Fusion System based on Multi-agent Systems to merge data from WSN

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Abstract*— This paper presents an intelligent multi-agent system that is aimed at improving healthcare and assistance to elderly and dependent people in geriatric residences and at their homes. The system is based on the PANGEA multi-agent architecture, which provides a high-level framework for intelligent information fusion and management. The system makes use of wireless sensor networks and a real-time locating system to obtain heterogeneous data, and is able to provide autonomous responses according to the environment status. The high-level development of the system that extracts and stores information plays an essential role to deal with the avalanche of context data. In our case, the multi-agent system approach results satisfactorily because each agent that represents an autonomous entity with different capabilities and offers different services works collaboratively with each other. Several tests have been performed on this platform to evaluate/demonstrate its validity.

Keywords—Wireless Sensor Networks; Ambient Intelligence; Information Fusion; Multi-agent Systems

I. INTRODUCTION

As it is possible to observe in [14], Ambient Intelligence (AmI) is considered "a new way to interact between people and technology, where the latter adapts to individuals and their context and contains a range of interactive devices capable of meeting the demands and requirements of the users". It is also essential to mention that the tools and technologies that form an AmI system must allow various autonomous functions with the ability to interact and integrate with people's environment and help making decision easily based on their daily actions with minimum intrusion. This can be applied especially to the healthcare system where the number of elderly people with some kind of dependency is rapidly growing at present and for this reason is necessary to develop more effective ways to provide social services [39].

Information fusion is based on aims and combines information at a low and high level. In this sense, intelligent approachs based on multi-agent systems (MAS) combined with information fusion process have been recently emerging [16], [1]. MAS [31] is increasing in importance in the research line of distributed and dynamic intelligent environments. Its use in this process satisfy the requirements and goals of the AmI systems. These intelligent systems offer a high-level tool to support people in several aspects of their daily life, this support includes the prediction of physical problems , dangerous situations, or provide a cognitive support. By integrating intelligent and dynamic mechanisms to learn from past experiences, the proposed architecture is able to provide users with better tools for supplying healthcare.

Nowadays, smaller, transportable and non-intrusive devices [42][30] are more and more efficient when gathering context-information [32]. Thus, the new ambient intelligence platforms should encourage the integration of such devices in order to create open, flexible and adaptable systems. Wireless Sensor Networks (WSNs) are mainly used to extract information about the environment and extend users' capabilities and automating daily actions with an interaction on it [24]. Real-Time Locating Systems (RTLS) is one of the most significant applications for WSNs. As we previously studied in [25], although outdoor locating is well covered by systems such as the current GPS (Global Positioning System), indoor locating needs still more development, especially with respect to accuracy and low-cost. The use of optimized locating techniques allows obtaining more accurate locations using very few sensors and computational requirements [4].

For all these reasons, it is possible to say that virtual organizations of agents are an ideal option to create and develop the open and heterogeneous systems such as those normally found in the information fusion process. This paper presents an intelligent multi-agent system aimed at improving healthcare and assistance to elderly and dependent people in geriatric residences and at their homes. In summary, our work consists on developing a good tested system for information fusion technologies in a real-world scenario, including the following actions:

- Develop an AmI based multi-agent system aimed at improving the healthcare of dependent people in geriatric residences and in their own homes, focusing on information fusion techniques. This system is developing under the PANGEA multi-agent platform [5], which provides a high-level framework for intelligent information fusion and management.
- Use of virtual organizations of agents for the overall management; and control systems for high-level sensor data management. The use of virtual organizations of agents facitilitate the incorporation of new information fusion techniques to the platform.

Self-adaptive virtual organizations allow the dynamic incorporation of specialized agents, which provides a framework for the incorporation of new information fusion techniques.

- Include a rule-based reasoning system to improve the accuracy of the results.

The remainder of the article is structured as follows: section two review the state of the art of related projects, as well as the various types of technology used in the study. Section three describes the basic structure of the developed system, which is composed of three distinct parts: real time identification and localization service; telemonitoring services; and an interface service for personnel. Finally, section four presents the results and conclusions obtained from the study.

II. Related Works

The work presented in [18] is a survey about wireless sensor networks for healthcare patients that includes some interesting systems. However, our system is not comparable from those taken into account. Our system is more than a decision support system since it integrates other capacities such as location, monitoring and prediction of dangerous situations. Fom this point of view, we can revise two types of systems, those for monitoring systems and those studying the pattern recognition of behaviours.

Related to the first field, in [9], the systems i.e. Arezzo, DeGeL, GLARE, GLEE, HeCaSe2 are compared. All of them were developed to monitore and with the recovered information, create alarms and facilitate the clinical decisions. SHAPHIRE [28] is a system developed to provide clinical decision support for remote monitoring of patients at their homes and at the hospital to reduce the load of medical practitioners and healthcare costs. The system CAMPH, a context-aware middleware for pervasive homecare, is presented in [26]. The middleware offers several key-enabling system services that consist of P2P-based context query processing, context reasoning for activity recognition and context-aware service management. However, camera based sensors for surveillance and security in which the images of the person are taken require acceptability of the elderly which may not be possible. BehaviorScope [10] processes streams of timestamped sensor data along with prior context information to infer activities and generate appropriate notifications. In this case, the activities of interest are pre-programmed into a specification that is used by the system to interpret the incoming sensor data stream. The system interprets the activities to generate summaries and other triggered notifications that are propagated to the users. However, these projects are for very specific purposes.

