at https://youtu.be/cqi9QGvMvuA

Figure 2. The Smart Bathroom Prototype.

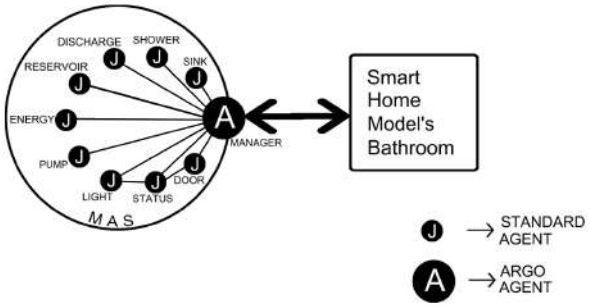

Figure 3. Interaction among agents.

the ARGO agent in every test, and we performed three repetitions for each case. To verify if exist variations in the measures, we adopted the average and the standard deviation. In this test, the emergency process (*status* agent) were excluded. In general, the results showed, that as the number of agents increases, the response time increases as well.

It can happen because of the use of several simple agents asking for perceptions and actions from the same ARGO agent and because the prototype uses only one ATMEGA328. The ARGO agent has a stack of requisitions to answer that increases depending on the number of agents in the MAS that can generate delays in the execution time. It is important to remark that the best approach is to use one controller for a few functions of the prototype managed by an ARGO agent. In this paper, we focus on testing the performance of the MAS when the number of controllers is limited (one controller in this case to several ARGO agents). Figure 4 shows some of the results considering the number of agents and the response time (in seconds).

We also performed throughput tests considering the number of requests for perceptions per second that were done by agents (without limiting the interval between these requests). We also verified the number of perceptions that were discarded by the agent. As results, it was verified that, in average, the agent in these tests shows a throughput five requests per second, where 100% of them arrived without being discarded by Javino. However, since eight simple agents are trying to communicate with the ARGO agent, the perceptions are not always updated in each reasoning cycle (since the agent can block or open the flow of perception at runtime).

In the test that was done with the *status* agent we

Figure 4. The results for some of the agents of the smart bathroom (seconds per number of agents employed in tests).

considered the time of execution from *free* status until it comes back to *free* status again). Again, we performed three repetitions for each of the following two cases: the agent *status*, the ARGO agent and more two standard agents; and the agent status, the ARGO agent, and more seven simple agents. The results show the same pattern of the former results of basic functions.

Two tests were performed to address the limitation of having just one controller. In the first one, the manager agent (that was programmed reactively) is responsible for the sensing and to distribute these perceptions to other agents while the remaining agents are responsible for the reasoning. The second one is similar to the former one, but the manager agent was programmed using belief plans and not achievement plans. As a result, the first test had a better performance compared with the second test, seeing that the first presented an answer time smaller than the second test. Therefore, the first strategy, only one agent communicates with the controller and the other agents has been adopted (sending to these other agents, perceptions coming from the controller; and receiving commands from these same agents and sending to the controller). This chosen strategy shows that the approach can be significant in applications of AmI because it reduces the loss of pervasiveness if it is compared to the second approach (second test).

And the last test was performed to evaluate the MAS managing the reservoirs (potable, rainwater and cistern), pumps, status logic, energy sources (electric and solar) and manual drives. Thereby, it can be observed that there are many functionalities for a single controller, but using different strategies can lead to a response time acceptable or not, depending on the strategy adopted. Moreover, the functions of reusing and saving natural resources remained functional independent of the strategy, since the *energy* agent uses the maximum of clean energy that it obtains and the *reservoir* agent gives priority to use rainwater and has a policy of

reuse.

5 Related Work

In this section, it is discussed some related works, and they are compared with the smart bathroom presented in this work. Many papers show methods of using MAS for AmI in Smart Homes. The MavHome [13] is a Smart Home which works like an intelligent agent, that is, according to the necessities of the residents it offers comfort in day-by-day tasks improving the time of the residents, reducing operation costs, and the security offered. The MavHome uses a MAS with agents divided into four layers named: decision, information, communication, and physical.

The Ambient Intelligence Environment Using Embedded Agents [12] uses concepts of ubiquitous computing environments, AmI, and embedded agents. In this way, the authors created an environment named iDorm which was controlled by an embedded agent that uses fuzzy logic, inside an architecture of different networks, and it uses different kinds of embedded computational artifacts. Both works present solutions that do not use an agent-oriented programming language and are specific and not reusable. Unlike, the smart bathroom presented here, which uses Jason as a programming language and also offers reductions in costs and security. Besides, ARGO is independent of the solution presented here and can be used in different domains.

In [18], an example of a project using MAS is a smart home with context aware information, that uses communication and interaction protocols to pass the information about the ambient to the agents. In turn, the agent's task is to observe user actions, predict and analyze the risk of performing a task. Besides, there are sub-agents which get the sensors' data and send to a super-agent (which, in turn, is connected with all the sub-agents). However, connecting a super agent to all sub agents can generate delays, and the solution does not provide an independent platform able of programming uMAS in different domains. The proposed smart bathroom uses a similar approach, where one agent is responsible for getting perceptual information from sensors, and it manages the requests of others agents to act upon the real world. Besides, ARGO is independent of domain, as stated before, and counts with mechanisms such as perception filters and blocking perceptions at runtime, which try to improve the performance of robotic agents.

6 Conclusion

This paper presented an uMAS of a smart bathroom model with the purpose of saving and reusing natural resources (water and energy). A prototype was constructed to simulate a real bathroom, and the uMAS was developed using Jason and the ARGO architecture. Applying BDI agents in robotic platforms is not a simple task since problems can arise depending on the number of perceptual information. ARGO provides mechanisms such as perception filters and internal behaviors that block and unblock the flow of perceptions from the real world and another one which specifies a time interval for getting perceptions (both behaviors stop the internal process of capturing perceptions using Javino at runtime). These characteristics help in the development of uMAS with an acceptable response time depending on the programming strategy adopted. Then, in this work, it was explored a strategy using a centralized ARGO agent responsible for managing actions and perceptions interacting with one controller and eight agents responsible for specific functions of the proposed smart bathroom negotiating actions with the centralizer.

It is important to remark that when employing more agents that controllers, the agents have to negotiate hardware resources and the performance can be compromised by actions that the time is a critical variable. For instance, verification of each energy to be used (renewable or bought) is a function that does not impact the user of the bathroom if it delays 5 or 10 seconds. However, if the shower takes too long to be turned on after somebody presses the button, one can question the effectiveness of the system. The best scenario for prototyping an uMAS using ARGO agents is to provide an agent ARGO dedicated for each controller employed whenever possible and communicating with each other exchanging perceptual information or delegating to standard agents the reasoning of a particular function. So, the experiments conducted showed that using a centralized agent when the number of functions are high and specialized per agents generates a bottleneck of requisitions (messages) that could delay in seconds the execution of certain functions.

For future works, an uMAS will be developed in a real room for managing the resources of our laboratory. Besides, a communication mechanism using the middleware ContextNet for the internet of things will be tested using Jason and ARGO agents. This middleware could be exploited to provide a way of two different MAS communicate. For example, a MAS responsible for one smart home will be able of communicating with a MAS responsible for a smart car. Another purpose is to transport cognitive agents among different MAS using a protocol for preserving their intelligence in cases such that an agent is in danger or has its hardware damnific. Besides, the Javic middleware intends to be a middleware to allow the communication of ARGO agents with PIC controllers.

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