Fuzzy Expert Systems and Multiagents for Intelligent Buildings

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Abstract: This paper describes the design criteria followed for the implementation of an Intelligent Dome System (IDS) for buildings. It was designed as a Client/Server system on a Blackboard Architecture. The IDS is conformed by 9 Specific Control Groups (SCG), and one central control (Dome). Each SCG is designed as a Multi Agent System and the Dome as a Fuzzy Expert System. Both, the SCGs as well as the Dome, work with Fuzzy Knowledge. The system was implemented in FuzzyJess, Jade and Java, and tested under the simulation of different conditions. In this paper we present the design and implementation process of the Dome and two SCGs: 1) energy savings and illumination, and 2) ventilation and air conditioning. We also present some results obtained from simulation experiments.

Keywords: Domotics, Intelligent Buildings, Fuzzy Expert System, Agents Systems, Client/Server, Decision Making.

1 Introduction

This article focuses on a proposal to be applied in automated buildings, which have intention to be into the category of intelligent. The proposed model is a Client/Server system, on a blackboard architecture. The design integrates *multiagent systems (MAS)* for trying to get specific services and to supervise the building's automation, and a *fuzzy expert system (FES)* for the integration of; services, resource management, and decision making under unexpected situations.

In [1] and [2] an Intelligent Building (IB) has been defined as one "that uses computer technology to autonomously govern the building environment so as to optimize user comfort, energy-consumption, work efficiency, and safety and monitoring functions". From this viewpoint an automated system will fulfill well this requirements, due to the fact that these systems are designed with the purpose of using computer capacities for specific tasks, and to control the operating sequence without human intervention. Nevertheless, in our design we have also considered the functional aspect of the building, the integration of services, and in a very relevant way the decision making capabilities, as it is suggested in [3] and [4], along whit the aspects that the previous definition mentions.

2 Design of the Intelligent Dome System.

The Intelligent Dome System (IDS) suggests an analogy with the functioning of the human body. Under this perspective the system is composed by reasoning, control, communication, and coordination processes of all services and systems of the building. Moreover, it integrates all these process in a central unit, which should make the right decisions to solve the problems under unexpected situations and emergency cases. Physically the IDS is conceptualized under four elements: devices, structures, automated systems, and the Dome. The designed IDS is an unrestricted system, which means that it is not tied up to any particular device, brand or building size. The only requirement is that the automated systems must send the information in the specific format. The Dome is the smart module of the building.

The general functioning of the system is as follows. First, the present state of all the devices is obtained by means of sensors, which are usually in charge of dedicated agents. From the collected information, each agent either starts a control action or does nothing in case of normal operation of the corresponding device. In both cases the information is passed to the Dome. When a device is out of an agent's control, a complete report is immediately sent to the IDS, which starts an inference process. The IDS's inference tasks are executed by the following modules; a specific control group for each functional area, an overall building's state monitor, an analyzer of the building's state, and finally a decision maker. The Dome picks up the information from the first three modules, which at the same time is integrated and analyzed to obtain the global state of the building. Based on this, the IDS starts making decisions that may affect one or more functional areas or services. All the modules or software levels, are shown in Figure 1, they form a layered pyramid whit ascending-descending control, depending if there is a help request or an order execution.

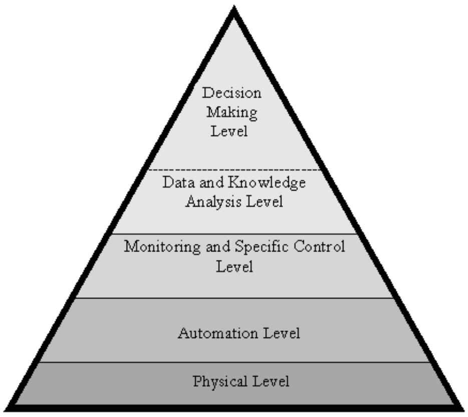

Figure 1. Software levels of the IDS

Basically we have identified nine groups: 1. heating, ventilation and air conditioning (HVAC), 2. energy savings and illumination, 3. communications (internal), 4. telecommunications, 5. office automation, 6. security and safety, 7. maintenance, 8. structured wiring, and 9. elevators and escalators.

