Agent-based Monitoring and Alert Generation for a Home Care Telemedicine System

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ABSTRACT

In the present paper, a multi-agent system is proposed, which can be integrated in the home care telemedicine system that was developed in the context of the Citizen Health System (CHS) European project, functioning as a contact center for diabetic and congestive heart failure patients. The objective of the multi-agent system is to provide a set of alert/notification mechanisms for the clinicians, helping them to classify the clinical condition of each patient. Therefore, despite the huge amount of data managed by the system, due to the daily use of the contact center's services, these alert mechanisms provide the clinician with an overview of the cases that need further examination and save him/her time from the trivial cases. The multi-agent system consists of different types of agents, each one assigned with specific tasks, which communicate with each other, in order to share knowledge.

INTRODUCTION

The management of the health status of chronically ill patients, suffering for example from diabetes mellitus, asthma or congestive heart failure, can be accomplished more effectively, by emphasizing prevention and advice, rather than hospital treatment. By using today's personal communications solutions as a technological platform, daily monitoring of fundamental vital parameters can become an indispensable tool for continuous health monitoring, education, management and assessment[1]. Overall, electronic monitoring at home promises cost effective health services and a new sense of realism in reaching a diagnosis. Home care applications turn the chronic patient into an active participant in the health delivery system, thus enhancing the quality of health services, since the data transmitted from the patient to the home care system are more artifact and error free, due to the increased knowledge and awareness of the patient himself[2]. An efficient home distance monitoring system requires, besides various measurements of vital signs or monitoring devices, the integration of several communication technologies and organizational support services[3].

In this paper, a multi-agent system is presented, aiming to provide added value to the services offered by a home care telemedicine system that was developed in the context of the Citizen Health System (CHS) European project, functioning as a contact center between diabetic and congestive heart failure patients and the medical personnel of the health service provider, e.g. a hospital or a clinic. The particular home care service gives to its users the option to establish monitoring and educational sessions with the contact center in a regular basis, through several communication platforms (regular phone, "Wireless Application Protocol"-enabled mobile device or via the WWW)[4]. The services provided by the contact center are customizable for every patient and adjustable according to the health status of the patient. Healthcare personnel, related with the services provided by the contact center, may also browse the data collected by using appropriate applications developed.

The contact center's role is to provide its services to the patients in a "24 hour" basis; therefore, an urgent need arises for efficient evaluation of the large volume of medical data collected during the patients' sessions. Specifically, an initial interpretation of the submitted data and a corresponding notification can help the clinician have an overall picture of the condition of his/her patients, with a hint about the cases in which detailed data browsing and evaluation is required. For this reason, a multi-agent system was designed and applied, aiming to monitor and evaluate the data submitted by the patients and provide the corresponding medical personnel of the contact center with information related to the events occurred. In this way, each agent of the system is assigned a specific task to accomplish, for example to assess the values submitted by the patients and share the knowledge discovered with other agents responsible for visualizing the information through appropriate messages. The architecture of the multi-agent system is distributed along several hosts of the

health service provider's Intranet, with each agent residing at the place where its activity is carried out, e.g. the contact center system or a physician's computer. The software agent paradigm was adopted for accomplishing such requirements, because of its autonomous, proactive and reactive nature, which comprise important features for deploying real-time applications like the one presented, as well as their ability to function efficiently in distributed environments[5].

METHODS

The Contact Center

The main objective of the generic home care telemedicine system, constructed in the context of the Citizen Health System (CHS) European project, is to provide monitoring, surveillance and educational services to patients suffering from chronic diseases (specifically diabetes and congestive heart failure), through several communication platforms. Particularly, communication between the patients and the CHS contact center is provided through the following alternatives:

1) Computer Telephony: through a regular telephone and a PC telephony application.
2) Wireless Technology: through a WAP-enabled handheld device and a WAP application.
3) Internet Technology: through a WWW browser and a WWW application.

