# Intelligent Context-based information fusion system in Health Care: Helping people live healthier

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***Abstract - Research on Intelligent Systems and context-based information fusion has matured during the last decade and many effective applications of this technology are now deployed. Context-based information fusion provides large quantities of information obtained from network sensors with heterogeneous characteristics, that needs to be efficiently processed. This paper proposes an intelligent system aimed at processing context information in health care environments. The system monitors patients and maintains a permanent fix on their location within a given context. The system uses information provided by sensors distributed throughout the environment. The intelligent agents take the information they receive and fuse it to improve the decisions and actions involved in their processing. This paper describes the proposed approach, focusing on the solutions provided by the agents through the information flow for the system.***

**Keywords:** Intelligent systems, context-based information fusion systems, Intelligent systems for fusion processing, Adaptive fusion system architectures.

## 1 Introduction

Information fusion has become increasily relevant during the last years. One of the reasons is the growing importance as rapid advances in sensor technology that provide information from the environment [11]. The sensors can be used to enable information fusion applications in different environments such as remote sensing, surveillance, home care, etc [5]. With the continuing expansion of the domain of interest and the increasing complexity of the collected information, intelligent techniques for fusion processing have become a crucial component in information fusion applications. The problem of Information Fusion has attracted significant attention in the artificial intelligence community, trying to innovate in the techniques used for combining the data and to refine state estimates and predictions. Intelligent systems can improve information fusion based on the context management aimed at supporting decision making, since the quality of decision making depends upon the quality of information at hand. A clear example are the multi-agent systems or the intelligent agents used for context-awareness that can provide both distributed fusion and advanced reasoning capabilities. Multi-agent systems can fusion information from different sources in a given environment and incorporate intelligent methods capable of facilitating decision support systems.

There is currently a considerable variety of sensors that can observe user contexts. The diversity of characteristics: observable parameters, temporal and sample cales, means of acquisition, etc., is a source of practical problems that, if they are to be solved, must be clearly understood [2]. Within the user context, the high level of dynamism is tied to important restrictions and factors to consider. Data fusion can improve the perception of the context information and solve some of these problems. These methods seek to widen the observational space, increase the contextual and temporal coverage, reduce ambiguities, and supplant any shortcomings in any individually considered contextual observations [2].

The search for effective and non-invasive solutions within a user context brings us to context-aware systems. These systems store and analyze all of the relevant information that surrounds and forms part of the user context. The user´s preferences, taste, location, frame of mind, activities, surroundings, vital signs, as well as the room temperature and lighting conditions, etc., comprise the information that can be classified as the initial context information, and can be easily captured from the user´s residence. The information is usually acquired through sensors located in different Wireless Sensor Networks (WSN). The current trend for displaying information to system users, given the large number of small and portable devices, is through an arrangement of distributed heterogeneous systems and WSN.

In this regard, multi-agent systems [6] facilitate the development of context-aware environments in the home. Multi-agent systems have been studied recently as monitoring systems [4] for the medical care [6]of sick and dependent individuals in their home [6][8]. These systems provide continual support in the daily life of these individuals, predicting potentially dangerous situations and managing the physical and cognitive assistance of each person [1]. Taking these solutions into account, it is logical to conclude that multi-agent systems facilitate the design and development of home care environments [1] and improve the services currently available, incorporating new functionalities. Multi-agent systems add a high level of abstraction regarding to the traditional distributed computing solutions.

This article presents the and improvement of the HealthCare Context-Aware Computing (HCCAC) multi-agent architecture, which is capable of supervising and monitoring persons in healthcare contexts. The goal of the HCCAC architecture is to provide solutions for the wellbeing of its users, by incorporating itself indistinguishably into their daily lives [6]. HCCAC integrates CBR-BDI [6] agents that are capable of learning beyond their initial knowledge, interacting autonomously with their environment. The coordination process among agents should organize the flow of information in such a way that the communication between the different agents, each equipped with a sensor, and the agent that incorporates the information, can be translated into an optimal use of global resources. HCCAC has been improved incorporating new mechanisms to facilitate the interaction with wireless sensor networks (WSNs) [4]. The new mechanism is based on a Service-Oriented Architecture (SOA) model for integrating heterogeneous Wireless Sensors Networks into HealthCare systems. The communication between the agents and the devices takes place with wireless technologies like ZigBee [7], while Radiofrequency (RFID) is used for identification [4]. These technologies provide the structure that is required for supporting the communication needs for the system agents with devices and data handling equipment. The simple integration and interaction between intelligent agents, sensors and devices is what led us to propose this new approach.