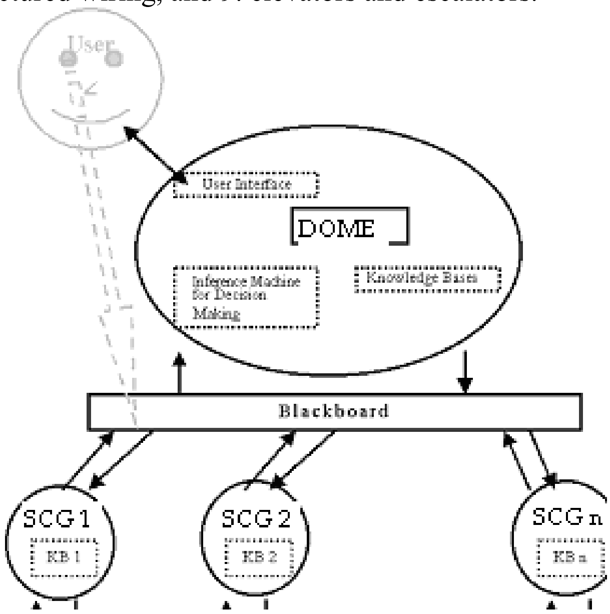

Figure 2 IDS components

3. Software Architecture of the IDS

The IDS has a hybrid architecture, which is composed mainly by Multi Agent Systems and Fuzzy Expert Systems, all of them supported by fuzzy knowledge bases (FKB). The general communication among all the components is based on the Sinted Transfer Protocol (STP/IP), a standard protocol developed jointly by UNINOVA and INAUT [5], and the messages are interchanged through a blackboard structure [6]. The Figure 2 shows the elements conforming the IDS.

3.1. Specific Control Groups

The Specific Control Groups (SCG) are groups of agents specialized in a specific functional area or service. The SCG's mission is to do basic functions of control and management of the devices. It is not an automation system, but a proactive control and management based on the analysis of the information on the current and the desired state of devices and services. The number and function of each SCG was determined according to the functional components of the building. The number groups can change depending on the services provided by the building.

3.2. The Dome

The Dome was implemented as a fuzzy expert system [7], and it is the brain of the IDS. Its mission is to supervise and to decide the operations of the facilities, services and equipment of the building. The Dome has multidisciplinary knowledge bases to prevent, detect, diagnose and solve failures or emergency situations. In special situations, when a particular SGC can't solve a problem, the Dome makes the pertinent decisions, establishes the actions, and supervises their correct execution

When the solution is out of the IDS's capabilities, the Dome sends a report to the building's administrator. The report contains the recommended activities and procedures to be performed, the fault's causes, and a complete analysis of the situation.

3.3. Blackboard and Communications Protocol

The *blackboard* is a repository of shared information and knowledge, which represents the state of the building and shows the coordinate actions among the IDS elements. The blackboard is divided into two parts: 1. the current state of the building and, 2. control and cooperation activities. The first is a GUI that, shows the values of all connected devices to the

IDS. The second part is a box where the SCGs put their information and the Dome puts its instructions on the actions to be done, or the required intervention of another module. The *communications protocol* is based on the Sinted Transfer Protocol (STP/IP), which is a protocol specifically designed for intelligent buildings, based on HTTP1. For our implementation we use only the instruction format, which has a request line, a header and an entity body. **Request Line:** The request line indicates the nature of the request, whether it is requiring or sending information, and at the same time indicates which are the resources, services or variables involved in the request, for example; `[put air-temp all].` **Header:** There are three types of headers, which provide additional information on the origin of the request. 1. General header, contains the date and hour when the request was sent. 2. Request header its function is to provide the identification of the user. 3. Entity header, indicates the nature or length of the entity's body. An example of a complete header is; `[hot September 10 2003 13:24:50 dome@xcel vl].` **Body of the entit**y. It is the sequence of bytes that will be interpreted according to the specifications in the entity header. It means that it can be an attached image, or a chain of characters containing a message, an instruction, or in some cases the file of the sent report.

4. Design of the IDS

In this paper we present just the development of the Dome, the blackboard application, and two SCG, 1. HVAC, and 2. energy savings and illumination.

4.1. The HVAC Multi Agent System

The functions of the agents belonging to this SCG are to monitor and control: air renewal, temperature, cleaning and humidity. Figure 3 shows the internal structure of an agent [8] implemented to carry on this functions, it has 11 behaviors with hierarchical control, upwards in case of fault and downwards when executing actions. It has also a domain specific FKB with different abstraction levels.

4.2. Multi Agent System for Energy Saving and Illumination

This SCG is responsible for keeping adequately illuminated each zone, according to the kind of activities taking place in the area. It must also keep the energy consumption at the lowest level possible. Moreover, the SCG must detect and solve short circuits and electricity leaks. The multi agent system [9] is composed by four agents. The agent one manages the illumination, the agent two is monitoring the devices and lamps energy consumption, and the agent three is in charge of the surveillance of the central energy boards. These three agents are coordinated by a fourth agent, which should work as an electrical engineer expert in building's installations. Its functions are shown in Figure 4.

