Enhance Collaboration in Diabetic Healthcare for Children using Multi-agent Systems

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ABSTRACT

We developed a multi-agent platform as a complement to the existing healthcare system in a children's diabetic healthcare setting. It resolves problems related to the difficulty of collaboration between the stakeholders of the problem domain. In addition, it gives us an opportunity to support the decision making of the stakeholders using Multi-agent Systems. The collaboration situation is believed to be improved by the agent-based services, such as, diabetes monitoring and alarm, scheduling, and task delegation.

Categories and Subject Descriptors

I.2.11 [Computing Methodologies]: Artificial Intelligence: Distributed Artificial Intelligence - *Multiagent systems,* J.3 [Computer Applications]: Life and Medical Sciences - *Medical information systems*

General Terms

Design, Reliability, Security, Human Factors.

Keywords

Multi-agent System, children's diabetic healthcare, collaboration, MAS coordination, diabetes monitoring and alarm, agent based scheduling.

1. INTRODUCTION

The need to make work more effective and an ongoing technical progress illustrate the necessity of coordinating and collaborating activities within health care systems. Agent technology is believed to be able to alleviate this necessity, as Nealon and Moreno stated in [1]: "the basic properties of intelligent agents (autonomy, proactivity, social ability) and the features of Multi-agent Systems (MAS) (management of distributed information, communication and coordination between separate autonomous entities) suggest that they offer a good option to consider when trying to solve problems in health care domains."

MAS techniques have been applied in the various health care fields of telemonitoring [2], medical monitoring and diagnosis [3-5], remote service and scheduling [6], elderly care and home care [7, 8] and healthcare coordination [9, 10].

Especially there are some applications in diabetic health care:

- *Diabetic monitoring and alarm*: The SuperAssist project introduces personal assistants in the care of diabetes patients, assisting the patients themselves, the medical specialists looking after the patients healthcare, and the technical specialists responsible for maintaining the health of the devices involved [11]. The SuperAssist framework aims to reduce the costs by improving the local, self-care capacity of people by efficient employment of remote, distributed expertise. The M2DM telemedicine service can monitor and receive blood glucose data, pass it to an intelligent agent that interprets the data and if needed trigger an alarm [12, 13]. The main contribution of the M2DM project is combining statistics, rule-based techniques and model-based techniques in its Knowledge Management agents in order to process the patient data and generate alarms automatically.
- *Biomedical control and management in diabetes*: Amigoni et al. introduced MAS to diabetic information management with the *anthropic agency architecture* [14]. The T-IDDM project provides telemedicine services to diabetic patients especially the management of insulin dependent diabetic patients [15]. The DIABTel telemedicine system complements the daily care and intensive management of diabetic patients through telemonitoring and telecare services [16]. Li and Istepanian proposed a model for diabetes management [17] and Tian and Tianfield developed a telemedicine system for diabetes based on agent technology [18].

Most of the applications above are focused on decision support systems, diagnosis and monitoring, coordination and management etc., in the hospitalized settings. In the case of chronic diseases, e.g. diabetes, most of the health care is given in homes or in other un-hospitalized settings. This paper describes how software agents can be used in children's diabetic healthcare in un-hospitalized settings. We argue that the agents we have implemented are able to help us overcome weaknesses in children diabetic healthcare of today, such as, communication problems, poor decision support, etc.

The paper is organized as follows. First, the diabetic healthcare management is described, with a focus on children diabetes. Then we describe the design and implementation of our MAS – IMAS.

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Short descriptions of the functionalities are given and last we discuss the system, draw conclusions and line out future work.

2. DIABETIC HEALTHCARE MANAGEMENT: CHILDREN DIABETES IN FOCUS

The diabetic healthcare management has been described in previous work [19]. Two main characteristics are the distribution of patients and the level of multi-care involved. Diabetic patients are geographically distributed and the care-providers (doctors, nurses, parents) are only occasionally working together. Diabetes regularly leads to many kinds of complications, e.g. for the eyes, feet, skin, heart, kidneys, nervous system, celiac diseases, etc. The diabetic healthcare normally takes place in un-hospitalized settings, e.g., at homes, at work, or during travels. Diabetes cannot be cured permanently, so the patients must be able to take care of themselves in the daily life. Corresponding care-providers must be involved, e.g., doctors and nurses from corresponding fields, dietitians, personal assistants, parents and school nurses in the case of diabetic children.