Related to the second field, the framework called DTFRA (Discovering of Temporal Features and Relation of Activities) focus on discovering and representing the temporal features of activity patterns from sensor data. The algorithm is able to discover features and relations, such as the order of the activities, their usual start times and durations by using rule mining and clustering techniques. Other related works focus on this specific activity are [37][3]. In some cases, these systems are extended with monitoring and modeling the activities of daily living [36]. Our work is improved in reference with this, because it is based on the multi-agent technology, which is highly appropriate to this end due to the need of fusioning information from heterogeneous distributed resources and autonomous entities. In this sense, the main contribution of this work is a system easily extensible that conforms a complete tool for health-care services based on WSN sensors networks. At the lowest level of the architecture we use the PANGEA multi-agent platform, which provides the basic characteristics for the perfect functioning of the agents.

Finally, the system called JTH [19] is the most interesting work found in our study. This system provides four main functionalities, including indoor monitoring, outdoor monitoring, activity and health state decision, emergency decision and alarm. It is a prototype of wireless sensor networks, an interconnection platform and a service management platform to support large scale data interconnections and real-time activity and health state reports to related persons (e.g. doctors or nurses, elder-self, relatives) via all popular communication approaches, such as automatic voice telephone call, SMS or Email etc.

A. *Rule-based reasoning systems*

The objective in developing an automated reasoning system is to create a system that enables one to take decisions based on the information obtained through the heterogeneous sensors.

As mentioned in [12], the most important step in information fusion is related to the transformation from the observed features and measures, which are obtained by multiple sensors, and a decision or inference, which is calculated by fusion evaluation and/or inference processes. Next, it is also critical to extract an understandable knowledge of the observed situations and the interactions between them. In most of the cases, this interpretation needs not only implicit information but also explicit data that must be extracted via knowledge-based methods such as rule-based reasoning systems.

The system applies information fusion algorithms which combine the information obtained from each of the sensors through a case-based reasoning (CBR) mechanism [22]. But, in most cases, CBR has not been used alone, but combined with various artificial intelligence techniques. Support Vector Machine (SVM) [41] has been used with CBR in this study to perform the classification of the data obtained by sensors and automatically create the intern structure of the case base from existing data. The system and thus, the agents that are part of it, uses various methods for base and meta-classifiers training as will be seen in Section IV. They are used in the extraction of data and the association rules from different sources of information.

B. *Information Fusion and Agents*

The information obtained from multiple sensors needs to be fused because no single sensor can get all the information, and the information from different sensors may be uncertain, inaccurate, or even conflicting [20]. This is the reason why information fusion is a fundamental part of sensor management.

There is a considerable variety of sensors that can observe user contexts and behaviours and multi-agent architectures that utilize data merging to improve their output and efficiency. Such is the case with Castanedo et al. [16] Pfeffer et al. [1], Liu et al. [47] or the system called HiLIFE [27]. In the works [6] [8] more cases can be consulted.

The adequacy of agents and multi-agent systems applied to information fusion has been deeper discussed in our previous work [43]. Open MAS [34] and Virtual Organizations of agents (VO) [35] [45] [23] [34], as a specialized version of MAS, are used in this paper to allow the inclusion of organizational concepts These concepts includes rules and norms [17], groups or institutions [29] and social structures [21]. As an evolution of the MAS, VOs are specially appropriated to implement the new algorithms for information fusion and to manage high level information. According to this, we have chosen the PANGEA platform for the development of the agents. PANGEA [5] is an open platform that allows any type of configuration, adaptation mechanisms, reorganization, search services, etc.

III. System Overview

We present an innovative MAS for AmI environments aimed at improving the healthcare of dependent people in geriatric residences and in their own homes. The improvement of the system is focused on information fusion techniques and extending the system proposed in [8].

The agents in the system are implemented within the agent platform PANGEA (Platform for Automatic coNstruction of orGanizations of intElligents Agents) [5]. PANGEA enables the system to create agents in charge of all the tasks of the system, allowing them to organize and communicate more easily and securely, regardless of how they are created, where they are located, what data to collect or what role they play within the system.

The three key concepts that come together in this system are:

- the use of virtual organizations of agents for the overall management;
- the control systems for high-level sensor data management.
- the sensors themselves will have to be managed and analyzed to extract information from them and apply them to our case study.

The principal characteristic that improves the functioning is the application of information fusion algorithms [7] that collect, merge and deal with data from Wireless Sensor Networks (WSN). The data collection is carried out in real-time according to the action that occurs in the environment, due to this, the agents can react accordingly in an automatic and instantaneous way. Thanks to this configuration the system enables the integration of an elevated number of WSNs with the advantage of a greater simplicity due to the reuse of available resources.