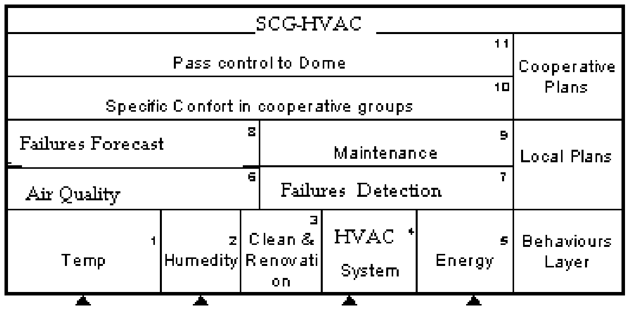

Figure 3 Architecture of an HVAC agent

4.3. Dome's Fuzzy Expert System

Some of the functions to be executed by the Dome are: making decisions when a SCG has failed to solve a problem or under unexpected situations. These decisions are made by means of the Fuzzy Expert System. The FES is designed to allow the Dome to behave as a human expert in building's supervision and management. Emulating the way an expert works, the Dome integrates the knowledge, on each functional service of the building, in corresponding fuzzy knowledge bases. In this work we present only the design and implementation of the HVAC and ES&I modules. The fuzzy expert system has one FKB for each area.

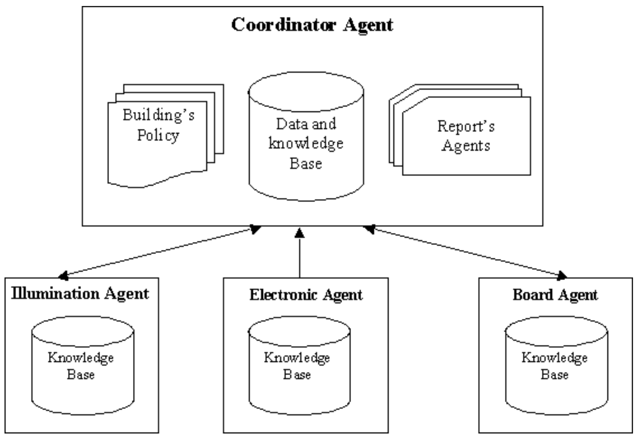

Figure 4 Multi Agent System for the ES&I system

4.4. Blackboard applet

The blackboard was implemented as an applet, its function is to show and update the values at the devices. The applet updates the STP instructions and notifies at the receptor of a new instruction. The applet also has a window of rules; which lists the rules being fired by the SGCs and the Dome.

5. Knowledge Engineering

In order to carry out the mentioned activities by each component of the IDS, first it was necessary to identify the variables that take part in the system. In our case we used Linguistic Variables (LV), which allow us to manipulate them in the form required by the fuzzy knowledge and rules. For the acquisition and formulation of the knowledge was necessary to interview human experts in the two functional areas implemented, we also consulted manuals and books related to their topics and particularly to their maintenance.

5.1. Knowledge Engineering for the HVAC

With the obtained information, from experts and manuals, a total of 20 LVs were identified, they are divided in variables related to: the air (3), the humidity (1), temperature (5) and, refrigeration system (11). In addition, we formulated a set of rules for control, maintenance, and detection and correction of failures. We came up with 8 rules for temperature control and 5 for humidity. For preventive maintenance we got 16 rules, and for detection and correction of failures a total a 17 rules were implemented. Some of the formulated rules appear in Table 1, which contains the fault, possible causes and recommended solutions. Later on, the rules are translated to the IF_THEN format.

Table 1 Some rules for faults in the HVAC

Fault	Possible causes	Proposed solutions
Temperature very high or very low	Pressure of the compressor out of rank Ducts or grids dirty Relays damaged	Verify and give maintenance to the compressor Give maintenance to the ducts Give maintenance to the relays
Air very hot	Damage in some of the following parts: condensing unit, compressor, cooling, motor.	Detect the damaged part and give the corresponding maintenance. If the temperature of the evaporator is the correct one, then check the coolant and the motor. In any other case, Check the condensing unit.

5.2. Knowledge Engineering for Energy Savings and Illumination

For the energy savings functions it was necessary to make an inventory of the devices and to locate them in the building's layout. In our case there were 16 electrical devices and 7 lamps defined as *templates*. In this functional area, we identified only 5 LVs: energy consumption, time, period, intensity and intensity change. We formulated 10 rules for energy savings, this rules control the devices according to requirements, device priority, type of usage and energy consumption. In the illumination case we have 8 rules, the management of illumination depends on the required activity, and the type of user. Some of these rules appear in Table 2.