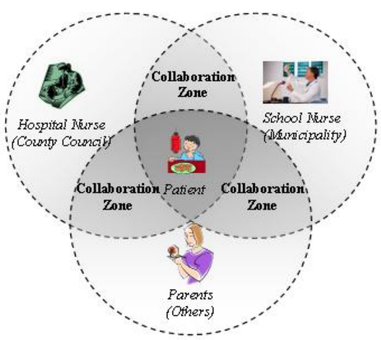

Fig. 1 The 'Collaboration Zones' between hospital nurses, school nurses and parents in the children diabetic healthcare setting. The patient is the least common denominator of the interactions.

It has been required by the nurses that this collaboration situation must improve. Based on interviews with hospital nurses and school nurses, the following problems/issues within the children diabetic healthcare were identified.

- *Communication problems*. The computer systems of the County Council and the municipalities are not compatible. In acute situations in school, the parents and the patients have to manually contact the hospital doctors or nurses by phones.

- *Intelligent Decision Support*. There is software attached with most of medical devices in the market to display the measured data in charts. This kind of software is installed on the patients' private computers where the measured data is also stored without easy access for nurses. Even if a graphical data presentation is available to the nurses, it may still be difficult to explain the situation to the patients via telephone or mail. A more intelligent computerized system is preferable.

Privacy. According to the law in a number of countries, medical journals of the patients cannot be transferred to anybody without the permissions from the patients or their guardians. Thus, neither the municipality nor the County Council can freely share a journal. Any new system is forbidden to break this privacy rule. This issue is left out of the scope of this paper, although we should be aware of it.

2.1 Scenario

To better explain the collaboration issues, we provide the following scenario.

Linus is a student of the fourth grade in a primary school. Unfortunately he is suffering of diabetes of type one and needs regular insulin injections every day. One day Linus felt unwell. So he went to the school nurse for the glucose measurement. The result from the glucometer did not provide enough information to the nurse since the nurse did not have the history record of Linus. Therefore, the nurse made phone calls to the parents and the hospital nurses for more information about Linus. After several phone calls, it was found that Linus had some high carbohydrate food at lunch, and did not take the insulin injection on time.

The above scenario illustrates a typical collaboration situation where the following problems can be found:

1. The glucose records are stored at separate places, e.g., hospital, home, schools etc. So it is difficult to access all of them from one location, when needed.
2. In acute situation, nurses have to communicate with the other care providers who are related to the patient, in order to get a systemic overview of the patient. Some of the communications can be automated, if the healthcare provider can remotely access part of the patient record, e.g., glucose record.

Insufficient information is provided to the care providers to make decisions. Some relevant information, e.g., patient activities, insulin injection records, is necessary for nurses in order to make decisions. However, that information is not presented.

3. DESIGN OF IMAS

In order to solve the above problems, we developed a MAS based system, IMAS, to support the daily healthcare activities of patients and healthcare staff. The IMAS system provides them with real time glucose monitoring and management, intelligent decision supports, user task delegation.

Various agent development methodologies and platforms exist. We adopted the Gaia methodology [20] for the system analysis and design of IMAS. Gaia was designed to deal with coarse-grained computational systems, to maximize some global quality measure, and to handle heterogeneous agents independent of programming languages and agent architectures [21]. The IMAS agents were implemented with JADE [22] making IMAS FIPA compliant [23]. In the IMAS settings, we assume that each agent is associated with a human user in the real world, e.g., a patient, a nurse, a parent, etc. Human users are considered necessary in this case, because we cannot rely on computer agents alone in acute situations for healthcare treatments. However, in a daily diabetic healthcare setting, computer agents can work by themselves without human control.