In the following, a typical patient interaction with the contact center is described (Fig. 1). As soon as the patient connects to the service, via the communication technology of his/her choice, an authentication procedure takes place, thus, addressing the security issues involved. In case of a successful login to the system, the patient has to select among submitting his/her daily measurements, browsing educational content or leaving a message to the corresponding physician. The schedule for each session type is defined by the physician of each patient, consisting one of the personalization parameters of the system.

During the measurements session, each patient may send the measurements of his/her personal vital parameters like blood pressure, glucose, pulse, temperature or weight. These measurements are taken at home using simple micro-devices (e.g. a home glucometer). The values that are keyed-in, using the selected communication technology, are checked according to a predefined medical prototype, in order to assure that they are logically acceptable, considering the vital signs they represent. Unexpected values are rejected and the patient is prompted to retype them. Complementary to the measurements are a number of questions asked to the patients, since the corresponding answers may be explanatory of their current health condition. The set of required values and questions may be personalized for each patient. All the data flowing to/from the contact center are stored in a Computerized Patient Record, specifically designed to meet the functional needs of the home care telemedicine system. As far as education is concerned, patients may choose to access educational messages (in text or voice format) among several categories available, according to their illness. Depending on the communication media, written or voice messages can be exchanged between the patients and the physicians, in any case stored in the Computerized Patient Record of the contact center.

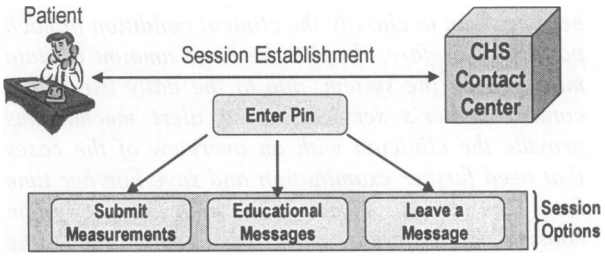

Figure 1. A typical patient session with the CHS contact center.

A set of in-house applications, that may be used by the contact center's healthcare personnel, have been developed that facilitate the administration of the patients' profile and the browsing of the measurements and answers that are submitted in each patient's session with the system. The physicians can browse all the patients' data submitted on a daily basis. However, this is a time consuming procedure, which is important only in case of problematic conditions, crucial changes in a patient's state or for retrospective analysis. Therefore, for a routine use, an identification mechanism for this kind of situations, that will automatically notify the medical personnel, would save time and provide an efficient management of alert conditions.

For those reasons, a multi-agent system was designed and implemented, aiming to provide additional value to the functionality of the CHS contact center.

Agent Functionality

Taking under consideration the advantages provided by the software agent paradigm[7], a prototype multi-agent system was constructed, in order to provide valuable medical information, useful for the assessment of patients' clinical condition.

Value has increased above the upper target limit
Value has decreased below the lower target limit
Value has increased above a personal upper limit
Value has decreased below a personal lower limit
Value was above the target upper limit and now it decreased to normal again
Value was above the target upper limit and now it increased to normal again
Patient left a message to his/her physician
Patient does not follow the predefined schedule
According to the answers of questions, life-style and symptom related information is provided

Table 1. The events monitored by the multi-agent system.

More precisely, the main objectives of the proposed multi-agent system are:

- To efficiently evaluate the medical data collected in each patient's session with the contact center, identify possible problems, e.g. if the value of a vital parameter submitted is out of predefined ranges, and notify accordingly the corresponding medical personnel in a real-time mode. Several steps are followed for vital parameter validation, according to the types of alerts that are activated for each patient. The value is classified as normal or problematic, according to upper-lower thresholds defined by the physicians. Currently, two ranges have been set, corresponding to different levels of severity: The target range resulted from clinical practice, out of which a patient is deregulated to a dangerous extent, and the personal range, indicating that the patient is well regulated, as explained in Table 1. The thresholds for the validation steps are stored as parameters in the Computerized Patient Record and can be adapted for each patient.
- To identify if a patient left a message to his/her physician and make a relevant notification. This is important in case a patient has some question for the physician or wants to notify him/her for a special situation.
- To monitor whether the patients follow their schedule or not and generate appropriate reports to the medical personnel. In such as case, the medical personnel should contact patients, who do not follow their schedule.
- To assess the answers submitted by the patients at the questions part of the measurements session and indicate possible problems.
- To visualize the information provided by the activities of other agents that participate in the system. Medical personnel should be informed about the outcome of agents' activities.