Table 2 Some rules for the ES&I system

Fault	Possible causes	Proposed solutions
The lamp doesn't light	Broken lamp, off contact, failure on the control device, short circuit.	Maintenance to the lamp, ask to the energy agent what happen?, verify whit the board agent the short circuits, or verify the control device.
Bad Illumination	Failures in the control device, obstacles in light zone, dirty lamp.	Maintenance to control device, ask to the SCG of monitoring if some object is into the light zone, maintenance to the lamp.

5.3. Knowledge Engineering for the Dome

The Dome works mainly with the same LVs of all the SCGs, thus it has 25 LVs, plus two more, one for fire and another to define a zone. The set of rules is composed by 17 related whit HVCA, 22 for ES&I and two more for internal control. The Dome has special knowledge that involves more than one SCG, for example when a fire is detected. We have defined 6 rules for fire cases and to prove that the cooperation among MAS, FES, SCGs and the Dome, is feasible to solve this kind of emergency events.

6. IDS Implementation

All the agent system was developed on JADE (Java Agent DEvelopment), version 2.5, of July 2002[10,11], JADE is a software framework to develop agent applications in compliance whit the FIPA standard specifications [12] for interoperable intelligent multiagents systems. It can then be consider an agent middle-ware that implements an Agent Platform and a development framework. The knowledge bases and the fuzzy expert system ware developed on JESS (Java Expert Shell), version 6.1 RCI of March 2003 [13]. JESS supports the development of rule-based expert systems which can be tightly coupled to code written in the powerful, portable Java language. This jointly whit the FuzzyJess extensions provide the capability for handling fuzzy concepts and reasoning. The interface and all the applets were written in Java.

6.1 Testing and Simulation

The implementation, testing and simulation of the system was on a model of the building of the research center at the Engineering and Technology Department of the Autonomous University of Tlaxcala, presented in Figure 5. It has 3 zones, 16 electrical devices and 7 lamps. In order to show the behavior of the system, in this report we present only some extreme situations. To perform the experiments we considered real situations, which were given to us by the human experts. In this particular example we evaluate a situation that involves the participation of the three knowledge bases, all the SCGs and the Dome. There is an emergency case in the central zone, the temperature is cold, few seconds later there is a fire localized in zone 2 of the building, there are people in the zone, and in zone 3 some devices are consuming too much energy. Each SCG reads its concerning information and immediately report to the Dome, which in real time starts reasoning the situation. When the variables are instantiated the corresponding rules are automatically fired. In this case the cold temperature is controlled first, and in parallel when the fire is detected, the own Dome turns on the alarms, makes a call to the firebrigade, and to the building's administrator , and places a request for the intervention of the SCG-ES&I to cut the energy in the zone of fire. It also instruct the people to get out by the safest exit, and orders the SCG-HVAC to extract the air on the zone. While the SCGs do their corresponding actions, the Dome stays alert to detect any eventual new abnormal situations. The normal state is recovered until the SCGs complete their tasks and the fire is under control. The actions sequence is listed on Figure 6.

6.2 Remarks on the Simulation Results

The evaluation of the performance of a system like the one presented here, is more subjective than quantitative. Its operation has to be observed at the moment that the events are happening, in order to be sure that the actions are correct and executed in the right sequence, and overall system's behavior is as expected. In all the performed tests the SCGs responded in time and form to the blackboard information, and executed the Dome's instructions in a coordinate form. The Dome was always able to make good decisions when it was needed. The results coming from the system were validated by human experts, and in all cases the observations made were satisfactory. Unfortunately, there were no similar systems available to compare our system's performance.

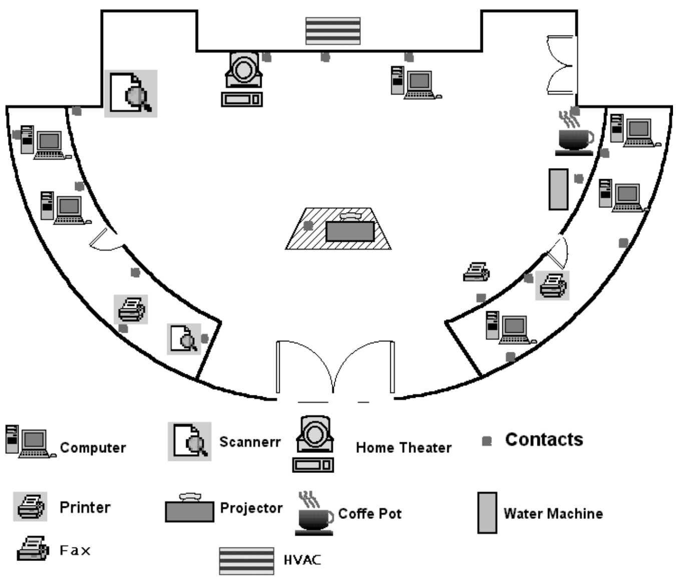

Figure 5. Research Center at the Engineering and Technology Department of theAutonomous University of Tlaxcala