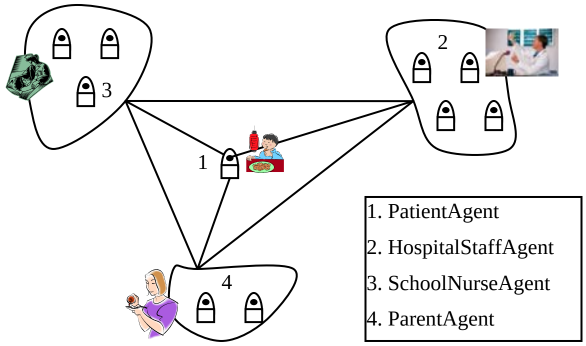

Fig. 2 The required communication paths of the IMAS architecture

IMAS agents work either on stationary PCs or on mobile devices like Pocket PC and Smart Phones. Each agent works for a user and provides some predefined services. The coordination among agents is realized though predefined IMAS communication protocols, i.e., the AlarmProtocol, the MeetingProcotol, the TaskProtocol, etc. Fig. 2 is an overview of the IMAS agent system. More details of each agent will be given later

3.1 Needs Specifications

There are many miscellaneous tasks in the daily diabetic healthcare. Some of them are critical and must be completed in a timely and precise fashion. For instance, the diabetic care providers (especially the nurses in this case) work on similar tasks by routine. They need to check the records of the patients before they visit them, and report the new information as they finish. The same task is performed several times every day, since they need to visit many patients. The task of retrieving and reporting the information of a patient is simple but must be done in an efficient and correct way, because delayed or wrong information may lead to serious consequences.

Through interviews, surveys and questionnaires with school nurses, hospital nurses and parents with diabetic children, we worked out the specification [24], based on which we defined the functionalities of the IMAS system. The system:

- receives data from medical devices and sends alarms to the corresponding agents/users when necessary,
- automatically organizes meetings for users, and
- decomposes predefined tasks and delegate sub-tasks to other agents/users.

3.2 Agent Services

Since children are not able to take full care of themselves, their parents are considered as important actors in the daily diabetic care. Various services are defined for the agents to handle. An agent may offer more than one services at the same time.

- Patient Manager (PM). The PM receives data from a sensor physically attached to the patient. It is also responsible for updating the patient record in the database.
- Patient Alarm (PA). The PA sends alarms to other relevant agents in an acute situation, e.g., if the glucose value is outside the allowed interval.
- Alarm Receiver (AR). The AR receives alarms and informs the human users.
- Meeting Manager (MM). The MM proposes a meeting to other agents, awaits their replies and informs them about the result.
- Meeting Responder (MR). The MR receives meeting proposals and reply to the MM. When a meeting is set, the MR also updates the calendar of its user.
- Task Manager (TM). The TM proposes tasks to other agents, awaits their reply and informs them with the final results (success or fail).
- Task Handler (TH). The TH receives task proposals from TM, accomplishes the tasks and reports to the TM.

3.3 Agent Roles

As illustrated in Fig. 2, we defined four kinds of agent roles, namely PatientAgent, ParentAgent, HospitalStaffAgent and SchoolNurseAgent.

- The PatientAgent works as a personal assistant to a patient. It provides its owner with real time glucose monitoring and management. When the glucose level is considered too high or too low, an alarm will be automatically generated and sent to corresponding agents, which continue to forward the alarms to their human users. Patients can also use their PatientAgents to record their daily activities, e.g., food intake, jogging, etc. This information will be provided to the medical staff for diagnosis.
- The ParentAgent works for the parents who have children with diabetes. It provides real time glucose monitoring, making it possible for the parents to access the current glucose status of their children.
- The HospitalStaffAgents work for the medical staff at hospitals. They manage the diabetic healthcare activities, e.g. meeting arrangement, task delegation.
- The SchoolNurseAgent works for the medical staff at school, e.g. a school nurse. The HospitalStaffAgent and the SchoolStaffAgent are functionally very similar.

3.4 Individual Agent Architecture

The design of individual IMAS agent is based on Müller's vertical layered architecture [25]. IMAS agent architecture consists of three components, namely Interface Layer, Agent Control Unit and Knowledge Base. See Fig. 3.