The above activities-tasks assigned to the multi-agent system are mainly related to the management and interpretation of the data stored in the Computerized Patient Record of the home care system. The sharing of the discovered knowledge among the agents of the system is achieved through appropriate agent messages, descriptive of the situation in each case. All this information is produced in real-time.

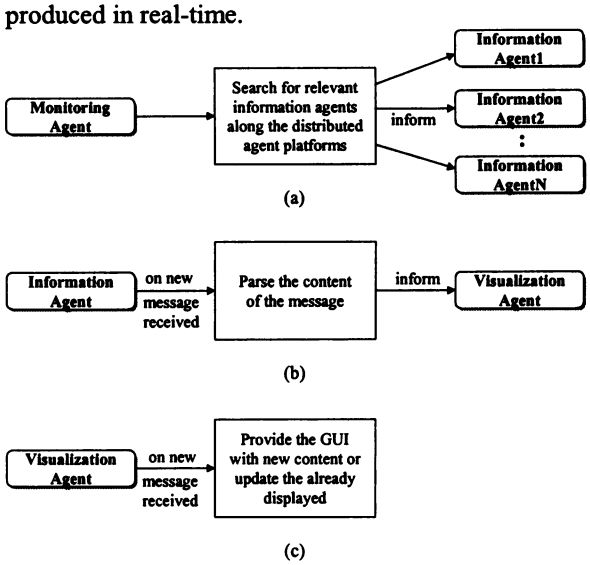

Figure 2. The block-diagram functionality of (a) the monitoring agent, (b) the information agent and (c) the visualization agent of the proposed multi-agent system.

Agent Architecture and Implementation

The main idea towards the implementation of the functionality described is the design of a multi-agent system, in which a specific task is assigned to each software agent. Decomposition of problems into simple tasks was a fundamental design principle, in order to ease the computational burden assigned to each agent. Accordingly, emphasis was given in coordinating the software agents of the system[6]. This approach provides a fast and flexible overall solution. Thus, three different types of software agents involved in the multi-agent system may be distinguished, according to their activities (Fig. 2):

- monitoring agents[8]
- information agents, and
- visualization agents

Each agent is located wherever its activity has to be done, e.g. the contact center computer system or a physician's personal computer. Thus, the software agents under consideration are distributed in the framework of the health care organization's Intranet. For this purpose, an agent platform, supplying mainly an appropriate agent execution environment, is installed in every location that agents have to operate. The agent platforms required are constructed using JADE (Java Agent DEvelopment Framework), which is compliant with the interoperability specifications of FIPA (Foundation of Intelligent Physical Agents)[9] and provides both an agent execution environment and the means to interconnect different distributed platforms.

Monitoring agents, residing at the contact center, incorporate various complex activities, for example medical data evaluation and identification of events that occurred in the system (Fig. 2). Specifically, the responsible contact center's agents identify monitored events in real-time. Following, when such events are identified, the corresponding physicians have to be automatically notified. Therefore, instant messages of appropriate content are sent to those information agents that are located at the physicians' terminals and are relevant to the specific types of events. For example, if a diabetic patient submitted an out-of-range blood glucose value, the corresponding information agent located at his/her endocrinologist's terminal would receive an appropriate message from the contact center's agent that identified the problematic value. This message, depending on its severity and the nature of the case, consists an alert or a simple informative message.

The list of information agents that will receive the messages generated by the contact center's agents is determined dynamically, through searching the yellow pages service provided by the DF (Directory Facilitator) agent of each agent-platform involved in the distributed architecture. Furthermore, information agents parse the received messages and according to their content, they provide the information to the visualization agents, which present the content via specifically designed graphical user interfaces. All the messages exchanged within the multi-agent system are in plain text format represented in the FIPA ACL communication language[9].