The remainder of the paper is structured as follows: section 2 presents the problem description. Section 3 describes the monitoring system for health care environments. Section 4 describes the Interpreter agent, the core of the architecture. Finally, section 5 presents the preliminary results obtained and section 6 describe the conclusions extracted from this study.

## 2 Background and Problem Description

Integrated information systems generally process very heterogeneous information. When the approach presented within this paper presents its information diagram to an agent that is requesting certain results, it must omit the variety of integrated information that the system has assembled. Consequently, the system has two fundamental tasks: (i) to integrate a known set of data sources that refer to a diagram of individual data and (ii) to generate a new unified diagram, based on individual diagrams, that is complete, summarized and comprehensible.

Recent years have given way to a number of multi-agent architectures that utilize data merging to improve their output and efficiency. Such is the case with Castanedo et al. [3], amplify the CS-MAS architecture to incorporate dynamic data fusion through the use of an autonomous agent, locally fused within the architecture. This agent is created dynamically by a centrally fused agent. These agents work in conjunction with the agents that control and manage the sensors to capture information. Therefore, at any given moment, there may be several locally fused autonomous agents that can generate duplicate information. There are also systems, such as that presented by Pfeffer et al. [10], which are based on the use of agents to supervise objectives within a dynamic environment. This system performs data fusion at the level where agents supervise objectives. The agents do not provide a coordinated approach in the supervision of objectives and, as a result, can make important objectives susceptible to attacks. The system attempts to avoid these attacks by creating supervising teams, but the information still remains dispersed among each of the supervisor agents. Other models, such as the one presented by Liu et al. [7] attempt to avoid the collision and inconsistency of data by using an information fusion method. The model is formed by two agents and three levels of data fusion that attempt to locate the most optimal and non-redundant data model. This system [7] focuses exclusively on fusing information without taking the data sources into account. It is also true that there are a number of systems, such as HiLIFE [11], which cover all of the phases related to information fusion by specifying how the different computational components can work together in one coherent system. These phases can range from the data fusion algorithms that operate in heterogeneous networks, to the computational methods that combine low and high level information, and dynamically manage intelligent sensors to acquire additional data. HiLIFE has also been integrated into the RETSINA [11] multi-agent system, which provides an agile and sophisticated reasoning mechanism using the information fused by HiLIFE.

The aforementioned studies clearly focus on information fusion with regards to multi-agent systems. There are data fusion models that obtain an optimized and efficient diagram. Few systems attempt to combine information fusion with information gathering components. Those that have attempted, do so through the union of two systems that have been developed independently, as is the case with Hi-LIFE and RETSINA[11]. Our study would like to go one step further and, in addition to capture information from multiple sensor networks, equip each agent with data fusion capabilities so that they can structure the information they receive both consistently and without redundancy.

## 3 Monitoring health care system

This section describes the main features of a monitoring system that integrates the HCCAC architecture [5] and wireless sensor networks and is aimed at improving healthcare of dependent people. The HCCAC system is based on a multi-agent architecture that is comprised of various types of intelligent agents [5]. The primary agent in HCCAC is the Interpreter Agent, which is integrated into the system. The purpose of this agent is to provide solutions for the wellbeing of the user through the use of action plans based on the information provided by the WSN sensors. The most important characteristics of the system are: (i) the Interpreter Agent has reasoning capability; it can analyze and reason the context data gathered by the system and provide proactive solutions, (ii) the Interpreter Agent can easily adapt to the context within which it acts, (iii) gather sensor data and messages from other agents in order to provide efficient solutions and (iv) the Interpreter Agent performs a data fusion with the information received. The system uses several WSNs in order to automatically gather context information. Based on the data received by the WSNs, the Interpreter agent fuses, evaluates and reasons the data in order to develop action plans and initiate events that affect the sensors that are also connected in the WSNs.