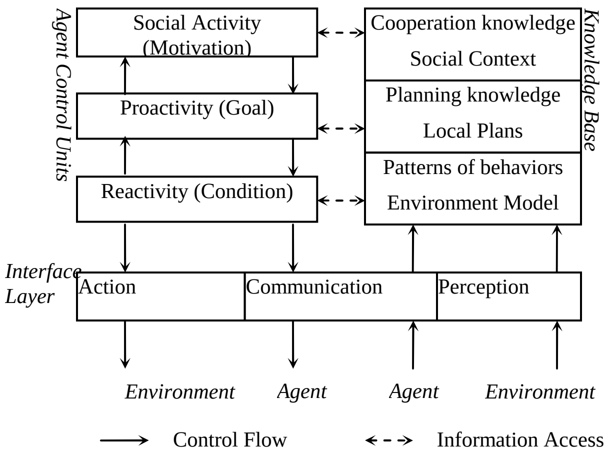

Fig. 3 IMAS Agent Architecture, based on Müller et al [25], consists of three main components, Interface Layer (IL), Control Units (CU), and Knowledge Base (KB).

The Interface Layer (IL) consists of *Perception*, *Action*, and *Communication*. *Perception* percepts the changes from the environment or receives orders from users, and updates the *Environment Model*. *Action* performs the agents' behaviors and *Communication* is the interface to other agents.

The Control Unit (CU) is designed on three levels, *Reactivity*, *Proactivity*, and *Social Activity*, which are connected to the levels *Environment Model* (EM), *Local Plans* (LP), and *Social Context* (SC) in the Knowledge Base (KB). The CU and the KB are interpreted and re-conceptualized with Engström's Activity Model [26]. Therefore, the new architecture, to some extent, manifests human activity aspects in the activities of software agents

The Reactivity component is driven by conditions. That is, when a specified signal is perceived by the Perception that requires action, the Reactivity component will be activated at once. The Proactivity component is responsible for local deliberation process. When perceiving changes in the environment and the EM is updated, the agent will deliberate its goals (desires) and generate plans from the KB to achieve the goals. The Social Activity component is responsible for the interaction among agents. To perform social activities, agents need to learn about the social context from KB.

3.5 Knowledge Base Design

One important aspect of our research is the re-interpretation and re-conceptualization of Müller's vertical layered agent architecture [25]. The vertical layer agent architecture requests that the knowledge base should be structured in order to satisfy two criteria: 1) the knowledge base is better to be structured in similar layers as the control unit, 2) the knowledge base should possess a structure that may cover not only the holistic aspects of collective agent activities, but also detailed plans that may accomplish individual agent tasks. We keep the three level knowledge base structure from Müller's model [25], and interpret it with the Activity Theory triangle model (see Fig. 4).

According to Engström's Activity Model, a human activity is composed of six components, subject (activity transformer), object (activity transferee), tools (activity media), rules (norms), community (relevant stakeholders), and division of labor (roles) [26]. We believe that the activities of software agents, who represent the human owners, can also be analyzed with this model. The agent activities, e.g., reactivity, proactivity, and social activity, can also be defined using the activity triangle model [27].

The agent activity consists of six components:

– Subject agent: this is the agent that conducts the activity.
– Object agent: this is the agent that may benefit from the output of the activity
– Tools: Tools is interpreted as Local Plans of the subject agents.
– Rules: The norms that the agents should follow when conducing this activity.
– Community: Community consists of the context of the activity. For example, what are the relevant agents that are involved in this agent activity?
– Division of Labor (DoL): how the subject agents divide their work.

Fig. 4 illustrates the six components of an agent activity. The six components are correspondingly stored in different levels in the KB according to Müller [25].

The Environment Model/world model is at the lowest level in the KB. Three factors are considered necessary in designing the patterns of agent behaviors, namely rules, division of labor, and community. Rules contains constrains and permissions that the subject agent has. Division of labor contains the information about the agent roles and responsibilities of the activity that the object agent benefits from. Community contains information about the agents and human users who are related to a specific activity. The basic analysis unit of such a database is the activity.