The context information includes not only information about the environment, the people who live in such environments is also monitorized. This information includes parameters such as location, temperature of the building, quality of the air, heart rhythm of the patient, etc.

At the level of the sensors, the basis of the WSN infrastructure of the system is made up of several ZigBee nodes. At higher levels (features and decision), it is possible to detect alterations in the environment and its corresponding response. For example, if a change within a node (a change of light for instance) is detected at the sensor level, the agents at a higher level can decide to send a warning message or perform an action. The actions and reactions are handled by the PANGEA platform since all the agents that formed the organizations are designed with the corresponding services and functions.

This configuration enables the capacity to manage a variety of sensors, other devices of diagnostic and different sources of information (maintenance records, monitoring and observations). The framework provides for information synchronization and high-level fusion [11].

The architecture defined three types of services that were designed to be applied within medical care environments, but they can be easily adapted to other types of case studies:

- Real Time Identification and Location Service: system for locating elderly or dependant people and staff.
- Telemonitoring service: system with different kind of sensors that fusion the information obtaining knowlegment and alerts.
- Caregiver support system: system that enables the caregivers to set alarms and plan daily tasks and routines to take care of the elderly.

The two first services are explained in the next subsections in greater detail, explaining how they are offered through the agents in the PANGEA system.

A. *Telemonitoring Service*

The rule-based telemonitoring service has the following purposes:

- Monitor through the use of data gathered from sensors for each participant.
- Use the “Presence of Trace” of each person.
- Know the different available means of monitoring (devices, professional and support personnel, resources, etc.) and the communication that exists among them, and use the assistance device to suggest certain actions to take;
- Control and know what is occurring in the global context of the residence of the person under supervision;
- Add and personalize rules as data are expanded.

The service is offered through a remote monitoring center, a sensor network, wireless actuators deployed within the environment, and a communication network that connects all the system components.

We propose this system together with a case study in which medical care is provided in a care facility and private home. This has the necessity for a complete sensors and actuators deployment both in the care facility and the home.

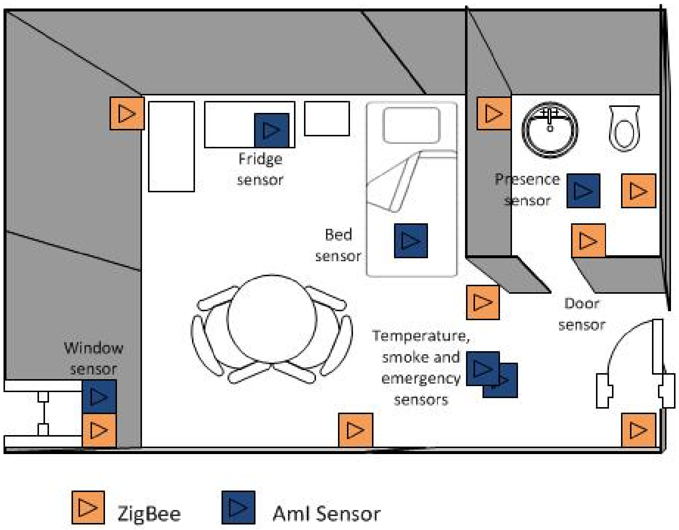

Fig. 1. Map of the deployment of sensors in the living quarters

Figure 1 shows a map of the deployment of sensors in living quarters. In addition to the ZigBee readers (orange squares), sensors (blue squares) were included in the movement pattern node: one associated with the bathroom, one with the bed, one with the dining table, and the other with the front door.

The sensors gather information from the context, that is, from both the elderly patient and the environment itself. The information is processed and analyzed by a set of mechanisms that facilitates the decision-making process and optimizes the response of professional and support personnel. Those responsible for assisting can access specific information regarding the elderly patients: physical location in the home, medical history, high risk situations detected, etc. Similarly, after providing assistance, the data gathered from the actions taken are gathered for their subsequent analysis.

TABLE I. TRACKING DATA USED.

Day of week (w)	1…7
Hour (h)	Seconds starting at 0:00
Node (n)	Current Node
User (u)	User id
Seconds (s)	Seconds from the previous node
Previous node (p)	ID of previous node
Previous time (l)	Seconds since the node was last accessed
Number of times (t)	Number of times user has been in node since 0:00.

The detection of anomalous behaviors is done through the detection of strange movement patterns of the users. In order to detect these patterns, a series of significant variables are established to measure a series of variables in each of the nodes in the graph that represent possible movement patterns. The values indicated in Table 1 are used for each node representing a movement pattern. The nodes for each movement pattern do not include the sample points in the map of intensities to reduce the number of values in the Table 1. In this table, the variables used in equation 4 are represented in parentheses.

The alerts generated by the sensors are managed through a multiagent architecture that applies algorithms to manage the information and make decisions. The alarm management system is based on a behavioral module which applies the Drools production rule system [13], allowing the information to be processed quickly and decidedly. The architecture applies information fusion algorithms which combine the information gathered from each of the sensors installed in the environment and the tracking information for each user to generate intelligent alerts through a case-based reasoning (CBR) mechanism [22]. The system includes a “daily activity planner” and a library of “rules” that generates alerts when something occurs contrary to the typical daily plan. For example: “If the subject remains in bed longer than eight hours, an alert is generated”.