Figure 1 shows the basic communication and infrastructure schema of the monitoring system. A network of ZigBee devices has been designed to cover each patient to be monitored. Each of the monitored patients carries a ZigBee remote control that incorporates a button which can be pressed in event of needing remote assistance or urgent help. Moreover, there are a set of ZigBee sensors that obtain information about the environment (e.g. light, smoke, temperature, doors' states, etc.) in which the user lives and that physical response to the changes (e.g. light dimmers, fire alarms or door locks). Each of these ZigBee nodes includes a C8051F121 microcontroller and a CC2420 IEEE 802.15.4 radiofrequency transceiver.

Each of the ZigBee and Bluetooth devices are connected as nodes. Each of the nodes are controlled by a Provider agent in the HCCAC system, which is in charge of gathering the information from the sensor, applying the first filtering process to the information received, and sending the information to the Interpreter agent.

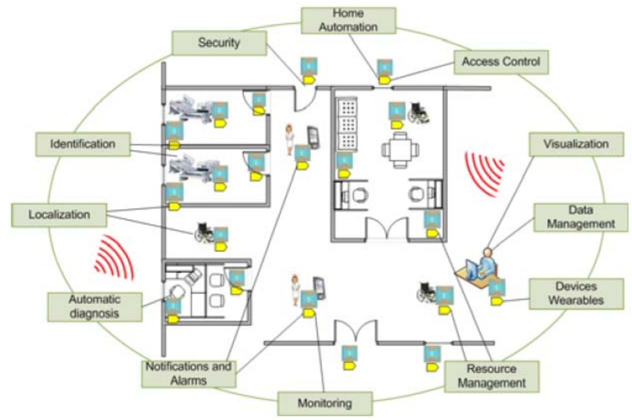


Fig. 1. WSN at healthcare facility.

There is also a computer and mobiles connected to a remote healthcare monitoring center via Internet. Alerts generated by the Interpreter Agent can be forwarded from the patients' homes to the caregivers in the remote center, allowing them to communicate with patients in order to check possible incidences. These alerts can be, for instance, the detection of a patient's fall or a high smoke level in the patient's home. This computer acts as device to control the Interpreter Agent and ZigBee master node through a physical wireless interface (e.g. a ZigBee network adapter as a ZigBee USB (Universal Serial Bus) dongle or a ZigBee node connected through the computer's USB port). The computer is also the master node of a Bluetooth network formed by the sensors working as slave nodes.

The following section provides a detailed explanation of the information that is obtained from the environment, how it is fused, stored, and finally, how it is processed and represented.

## 4 Interpreter Agent

The purpose of this agent is to improve the quality of life for the user by providing efficient and relevant solutions in execution time. The most important characteristics of the system are: (i) the Interpreter Agent has reasoning capability; it can analyze and reason the context data gathered by the system and provide proactive solutions, (ii) the Interpreter Agent can easily adapt to the context within which it acts and (iii) gather sensor data and messages from other agents in order to provide efficient solutions. In order to meet the user´s expectations, the Interpreter Agent is based on Case Based Reasoning (CBR).

The Interpreter agent proposed in the framework of this research is a CBR-BDI type of agent specially adapted to resolve the context information-based problem. These agents use the concept of CBR to gain autonomy and improve their problem-solving capabilities. The method proposed in [20] facilitates the incorporation of case-based reasoning systems as a deliberative mechanism within BDI agents, allowing them to learn and adapt themselves, lending them a greater level of autonomy than what is normally found in a typical BDI architecture [19]. Accordingly, Interpreter agents can reason autonomously and therefore adapt themselves to environmental changes. The case-based reasoning system is completely integrated within the agent architecture. The Interpreter agents incorporate a “formalism” that is easy to implement, in which the reasoning process is based on the concept of intention. Intentions can be seen as cases, which have to be retrieved, reused, revised and retained. A direct relationship between case-based reasoning systems and BDI agents can also be established if the problems are defined in the form of states and actions.