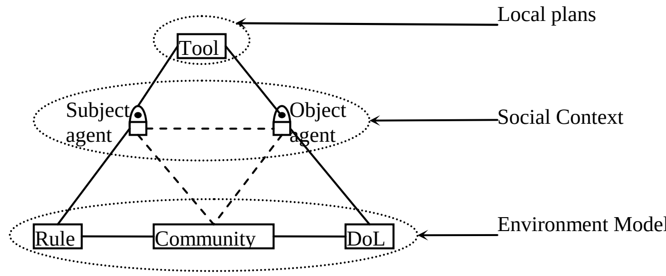

Fig. 4 Activity model used in Knowledge Base design. In a community (MAS or holonic agent groups), the subject agent conducts an agent activity, which the object agent benefits from. Subject agent and object agent are mediated by Tools (local plans); subject agent and community are mediated by Rules (norms); object agent and community are mediated by Division of Labor (agent roles). The mediation is represented by the solid lines. Dashed lines indicate the relations are not direct and need mediations.

The Social Context consists of the contacts and the relationships between the subject agent and the other directly related agents (object agents). That is, how to define the relationship and the coordination between subject agents and object agents.

The Local Plans/Tools consist of planning knowledge that reflects the mental context of the agent. Local Plans store agent plans that are basically series of agent actions. Each plan is associated with pre-condition and post-condition/goal. Agents may choose plans to satisfy their goals at run time.

The Knowledge Base is designed as a recursive hierarchy of Local Plans, Social Context and Environment Model. The design and implementation of the KB require a thorough description of the diabetic healthcare field, which is not in the scope of this paper and will be described in future work.

4. IMPLEMENTATION OF IMAS

So far, the first prototype of IMAS has been developed with functionalities to meet the objectives in the needs specifications. Issues about usability, user interface design, are omitted since this paper focuses on the agent development.

4.1 Patient Control Panel

The patient is provided with a Patient Control Panel (PCP), which is a part of the PatientAgent. It may help the patient to record diabetes related activities, (food intakes, insulin injections, exercises etc.). The recorded activities will be provided together with historical glucose data to the care-providers when an alarm occurs.

The Patient Control Panel has several kinds of user interfaces implemented depending on the platform of the users' devices. It can be an application running on Windows Mobile, or a Java program running on a Java-supported mobile, or an application running on stationary PC. Fig. 5 is an example of the Patient Control Panel running in Windows Mobile 5.

Fig. 5 Patient Control Panel on mobile

4.2 Real-time Glucose Monitoring

Software agents make continuous glucose monitoring possible. In the testing phase, the glucose level is simulated. In practice the glucose level may be measured automatically by a glucose sensor which, for example, is a chip built into the body of the patient. In this case, the glucose level is monitored in real time. Traditionally, the glucose levels are measured four times every day: breakfast, lunch, dinner and bedtime. Fig. 6 shows a situation where the glucose level is too high during a restricted amount of time. The real-time monitoring function is provided to the patient, the parents and the medical staff.

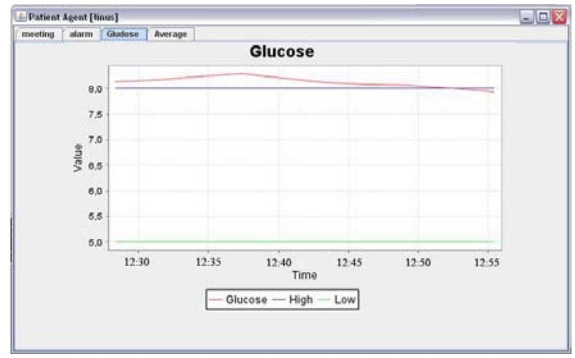

Fig. 6 Real-time glucose monitoring where 8.0 mmol/l and 5.0 mmol/l represent high and low level of glucose.

With real-time monitoring, it is possible to provide alarm functionality to the patients and their care providers. A preferred interval is pre-defined by the patients or their care providers based on the specific situation of the patients. When the glucose level is detected to be dangerous, i.e. outside the preferred interval, an alarm is sent to the corresponding agents and human actors automatically. The receivers of the alarm are chosen based on an analysis of the KB. Since the KB keeps track of the SC and EM, which in turn is based on real world measures, it is quite straightforward to choose which corresponding care-providers that should receive the alarm.