The agent that detects untypical or incongruous behaviors is based on the use of predefined rules that are executed over the data from the Table 1. The rules are stored in a text file and they can be modified without recompiling the source code. The Drools production rule system [13] was used to configure the rules engine. Drools is a business rule management system (known as BRMS, Business Rule Management System) with a forward chaining inference based rules engine, using an implementation oriented toward Rete algorithm objects [2]. Drools is also used to manage the information provided by the sensors. The information assembled from the sensors makes it possible to know the state of the environment as well as the time instance in which the change was made and the number of measurements taken in that particular state, as shown in Table 2. The variables used in equation 4 are represented in parentheses.

TABLE II. SENSOR INFORMATION

Sensor (id)	Id sensor
Time (dt)	Date of last change
State (ds)	State of the sensor
Measurements (dm)	Number of measurements taken in the state
Alarm (da)	Alarm activated

Working together with these rules, a CBR is used to generate additional rules based on J48 to detect new cases identified as anomalous. If any of the procedures detects anomalous behavior, an alarm will sound, unless a Drool rule to cancel an alarm that has been activated through J48 is detected. The ability to automatically cancel rules is used to avoid launching a false positive and allow the automatic cancellation of an alarm considered to be incorrect.

The information according to Table 1 and Table 2 is modeled as the formal specification of the case (1) . The meaning of the variables are described in the tables 1 and 2.

$$c_i = (w_i, h_i, n_i, u_i, s_i, p_i, l_i, t_i, D^i)$$
$$D^i = \bigcup_j d_j^i \quad (1)$$

$$d_j^i = (id_j, dt_j, ds_j, dm_j, da_j)$$

As new cases are received in the system, they are introduced into the reasoning cycle. The CBR cycle is defined for each of the following steps: retrieve, reuse, revise and retain. A prediction is made regarding the need to generate an alarm. The complete process is described in Figure 2.

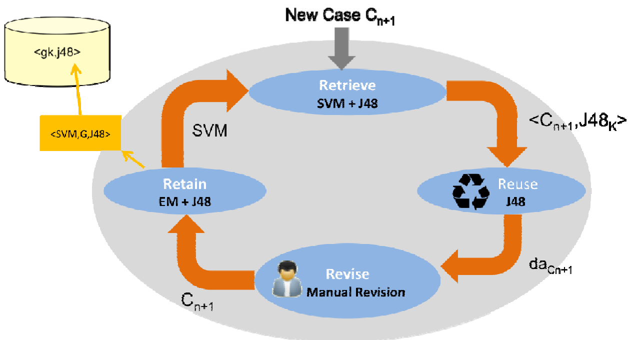

Fig. 2. CBR reasoning cycle

The retrieve phase is initiated when a new case arrives to the system. Then, it is associated or classified with one of the groups gk into which the memory is divided. Once the group is determined, the J48 classifier associated with the set is recovered or created, if it did not previously exist. In order to perform the classification, the SVM is applied.

```
store ← false;

// Retrieve phase
SVM ← retriveSVMFromDatabase();
g_k ← retieveMostSimilarCluster(SVM);
if ∃J48_k ∈ g_k then
    j48_k ← retrieveDecissionTree(g_k);
end
else
    j48_k ← buildDecissionTree(g_k);
end

// Reuse phase
da_{c_{n+1}} ← classifyNewInstance(j48_k, c_{n+1});
```

Fig. 3. Retrieve and reuse algorithm

During the revise phase, the classifier retrieved in the previous phase is applied to the new case, and a prediction is obtained.

The retain phase determines if the prediction made in the revise phase was satisfactory; if it was not, the prediction is updated. During the revise phase the expert confirms the prediction and during the retain phase the prediction is stored according to a results obtained. That is, the system is capable to detect new cases identified as anomalous, is capable to automatically cancel rules is to avoid launching a false positive of an alarm. If the prediction is incorrect, the new case is introduced into the system and the process of clustering and creating a classifier is carried out for each of the clusters created.

The EM (expectation-maximization) method [44] is used to create the clusters since it facilitates the creation of groups without requiring the number of clusters to be previously indicated. Additionally, it works with nominal data. Finally, the SVM is constructed according to the new groups and the system constructs the decision tree J48 for each group.

```
// Revise phase.  Manual revision.
if misclassified(da_{c_{n+1}}) then
    c_{n+1} ← reviseNewCase(c_{n+1});
    store ← true;
end

// Retain phase
if store then
    C ← C ∪ c_{n+1};
    G ← buildClusterEM(C);
    SVM ← buildSVM(C);
    storeSVM(SVM);
    foreach g_k ∈ G do
        j48_k ← buildJ48(g_k);
        store(j48_k);
    end
end
```

Fig. 4. Revise and retain algorithm

B. *Identification and Location Service*

The Identification and Locating service can identify and know the position of the user or a particular object at any moment.