RESULTS

Appropriate graphical user interfaces were developed for the visualization of the knowledge discovered by the multi-agent system. In Fig.3 a screen capture of the GUI providing medical information concerning the congestive heart failure patients, is presented. This GUI is consisted of five panels, each of them related with different type of information, regarding the patients' contacts with the system.

Specifically, the 'Daily Contacts' panel provides a daily list of patients that have used the service and it is updated whenever a new contact occurs. The other four panels of the GUI correspond to the monitored events described in Table 1. More precisely, the 'Out of limits contacts' panel provides information regarding the submitted values that are beyond either the target limits or the personal limits, indicating patients for which a deterioration of their health status occurs and to what extent. In the same panel there is a notification for patients that have left a message for their physicians. The 'From out-to-in range contacts' panel informs the physicians about patients whose measurements have come to the normal range, indicating an improvement of their health condition. In the 'Schedule monitoring' panel, information regarding the patients' conformance with their session-schedule is provided. Thus, notification is provided, in case a patient did not establish a scheduled session with the system. Finally, in the 'Questions monitoring' panel life-style and symptom related information is provided, via the answers given by the patients during the measurements sessions.

The user of the graphical user interface is also able to record the information displayed in a text file, for further use, by following a menu selection, or clear the content provided in each panel by pressing the corresponding button controls.

CONCLUSION

The presented work is an effort towards the integration of IT in the health delivery process, within the context of home care systems. It aims to add value to a contact center by means of facilitating the monitoring process. In a typical contact center, physicians have to browse patients' medical data on a daily basis, in order to keep track of their health status. In the agent-based scheme presented, rules defined by the physicians, with thresholds customized for each patient, can be applied for the characterization of the patients' status. Therefore, alerts can be generated for the physician, notifying him/her when patients' condition is deteriorating or improving, or patient does not follow the required schedule. This scheme provides the physician online with non-redundant information, filtering out trivial

cases and extensive and timely medical data browsing. The usability of the proposed system is meant for evaluation during the clinical trial phase of the CHS project.

The alert mechanisms presented can be further improved, adding more intelligence and medical expertise to the system. For example, although thresholds are customized for each patient, the rules that are applied to medical data are predefined at present. More intelligent schemes can be developed, incorporating a mechanism for rule generation, either in a supervised or unsupervised way.

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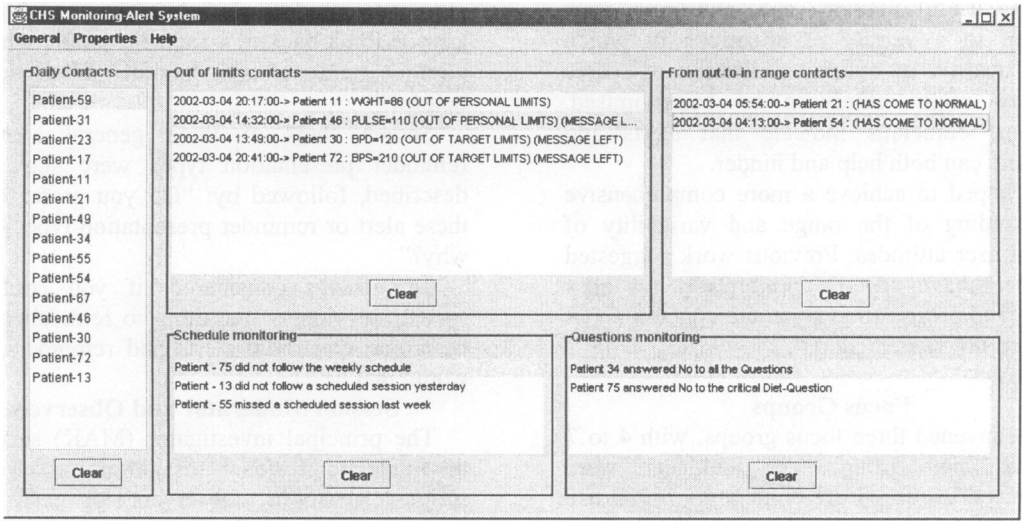

Figure 3. The graphical user interface providing monitoring information and alerts to the medical personnel of the contact center.