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A Multi-Agent Based Approach to Support Adaptability in Home Care Applications

A. Armentia*, U. Gangoiti*, R. Priego*, E. Estévez, M. Marcos***

**Dept. Ingeniería de Sistemas y Automática. ETSI Bilbao, UPV/EHU*
Spain (e-mail: aintzane.armentia, unai. gangoiti, rafael.priego, marga.marcos@ehu.es)
***Dept. Ingeniería Electrónica y Automática EPS de Jaén*
Spain (e-mail: eestevez@ujaen.es)

Abstract: Health systems are evolving to cope with the increasing costs of providing high-level medical care to elderly people maintaining their quality of life. Smart homes, where ambient and biomedical sensors can coexist, have become a suitable approach to address the main goals of home care scenarios: preventive care, recognizing deteriorating health and allowing a personalized care. To achieve these goals, applications have to exhibit adaptability and availability among other characteristics. Adaptability allows tracking the patient's state as well as reacting to abnormal situations. Availability ensures the execution of the application under failure of processing devices. In order to meet these requirements, this paper proposes a general-purpose middleware architecture based on multi-agent technology that provides mechanisms to: develop customizable applications based on the separation of concerns principle; manage the execution of applications; support adaptability by means of event-based relationships among applications; ensure availability through the use of replicated agents. The performance of the proposed middleware is assessed in terms of reaction time to adapt to irregular situations for different availability levels (number of replicated agents) and number of application services.

Keywords: Multi-agent System; Home Care; Availability; Adaptability.

1. INTRODUCTION

Ongoing population's ageing process is becoming one of the main challenges in developed countries as it results in a substantial increasing of social and financial loads (World Health Organization, 2013; United Nations, 2001; World Health Organization, 2011). Indeed, elderly demand concrete and long-term medical services which imply high expenditures in public health systems, whilst they need their independence living at home. Thus, medical care should not interfere with their daily living. In this context, several institutional initiatives (European Commission, 2013, 2014; AAL JP, 2012) have been and still are aiming at providing elderly with suitable medical care enhancing their quality of life without leaving homes, and relieving, at the same time, medical expenses.

During the last years, smart homes have become a promising opportunity to foster independent living together with the required medical care, as they integrate ambient intelligence and automatic control (Sadri, 2011; De Silva et al., 2012). In these smart environments, buildings are enriched with ambient sensors whilst people are equipped with biomedical sensors. Several processing nodes analyze the gathered data deciding the actions to take in order to allow a never-ending supervision of the residents and their environment. Therefore, the system infrastructure is composed by a set of different types of nodes. Among them, it might be embedded devices with limited available resources, such as mobile phones, biomedical sensors, and environmental sensors.

Home care is aimed at providing preventive care, recognizing deteriorating health and allowing a personalized care. Thus, home care applications have three main objectives: (1) monitoring, (2) early recognition, and (3) rapid and suitable reaction. The patient's health is monitored by means of sensing its vital functions. On the other hand, environmental measures are also acquired. Both types of measurements must be performed at the right frequency. This allows a continuous knowledge about the evolution of the patient's status. In addition, the analysis of these data can be used to foresee possible hazardous situations. In case of emergency, all the collected information can be used to provide the most suitable and personalized care. Indeed, although medical guidelines are used to guide decisions about specific health problems in a general way, the medical treatment of a patient has to be customized to its health and environment. For instance, pulse rate is always measured in the same way, whilst the reaction to the same value depends on various factors including the patient's age, the amount of exercise, the air temperature, etc.

In summary, a correct management of home care applications for elderly requires:

- Mechanisms for defining the sensing (periodic or on demand) and processing of biomedical and environmental signals, as well as the actions to take.
- Mechanisms that allow applications to evolve as patient's status does (adaptability) which results in

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reacting to irregular situations without direct external intervention. This requires mechanisms to initiate the processing of new biomedical variables as a result of the processing of others, or even as a result of a change in environmental conditions. For example, in case of fire it might be useful to monitor patients' vital signs in order to provide a first level care when emergency services arrive. Additionally, resource consumption may also be a constraint, mainly when embedded devices are involved.