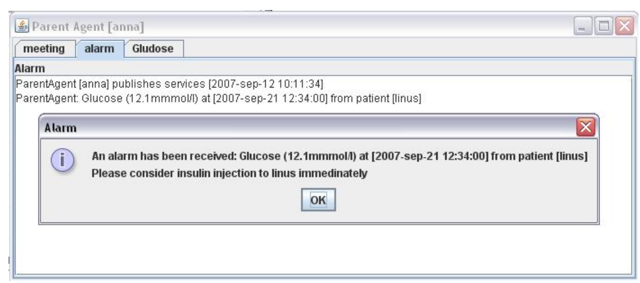

Fig. 7 ParentAgent receives an alarm

4.3 Decision support to diagnosis

When care-providers receive alarms, they are notified that the patient is in an acute health state. Necessary actions must be taken as soon as possible. But first, a detailed check on the health state of the patient is needed. For example, what are the daily average glucose levels during the last week or month, what kind of food has been eaten in the last week or is the insulin injection done properly in time?

In this case, IMAS agents will automatically generate useful diagrams and information for the care-providers, such as daily average glucose levels in the last month, patient activities in the last week etc. Fig. 8 shows the daily average glucose level in the last 30 days.

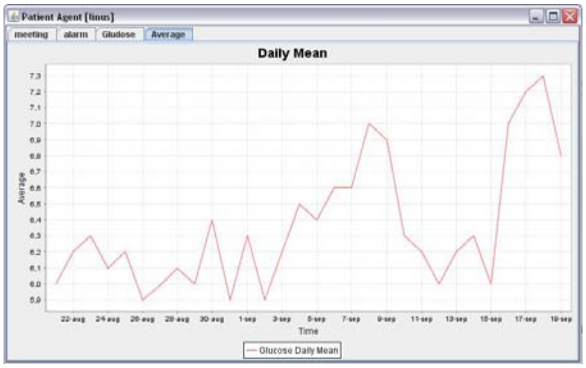

Fig. 8 Daily average glucose level.

4.4 Meeting arrangement

The healthcare actors often need to meet, e.g., routine meeting every three months, or urgent visit when acute situation occur etc. Based on the analysis in the KB, the IMAS agents may propose a meeting to its human actor with details of the meeting participants, length, location, time and so on. The human actor may edit the meeting proposal and ask the agent to send it to the agents that represent the invited meeting participants (see Fig. 9). The responding agents will check the calendars of their human actors and reply with reasonable meeting configurations. We reuse the protocol of Heine et al. [6], to coordinate the meetings.

The meeting proposing functionality is only provided to the medical staff, e.g., school nurses, hospital doctors and nurses, due to the reality that the medical staffs are normally quite occupied during their work. Therefore, it is better for them to start the meeting proposal with their available meeting alternatives. And all agents are afterwards able to respond to the meeting proposals.

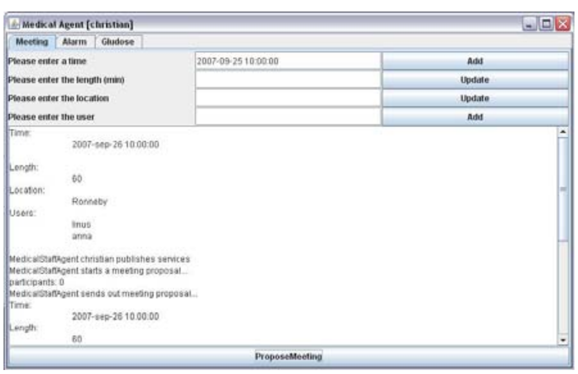

Fig. 9 Meeting proposal

5. DISCUSSIONS

This research has impacts and further improvement on both theoretical MAS development and practical perspectives of children's diabetic healthcare.

Theoretically, the Vertical Layered agent architecture is interpreted and re-conceptualized with the Activity model. This is important when the agents are working in a social and human-involved environment such as the medical healthcare environment is.