Case Based Reasoning uses past experiences to solve problems [20]. The objective of CBR systems it to solve new problems by adapting solutions that have been used to solve similar problems in the past. The Interpreter Agent also utilizes the concept of Case Based Planning (CBP) to generate solution plans, using past experiences and planning strategies. One example of how the Interpreter Agent works is its ability to apply the user´s temperature preferences when the user´s presence is detected within the environment. The system stores user preferences for the desired temperature. The system also stores the case base for the same user with past temperature preferences and similar temperature conditions, including external temperatures. The Interpreter Agent uses this information and similar case base plans to automatically adjust the control mechanism for the temperature when it detects the presence of the user. The system can thus maintain the desired temperature for each user within a specific context. The following section describes the design of the Interpreter Agent in greater detail.

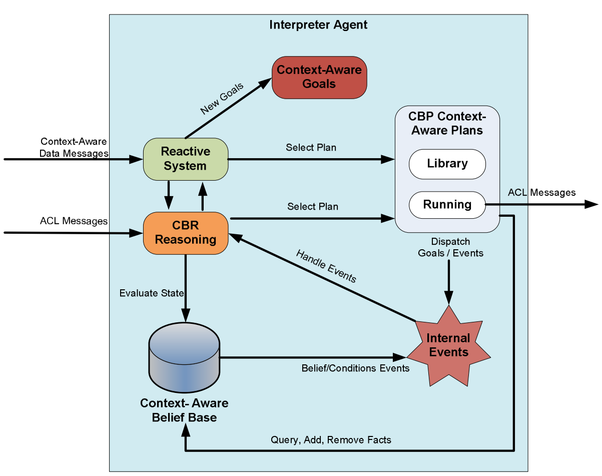


**Fig. 2.** Overview of the Interpreter Agent Architecture.

Figure 2 provides a summary of the architecture for the Interpreter Agent. All messages received by the Interpreter Agent, as well as internal events and new goals, are the first steps towards the internal reactions and the deliberative and reasoning mechanisms processed by the Interpreter Agent. The most significant new feature of the Interpreter Agent´s design, as seen in figure 1, is the integration of a CBR reasoning engine and a reactive system that gathers data from the sensors and control systems. This makes the design unique in its conception and reasoning capabilities. Based on the results from the CBR reasoning engine, the Interpreter Agent sends plans through the CBP Context-Aware Plans. These plans can be executed immediately as events, or new plans can be generated and stored in the context-aware library to be executed at a future time. The execution of plans can modify the base of context-aware beliefs, send messages to other agents, create new context-aware goals or produce internal events. These action plans can respond to sensors installed in the system and facilitate the user´s daily tasks, making the time spent by the user in the context-aware environment much more comfortable. The plans are used by different types of HCCAC system agents that manage the active devices. The functionality implemented in Java classes can also be incorporated in other similar systems. The next section presents a low level AUML design for the Interpreter Agent, followed by the implementation of Jadex.

As shown in figure 3, the AUML design produces a diagram of classes for the Interpreter Agent, the most important agent within the HCCAC architecture. The agent has five capabilities and four services, as described in figure 3. The capabilities are: (i) P-Solution, (ii) C-Sensor, (iii) S-Plans, (iv) St-Data and (v) E-Result. The services are: (i) Provide Information (ii) Describe Plan, (iii) Provide Plan Result and (iv) Component Task Assignment.

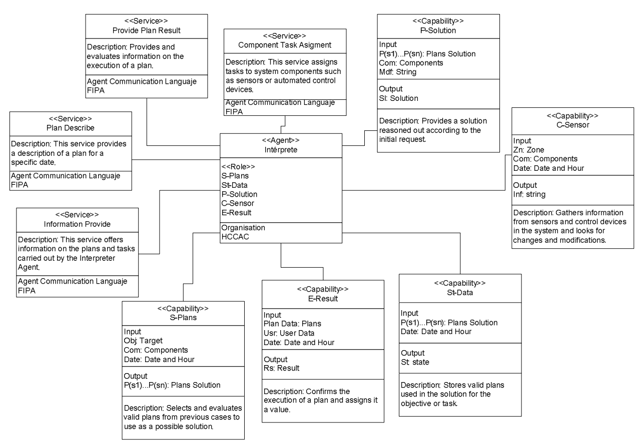


Fig. 3. Diagram of the different classes for the Interpreter Agent.