7. Conclusions and future work

With the results obtained in different system's test, we have been able to verify that the IDS behavior is efficient and adequate. The integration of MAS and FES resulted to be a reliable architecture to solve unexpected situations in a coordinate way. This was mainly due to the use of the blackboard architecture, allowing the execution of concurrent processes. Although we are aware that the knowledge bases, implemented until now, need to be extended to include all possible emergency or unexpected situations, the system at its present stage is performing at a very acceptable level. Moreover, according to us, and to the experts that already have observed the system functioning, our approach is in the right direction.

```
[HvacAgent->Temp Behaviour]
[PUT globalTemp blackboard OK Friday Aug 8, 2003 2:34:05 PM
scgHvac@temps msg[temperature is under control]]
[HvacAgent->Temp Behaviour]
[PUT passControl Dome Temp Friday Aug 8, 2003 2:34:05 PM
scgHvac@temps msg[temp one is outter my control]]
[HvacAgent->Temp Behaviour-> out Temp Behaviour]:
return the control to the previous behavior, because the fault is not in the
ducts
The error cannot be corrected, the temperature difference is too much ...
[HvacAgent->Temp Behaviour]
[PUT passControl Dome Temp Friday Aug 8, 2003 2:34:05 PM
scgHvac@temps msg[temp two is outter my control]]
[HvacAgent->Humidity Behaviour]
[Humidity Actions]
        Humidity is OK
[EnergyAgent->Savings Behaviour]
[ GET Action Dome xxx Friday Aug 8, 2003 2:34:05 PM energy@sgnivas
msg [ device d15 lose energy, use constant]]
[ PUT device d14 off Friday Aug 8, 2003 2:34:05 PM energy@sgnivas msg
[ d14 turn Off, Use ~permanent, state work, activity None]]
[EnergyAgent->Illumination Behaviour]
[Domo Actions]
(turn On FIRE ALARMS)
(calling the Firebrigade)
(calling the Administrator)
[ GET  Service Energy xxx Friday Aug 8, 2003 2:34:27 PM
domo@omodavle stp [ PUT contacts Ztwo turnOff Friday Aug 8, 2003
2:34:27 PM domo@omodavle VL [ turn Off the contacts]]
[ GET  Service Hvac xxx Friday Aug 8, 2003 2:34:27 PM domo@omodavle
stp [ PUT air Ztwo extract Friday Aug 8, 2003 2:34:27 PM
domo@omodavle VL [ extract the air]]
[ GET  Service Administrator sTone Friday Aug 8, 2003 2:34:27 PM
domo@omodavle msg [ Is necessary review the temperature sensor in
zone one]
[HvacAgent->Clean Behaviour]
[ PUT Air Z2 extract Friday Aug 8, 2003 2:35:06 PM energy@noitanimulli
VL [ extract air zone two]]
[Humidity Actions]
        Humidity is OK
[EnergyAgent->boards Behaviour]
[ PUT device d11 off Friday Aug 8, 2003 2:36:23 PM energy@sgnivas msg
[  domo orders]]
[ PUT device d10 off Friday Aug 8, 2003 2:36:23 PM energy@sgnivas msg
[[  domo orders]]
[ PUT device d9 off Friday Aug 8, 2003 2:36:23 PM energy@sgnivas msg [
domo orders]]
[ PUT device d8 off Friday Aug 8, 2003 3:36:23 PM energy@sgnivas msg [
domo orders]]
```

Figure 6 Actions of the IDS in our example

Still, more work has to be done, as to complete all the other SCGs corresponding to the rest of the functional areas. The architecture presented, in case of being fully implemented, will allow the possibility of ending up with a really smart building. Motivated by the obtained results we argue that this design is feasible to be implemented in real world. The next step in this work will be to implement the rest of the SCGs and integrate the full IDS, first in a physical prototype and next in a real building. Furthermore, we are in the process of applying the proposed IDS concepts and architecture to other domains that require monitoring, control, and central decision making over different areas.

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