The configuration used in the system is similar to the configuration of our previous system presented in [8]. It consists of a ZigBee tag mounted on a bracelet worn on the users' wrist or ankle, several ZigBee readers installed throughout protected zones, and a central workstation where all the information is processed and stored. These readers are installed all over the facilities so that the system can detect when a user is trying to enter a forbidden area according to the user's permissions profile. The ZigBee network also allows obtaining information of the environment from different sensors, such as temperature sensors, light sensors, as well as smoke and gas detectors. In addition, different locating techniques can be used as readers and tags carried by patients and medical personnel. These devices are small enough to be carried by a patient, a caregiver or even an object, and have a battery life of up to six months. The location of users is given as coordinated points obtained from the locating techniques provided by a locating engine [25].

The system allows users to keep track of any tag in the system as well as receive distinct alerts in real-time coming from the system in any Web-based device, such as PC or a smartphone carried by doctors and nurses. Some of the different alerts include panic button alerts (when users press a panic button on their tag or in a fixed device including such a button), forbidden area alerts (when users enter a forbidden area according to their permissions), as well as low-battery alerts (if a tag in the system should be recharged).

In a similar way as that of the previous module, it can also use algorithms to manage alerts related to the location of the users and objects in relation to the area in which they are found, permission, etc. It does so by employing a set of location algorithms [7], which provides greater precision in locating people than current location systems. These algorithms fuse the information gathered from different sensors: ZigBee, Wi-Fi, accelerometers and compasses.

The location system's start-up procedure was modified to avoid problems produced by these algorithms. Instead of calculating the position of a tag based on the position of the reader, we instead calculate a map of intensities for the environment. We take the tag and calculate the RSSI levels obtained for each reader in the different areas. Using this procedure, for every point (x,y) in a plan, we obtain a set of measurements represented in:

$$m_i = (x_i, y_i, node\_id_i^1, rssi_i^1, ..., node\_id_i^n, rssi_i^n) \quad (2)$$

where m_i represents the measurement i, x_i, y_i represent the x-coordinates and $node\_id_i^j$, which is taken from the plans for measurement, i represents the identifier for node j for measurement i, and $rssi_i^j$ represents the RSSI value of node j from measurement i. Using $m = \bigcup m_i$ we can build a classifier based on the data from m. The classifier is incorporated into the system's LocationAgent, which is in charge of determining coordinate x according to the values from the RSSI signals obtained from the different readers. The classes are defined according to the different pairs of values (x_i, y_i).

A Bayesian network was the method we decided to employ. There are various Bayesian network search mechanisms, including tabu search [38], K2 [38], HillClimber [38], TAN (Tree Argumented Naive Bayes) [33]. We have also used conditional independence, an algorithm based on the calculation of the conditional Independence test for the variables to generate a DAG that can obtain probability estimates. Assuming r pairs of different values for (x_i, y_i), the probability of measurement m belonging to class i applying classifier C is defined as follows:

$$p_i = C(m') \quad (3)$$

where m is the class with k<r if

$$p_k = Max\ (p_i)\, with\ i = 1 \ldots r \quad (4)$$

The algorithm simply places the tag in position (x_i, y_i) with greater probability.

IV. Results and Conclusions

A real-world case study was prepared in a medical care environment for the elderly to test the system. The proposed system was implemented in the "El Residencial La Vega" care facility in the city of Salamanca and was tested over a period of 8 months. El Residencial La Vega facility has residence areas for the elderly as well as rooms similar to their patients' home. The tests were carried out in two directions: (1) Test tools developed. And (2) test the rule system and the location algorithm.

With respect to the developed tools, two different tools have been developed to be used by different users of the system and where the results of the fusion of sensor data and information stored in the system can be consulted. All these functionalities are implemented with PANGEA, so we must make it clear that these features are just a sample of what could turn out to be because this platform is very easy to scale and the system can be enhanced.

The system includes a set of graphical interfaces that can display an enriched form of all the information provided by the agents based on the data they have received. This makes it possible to access all the system information and the systems themselves using practically any device that can execute a simple web browser.

Fig. 5. System interfaces

With respect to the results of the rule system and the location algorithm, the precision of the location algorithm was analyzed by comparing the mean absolute error obtained from applying the proposed procedure to the means obtained from multilateration and signpost. Besides, the Bayessian network was replaced by others classifiers in order to compare the performance. The calculation in the maps of intensities was performed by measuring the steps taken when walking through the different hallways and rooms. In each monitored area, a reference point was used to represent the area, manage the information, and therefore reduce the information that needed to be stored. In each room, a mesh was used to simulate movement patterns and obtain the surface of the room that was measured. The mean absolute error obtained is shown in Fig. 6.