- Mechanisms for managing widespread devices with different capabilities (from embedded devices to those with high processing capacities).
- In home care applications it is important to guarantee that information about patients and application state is not lost, especially in emergency cases. Therefore, applications' availability should be guaranteed even in case of node failure.

From an implementation point of view, multi-agent systems are suitable for developing adaptive applications such as those for home care as they are able to answer to changes on their environment (Weiss, 1999). There is not a unique definition for agents, but their main characteristics were identified in (Wooldridge et al., 2009): agents are *autonomous*, being able to make decisions without direct human intervention. They are also *proactive* as their behavior is goal-directed, and *reactive* as they are able to answer to changes on their environment. Finally, agents are *social* considering that they interact, including negotiation.

Indeed, the use of agent technology in health care is not new as it is reviewed in (Isern et al., 2010). However, many works are based on the use of agents with concrete roles aimed at facing particular problems, where every agent is defined and developed for a specific purpose (Kaluža et al., 2010), and those in (Isern et al., 2010). Therefore, the application is monolithic and it includes the service to be provided as well as the mechanisms to fulfill non-functional requirements. The work in (Su et al., 2011) presents an agent-based platform that allows monitoring of the vital signs of distributed patients, and automatically warning of abnormal situations to the medical staff. With this purpose, six different types of agents are distinguished, each one with a concrete set of generic tasks. Thus, the functionalities an agent can perform are limited. The architecture proposed in (Bajo et al., 2010) combines agent technology and service orientation, offering specific services for the registration of services, their implementations, and virtual organizations. It allows modifying the organizational structure by creating new organizations, or by adding and resigning members. However, this capability is restricted to concrete roles with high permission level. In a crisis management scenario, system availability to users is assured in spite of node failures, by means of the application design, the communication protocols established among agent roles, and by means of human intervention (García-Magariño et al., 2013). Nevertheless, as far as authors know, there is no mechanism to recover into other nodes the tasks of the agents running on the failed node.

In this context, this work is focused on offering a generic infrastructure that manages distributed applications for home care. Applications are executed under the control of a general-purpose multi-agent middleware that makes use of the design principle of separation of concerns. It offers generic mechanisms to define customized applications for elderly care at home, meeting the requirements previously stated. It supports the adaptability of applications by means of the definition of an event-based ontology, whilst it also controls the execution of several applications. With this purpose, it proposes an agent structure that makes a clear distinction between the service provided by the agent (specific to each agent) and the management tasks specific of the middleware platform (common to all agents). This separation makes it easier the development of applications, so that the software developer only has to provide the service to run in each agent, regardless of the underlying platform or technology. Moreover, this middleware can be applied to other application domains with similar requirements.

The layout of the paper is as follows: section 2 presents the foundations for designing target applications that have to react to changes on the patient's status, identifying also the requirements to fulfill by a middleware. As an example of application design, a case study is described which is also used in Section 3 to illustrate the architecture and implementation of the multi-agent based middleware prototype. Section 4 presents the evaluation of the middleware performance for different metrics related to adaptability and availability issues. The paper ends with some concluding remarks and future work.

2. APPLICATION DESIGN AND MIDDLEWARE REQUIREMENTS

Medical professionals own the knowledge for defining the functional aspects of applications, that is, the time instants in which measures have to be acquired, how to react to all the possible situations in monitoring, early recognition, and rapid and suitable reaction for every patient. Thus, they should be the responsible for the application definition. For example, Fig. 1 illustrates an example of an application consisting of a composition of services.

Component-based development has been proven as a suitable design methodology to meet the adaptability requirement. Indeed, component-based engineering proposes to build complex and distributed systems as a set of interconnected reusable components. This modularity allows system reconfiguration by means of adding new components or removing existing ones. As a consequence, system flexibility, reusability and reliability are improved (Szyperski, 1998).

The modeling aspects of the target applications by means of component-based engineering is presented in (Estévez et al., 2011). As Fig. 1 illustrates, the definition of an application (stated by the medical professional) can be described as a set of interconnected components, each offering a service that represents a customization of a generic health care service for a particular patient. Thus, in this phase it is necessary to identify which services are needed, when they have to be executed, which information has to be transmitted among