The initiative to communicate is not only taken by the human user but also by the software agent, e.g. reporting exceptional measurements of the health state of the patients based on an all day around monitoring. Real-time monitoring combined with user provided activity recording constitute the core of IMAS. By combining new and historical data to appropriate agents, the diabetic health care setting should improve in both efficiency and quality.

Task delegation is another aspect that the IMAS can deal with. Some tasks, e.g., arranging activities like meetings, can be delegated to the agents. It is always a problem when arranging a multi-person meeting; especially when the participants are distributed at different places [6]. With agents provided, such activities can be easily delegated to the agents that will coordinate the meetings using predefined protocols.

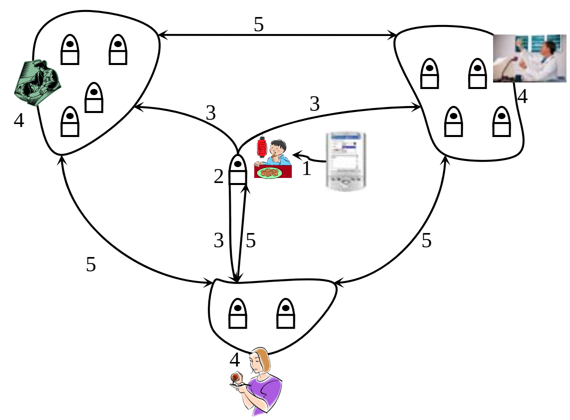

Fig. 10 Information flows in IMAS. (1) Patient Control Panel records activities. (2) Glucose monitoring. (3) Alarm. (4) Decision support to human actors. (5) Meeting arrangement.

Fig. 10 illustrates how the IMAS system helps to practically improve the diabetic healthcare collaboration with its agent based services. The diabetic healthcare collaboration situation that is illustrated by the scenario in Section 2 is believed to be improved by the IMAS system.

1. The glucose records and diabetes relevant information are now stored in a centralized database, which can be accessed by the care providers from any location. The patient now uses a mobile with a Patient Control Panel installed. Whenever there is a new glucose record, the Patient Control Panel will store the new record in a central database. The storing process is done automatically via the connection between the glucometer and the Patient Control Panel. Besides the glucose record, each time the patient eats anything or takes any exercises, he/she will use his/her mobile to report the activity, , which will also be stored in the database. See Fig. 5.

2. When an acute situation happens, PatientAgent will check the glucose record history and the activity record of the patient. Based on the Division of Labor, which is stored in the EM in its KB, PatientAgent chooses corresponding care providers, and sends them alarm messages with appropriate suggestions. (See Fig. 7). Other irrelevant care providers

will not receive this alarm message. Nevertheless, a system log message will be generated and stored, so that all care providers can see what has happened to Linus, if they want to.

When the alarm message is received, the agents of the care providers will search for useful information about the patients and present it with suggestions to the care providers, who need to confirm that the suggestions from the agents are convincible. Nevertheless, the decisions are made by the human users; the agents only provide relevant information to them.

6. CONCLUSION AND FUTURE WORK

The collaboration situation in diabetic healthcare can be improved with IMAS. The IMAS provides a formal communication channel for all human actors. With predefined protocols, much information, such as glucose values, meeting details and task reports, can be automatically transferred to relevant agents. Some unnecessary visits to the medical staff may be avoided, since the software agents can provide intelligent decision support to the patients. This obviously decreases the communication and coordination burden of the diabetic healthcare management and gives the staff the possibility to provide healthcare of higher quality to a lower cost.

In the future, we will continue working with the details of the design of the Control Unit and Knowledge Base. Firstly, the KB, especially the EM, will be further developed to model the important aspects of the reality. Secondly, the stored knowledge should be processed in the Control Unit in a way so that the agent can make more effective decision. Principles from Activity Theory is hoped to be applied in this case.

With the introduction of IMAS, the quality and efficiency of diabetic healthcare can be improved. The IMAS provides diabetic healthcare actors, especially the patients, with glucose monitoring and decision supports in diabetic diagnosis. From care providers' side, part of their jobs can be accomplished by the agents, e.g., arranging meetings, generating, storing, and fetching glucose reports, thus saving time for the staff, at the same time as the quality is improved.

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