In order to carry out the alarm detection procedure, the users' movement patterns were stored over a period of one week. During this time, the patterns were classified to include unusual behavior. The number of measurements taken is 983, following the information shown in table 1 and table 2. A total of 173 unusual situations were identified. This information was used to create a decision tree that was subsequently used to perform the classification. The rules that were generated are similar in form to the following rule: if User=13 and Node!=13001 and sensor=13002 and state=1 and measurements>10 then alarm=1. The rule refers to user 13, which is why the sensor identifiers and the nodes in the user's bedroom begin with 13. When 10 consecutive measurements are detected in a position different from the closest node, which is located in the refrigerator, an alarm will sound. When the rules are detected, as indicated in rule 1, where all the sensors and the user belong to the same room, they are generalized for all users so that the user ID, sensor and node information are all modified for the other users.

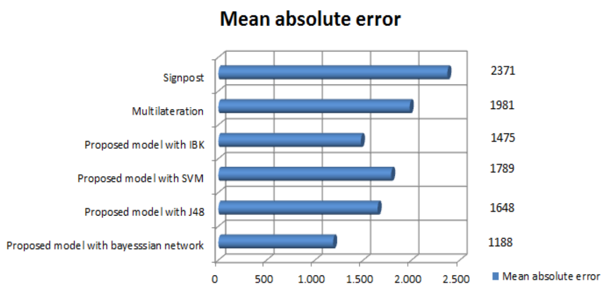

Fig. 6. Error Comparison Between Different Methods Applying Maps Of Intensity And Algorithms Without Them

The system was cross validated applying the one-leave-out technique, which resulted in an average prediction rate of 93.5%. The percentage of false negatives rose to 1.2% and the remainder were false positives.

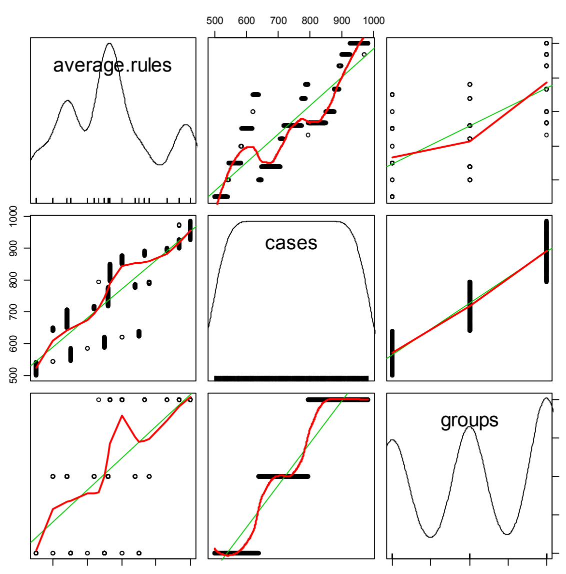

Fig. 7. Evolution of the system

In order to analyze the evolution of the system, we began with 500 cases and introduced new cases into the system until reaching 983, as previously indicated. Figure 7 shows the change in the number of groups in the case base, the evolution of the number of cases and the average number of rules for each group. The diagonal graphs represent the function of density for the indicated variable. For the remaining cells, file i, column j, the x-axis represents the variable indicated in cell ii, while in the y-axis the variable is associated with cell jj. The dot points represent each element; the red line represents the tendency according to the represented element, the green line the regression rect. For example, in file 1, column 2 we can see the variation of the average number of rules as the number of cases increases from 500 to 1000. We can see in the red line that the tendency increases as the number of cases also increases. However, we can see in the file 1 column 3 that the average number of rules for each group varies between 13 and 16. Similarly, the number of rules also increases, although to a lesser extent, with the number of groups, as shown in the graph shows.

It is possible to observe in the results that the system proposed goes beyond the performance of the system currently used in the La Vega Residence and improves the existing teleassistance system, providing learning and adaptation capabilities. These kinds of systems where the information fusion of heterogeneous devices are currently very limited, as they require the elderly patients to make a conscientious and deliberate effort in their home (for example, pressing the panic button) and do not offer an automated and intelligent detection of high risk situations. The proposed system characterizes an improvement with regard to existing platforms, as shown in its application in the case study. The case study incorporated a set of devices that comprise sensors, id or locating elements, push button actuators and interactive elements such as screens. The study also incorporated a control center that interacts continuously with the system and a data repository, which is very useful for tracing services and the personalization of spaces and services. As a whole, this presents an innovative intelligent multi-agent system aimed at improving health care and assistance to elderly and dependent people.

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References

[1] A. Pfeffer, S. Das, D. Lawless, B. Ng, Factored reasoning for monitoring dynamic team and goal formation, Information Fusion 10 (1) (2009) 99-106.

[2] B. Berstel, Extending the RETE algorithm for event management, in: Temporal Representation and Reasoning –Proceedings - Ninth International Symposium, 2002, pp. 49-51.

[3] B. Gottfried, H. W. Guesgen, S. Hubner, Spatiotemporal reasoning for smart homes, in Designing Smart Homes, in: The Role of Artificial Intelligence, Springer, 2008, pp. 16–34.

[4] C. Nerguizian, C. Despins, S. Affès, Indoor Geolocation with Received Signal Strength Fingerprinting Technique and Neural Networks, in: 11th Int. Conf. on Telecommunications, Fortaleza, Brazil, 2004, pp. 866-875.