## 4.1 Context Information

The Interpreter agent performs a detailed analysis of the information that it received in order to generate efficient solutions. The capabilities of the Interpreter agent can be analyzed as follows. To begin, the Interpreter agent administers and fuses the information, and distributes tasks among the remaining system agents, which in turn communicate with the Interpreter agent to transmit any changes in the context, tasks, or additional specific user information, which is then updated by the Interpreter agent. The Interpreter agent manages all cases of inserting, deleting and updating each user. It controls the connection and disconnection of the users to the system. It continually calculates the location of the users, informing where each one is located. Additionally, it is responsible for optimizing the task planning prior to any event that may require a new plan, such as with the number of system users, or when there is a change in the condition of the context, for example, a sudden change in temperature, or a gas or water leak.

**Scheme**: Interpreter Agent

**Description**: Manages the database and distributes the tasks among the remaining agents in the system.

**Attributes**:
User - Location – Temperature – Gas Control – Fluid Control - LocationGPS – Light Control – Smoke Control – Preferences - OnOffDevice

**Protocols and Activities**:
ConsultBD, UpdateBD, Make Planning, Send Planning, Discharge Conection, User Disconnection, Access Control, Response Context Request, Get User List, Generate Context Change, Alert Response, Change Conditional Context, Information Request, Location Request, Terminal Discharge, Terminal Cancel.

**Permits**:
Update (User | Terminal | Location | Planning | Login | Alert)

**Responsabilities**:
Interpreter = (ConsultBD | UpdateBD | Make Planning | Send Planning | Discharge Login | User Disconnection | Access Control | Response Context Request | Get User List | Generate Context Change | Alert Response | Change Conditional Context | Information Request | Location Request | Terminal Discharge | Terminal Cancel)

Fig. 4. Diagram of the Interpreter agent.

Figure 4, which provides a diagram of the Interpreter agent, describes the information that it gathers and manages, its protocols, activities, permission and responsibilities. The Interpreter agent has a context-aware belief base in which it stores all events that constitute its knowledge base. It structures these beliefs and relates them within the context-aware environment and with the user. The beliefs may include: (i) the location of the user taken from a RFID (Radio Frequency Identification) chip carried by the user, and transmitted by the location sensors to the system, (ii) the exterior temperature captured from web services, (iii) the interior temperature gathered from ZigBee temperature sensors connected to the WSN, (iv) the illumination gathered from the ZigBee light sensors connected to the WSN, and (v) the level of smoke taken from the ZigBee smoke detectors connected to a WSN. All of these data are initially captured and filtered by the HCCAC system provider agents. The provider agents send this information to the Interpreter agent, which stores and processes it. When the Interpreter agent received this information during the fusion process, it can do one of three things: (i) accept the information, because it is completely coherent and non-redundant, and therefore useful for reasoning and actions within the environment, (ii) reject it because it is duplicate information that the agent already contains and is therefore disposable, or (iii) refine the information, which is useful but cannot be stored as is, and requires a specific type of processing. One example of refining information is when the Interpreter agent receives the same status information from a particular sensor. In this case, the Interpreter agent does not store all the information it receives; instead it groups it according to periods of time in which the sensor status has not changed.