[5] C. Zato, G. Villarrubia, A. Sánchez, J. Bajo, J.M. & Corchado, (2013). PANGEA: A New Platform for Developing Virtual Organizations of Agents. International Journal of Art. Intelligence, 11(A13), pp. 93-102.

[6] D. I. Tapia, J. A. Fraile, A. De Luis, J. Bajo, Healthcare information fusion using context-aware agents, in: Manuel Graña Romay, Emilio Corchado, and M. Teresa Garcia Sebastian (Eds.), Proceedings of the 5th international conference on Hybrid Artificial Intelligence Systems -

Volume Part I (HAIS'10), , Springer-Verlag, Berlin, Heidelberg, 2010, pp. 96-103.

[7] D. I. Tapia, J. A. Fraile, S. Rodríguez, R. S. Alonso, J. M. Corchado, Integrating hardware agents into an enhanced multi-agent architecture for Ambient Intelligence systems, Information Sciences 222(10) (2013) 47-65.

[8] DI Tapia, A Abraham, JM Corchado, RS Alonso. Agents and ambient intelligence: case studies. Journal of Ambient Intelligence and Humanized Computing 1 (2), 85-93. 2010.

[9] D. Isern, A. Moreno, Computer-based execution of clinical guidelines: A review, International Journal of Medical Informatics 77 (12) (2008) 787-808.

[10] D. Lymberopoulos, A. Bamis, T. Eixeira, A. Savvides, BehaviorScope: Real-Time Remote Human Monitoring Using Sensor Networks, in: Proceedings of the International Conference on Information Processing in Sensor Networks, 2008, pp. 533-534.

[11] D.I. Tapia, F. De la Prieta, S. Rodríguez, J. Bajo, J. M. Corchado, Organizations of Agents in Information Fusion Environments, in: L. Antunes, H. S. Pinto (Eds.), Progress in Artificial Intelligence - 15th Portuguese Conference on Artificial Intelligence - Portugal, 2011, 59-70.

[12] D.L. Hall, J. Llinas, An Introduction to Multisensor Information fusion, in: Proceedings of the IEEE. 85(1), 1997, pp. 6-23.

[13] Drools. The Business Logic Integration Platform (accessed December 2013) http://www.jboss.org/drools/

[14] E. Aarts, R. Wichert, Ambient intelligence, Technology Guide, Springer Verlag, Berlin, 2009.

[15] E.L. Waltz, J. Llinas, Multisensor Information fusion. Artech House, Norwood, USA, 1990.

[16] F. Castanedo, M.A. Patricio, J.M. García, J. Molina, Information fusion to Improve Trajectory Tracking in Cooperative Surveillance Multi-Agent Architecture, Information Fusion 11 (2010) 243-255.

[17] F. Zambonelli, Abstractions and Infrastructures for the Design and Development of Mobile Agent Organizations, in: Proceedings of the Agent-Oriented Software Engineering II, 2002, pp. 245-262.

[18] H. Alemdar, Cem Ersoy, Wireless sensor networks for healthcare: A survey, Computer Networks, 54, (15) (28) (2010). 2688-2710.

[19] H. Huo; Y. Xu; H. Yan; S. Mubeen, H. Zhang, An Elderly Health Care System Using Wireless Sensor Networks at Home, in: Sensor Technologies and Applications SENSORCOMM'09. Third International Conference, , 2009, pp. 18-23.

[20] H. Luo, S. Yang, X. Hu, X. Hu, Agent oriented intelligent fault diagnosis system using evidence theory, Expert Systems with Applications, 39 (3) (2012) 2524-2531.

[21] H.V.D Parunak, J. Odell, Representing Social Structures in UML, in: Wooldridge, M., Weiss, G., Ciancarini P. (Eds.), Agent-Oriented Software Engineering II, 2002.

[22] J. Bajo, J. Vicente, J.M. Corchado, C. Carrascosa, Y.D. Paz, V. Botti, J.F.D. Paz, An execution time planner for the ARTIS agent architecture, Engineering Applications of Artificial Intelligence 21 (2008) 769-784.

[23] J. Pavon, J.J. Gomez-Sanz, Agent oriented software engineering with ingenias, in: V. Marik, J.P. Müller, M. Pechoucek (Eds.), Proceedings of CEECMAS, Heidelberg, Germany, 2003, pp. 394–403.

[24] J. Sarangapani, Wireless Ad hoc and Sensor Networks: Protocols, Performance, and Control, first ed., CRC Press, Boca Raton, 2007.

[25] J.F. De Paz, D.I. Tapia, R.S. Alonso, C.I. Pinzón, J. Bajo, J.M. Corchado, Mitigation of the ground reflection effect in real-time locating systems based on wireless sensor networks by using artificial neural networks, Journal of Knowledge and Infor. Sys 34 (1) (2013) 193-217.

[26] K. P. Hung, G. Tao, X. Wenwei, P.P. Palmes, Z. Jian, N. Wen Long, W. T. Chee, H. C. Nguyen, Context-aware middleware for pervasive elderly homecare, IEEE Journal on Selected Areas in Communications 27 (4) (2009) 510-524.