All actions are structured through Java objects, which represent beliefs. These objects each have a name and attributes that have simple or multiple values, according to the type of information that the attribute stores. For example, an object that represents the information from the smoke detector will have an attribute with a simple value that indicates whether the fire alarm should or should not sound, and another object that represents the information for the temperature will have an attribute with a multiple value that indicates a range of temperature within specific periods of time. The beliefs base also incorporates the concept of data bases related to objects. The language for queries related to objects, Object Constraing Language (OCL) used in the HCCAC system, can recover subsets of contextaware beliefs. The filtering conditions for beliefs represent an expression of a particular state, for example one or more than one belief. Once the condition is satisfied, an internal event is generated, and this event activates a plan or gives way to dopting a new set of objectives. In the Interpreter agent, beliefs represent changes in the state of the sensors installed within the context-aware environment. This makes it possible to easily add new types of sensors that can assist in the daily tasks of the user, or to add a new state for a given sensor to a task plan at a future time. All of the task plans and actions plans specific to the Interpreter agent contribute towards achieving the final objective.

## 5 Results

Context-based information [17] is particularly promising as a support for health care environments. Sensors and communication devices facilitate sending and receiving information in a ubiquitous and non-intrusive manner. The system presented in this paper proposes an innovative technological solution consisting of an intelligent environment for monitoring health care environments. An initial prototype has been constructed and the system has been tested under simulation conditions, and the results obtained are promising. To validate the system, we designed a series of tests. The tests, which involved 50 patient agents, 10 nurse agents and 2 doctor agents, allowed us to evaluate the system. Specifically, the simulation time established for the experiments was a period of 5 weeks. The evaluation was mainly focused on monitoring the activities of the patients, in order to evaluate the proposal compared to a previous one [14].

The incorporation of new RFID and NFC sensors into the care environment significantly improves a number of functions that include monitoring attempted escapes, controlling medication and food intake, and detecting anomalies in the patient's behavior, as shown in Table 1.

TABLE 1. Comparison of control functions in the home care facility before and after implementing the improved HCCAC system

| Sensors | Control escapes | Control Medication | Control Food Intake | Anomalies in Patient behavior |
|---|---|---|---|---|
| Before HCCAC | 64 | 91 | 86 | 46 |
| After HCCAC | 93 | 100 | 100 | 85 |

Table 1 shows the percentage of success in controlling various functions within the care facility. The improved HCCAC system provides succesful behaviour in controlling attempted escapes, allowing for an immediate response in 93% of the cases. Additionally it is possible to control the medication and food intake of each patient with a 100% efficiency rate. The system makes it possible to avoid errors in the administration of medication and the special diets for the patients. Finally, the new sensor network makes it possible to detect anomalous behaviors among demented patients and create behavior patterns for risky situations. The Interpreter agent takes into account past experiencies in order to organize the new tasks in the system. In this sense, the improved HCCAC system takes advantage of the previous experiences and learns these past lessons. This behaviour provides a great capacity for adaptation, as show the results obtained and shown in Table 1.

## 6 Conclusion

The approach presented in this paper acts like a global system in context-aware systems. It not only captures information from its surroundings and responds users requests, but it also collaborates with the information system to constantly evaluate the attributes of the user´s context and provide proactive solutions. The solutions provided by the system are supported by a knowledge base that the system continually stores and processes. The approach presented in this paper can be considered as a novel system compared to others context-aware types of works [13] [15] [16] [18]. Other studies have focused on gathering data from the user´s position. Others, such as [17], in addition to locating users within the context, try to improve the communication in a hospital center between patients and medical personnel by capturing such context attributes as weather, the patient´s state or the user´s role. However, the new services offered in our proposal allow a closer and more natural and indirect interaction. The user can perform daily tasks and receive support from an intelligent environment without needing direct interaction. As a result, the user does not actually need to learn to use the system since the system itself manages the environment, and user satisfaction is notably increased.

Although there is still much work to be done, the system prototype developed in this study improves security in health care environments, to take care of dependent persons through the use of control and alert devices. It also provides additional services that automatically react to emergency situations. As a result, the improved HCCAC system creates a context-aware environment that facilitates the development of distributed intelligent systems and provides services for health care purposes. This makes it possible to automate certain monitoring tasks and improve the quality of life for the individuals. Furthermore, the proper use of mobile devices facilitates social interactions and knowledge transfer. Our future work will focus on obtaining a model that can define contexts and improving the proposed prototype and testing it on real environments, on patients with different needs and characteristics.

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