[27] K. Sycara, R. Glinton, B. Yu, J. Giampapa, S. Owens, M. Lewis, LTC C. Grindle, An integrated approach to high-level information fusion, Information Fusion 10 (1) (2009) 25-50.

[28] L. GokceB, A.D. Asuman, A.O. Mehmet, A.T. Ibrahim, A.Y. Mustafa, A.O. Alper, SAPHIRE: A Multi-Agent System for Remote Healthcare Monitoring through Computerized Clinical Guidelines, in: R. Annicchiarico, U. Cortes, C. Udiales (Eds.), Agent Technology and e-Health, Whitestein Series in Software Agent Technologies and Autonomic Computing, Springer Verlag, Berlin, 2008, pp. 25-44.

[29] M. Esteva, Electronic Institutions: from specification to development Ph. D. Thesis, Technical University of Catalonia, Spain, 2003.

[30] M. Marin-Perianu, N. Meratnia, P. Havinga, L. de Souza, J. Muller, P. Spiess, S. Haller, T. Riedel, C. Decker, G. Stromberg, Decentralized enterprise systems: a multiplatform wireless sensor network approach, IEEE Wireless Communications 14 (2007) 57-66.

[31] M. Wooldridge, N.R. Jennings, Agent Theories, Architectures, and Languages: a Survey, in: ECAI-94 Proceedings of the workshop on agent theories, architectures, and languages on intelligent agents,Amsterdam, The Netherlands, 1995, pp. 1-22.

[32] M.L. Borrajo, J.M. Corchado, E.S. Corchado, M.A. Pellicer, J. Bajo, Multi-Agent Neural Business Control System, Information Sciences 180 (6) (2010) 911-927.

[33] N. Friedman, D. Geiger, M. Goldszmidt,. Bayesian Network Classifiers, Machine Learning 29 (1997) 131-163.

[34] N. Jennings, M. Wooldridge, Agent Technology:Foundations, Applications and Markets, Springer, Germany, 1998.

[35] O. Boissier, B. Gateau, Normative multi-agent organizations: Modeling, support and control, in: G. Boella, L. W. N. van der Torre, H. Verhagen (Eds.), Normative Multiagent Systems, Germany, 2007.

[36] P. George, X. George, P. George, Monitoring and Modeling Simple Everyday Activities of the Elderly at Home, in: 7th IEEE Consumer Communications and Networking Conference, Las Vegas, USA, 2010, pp.1-5.

[37] P. Rashidi, D. J. Cook, Keeping the resident in the loop: Adapting the smart home to the user, IEEE Transactions on Systems, Man. and Cybernetics39 (5) (2009) 949–959.

[38] R.R. Bouckaert, Bayesian Belief Networks: from Construction to Inference, Utrecht, Netherlands, 1995.

[39] R.S. Alonso, D.I. Tapia, G. Villarrubia, J.F. De Paz, Agent Technology and Wireless Sensor Networks for Monitoring Patients in Residences and Their Homes, 11th International Conference In Practical Applications Of Agents And Multiagent Systems – Workshop on Agents for AAL and E-health, Salamanca, Spain, 2013, pp. 417-418.

[40] R.S. Alonso, D.I. Tapia, O. García, D. Sancho, M. Sánchez, Improving Context-Awareness in a Healthcare Multi-Agent System, 9th International Conference In Practical Applications Of Agents And Multiagent Systems – Workshop on Agents for Ambient Assisted Living, Salamanca, Spain, 2011, pp 1-8.

[41] S. Pang, T. Ban, Y. Kadobayashi, N. Kasabov, Personalized Mode Transductive Spanning SVM Classification Tree, Information Sciences 181 (2011) 2071-2085.

[42] S. Rodríguez, F. De la Prieta, E. García, C. Zato, J. Bajo, J.M. Corchado, Virtual Organizations in Information Fusion, in: 9th International Conference In Practical Applications Of Agents And Multiagent Systems – Special Session on Adaptive Multiagent Systems, Salamanca, Spain, 2011, pp. 195-202.

[43] S. Rodríguez, Y. De Paz, J. Bajo, J. M. Corchado, Social-based planning model for multiagent systems, Expert Systems with Applications38(10) (2011) 13005-13023.

[44] T.K. MoonEM. The expectation-maximization algorithm. Signal processing magazine, IEEE, 13(6), 1996, pp. 47-60.

[45] V. Dignum, A model for organizational interaction: based on agents, founded in logic, PhD. Thesis, 2004.

[46] W.L. Seon, K. Yong-Joong. L. Gi-Sup, O.C. Byung, L. Nam-Ha, A Remote Behavioral Monitoring System for Elders Living Alone, in: 7th International Conference on Control, Automation and Systems, Seoul, Korea, 2007, pp. 2725-2730.

[47] Y.H. Liu, S.Z. Wang, X.M. Du, A multi-agent information fusion model for ship collision avoidance, in: Proceedingsof the International Conference on Machine Learning and Cybernetics, 2008, pp. 6-11.