A Multi-agent Approach to the Design of an E-medicine System

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Abstract. E-medicine covers the whole range of medical process and service. Multi-agent approach is suitable for the development of e-medicine systems. In this paper, firstly the requirements of e-medicine are analysed, and a taxonomy is proposed for e-medicine systems. Secondly multi-agent approach is introduced for developing e-medicine systems, and the design of agents and the design of multi-agent structure are presented for e-medicine systems. Finally a case study is presented on a telemedicine for diabetes to illustrate the development of e-medicine systems.

Keywords: E-medicine; telemedicine; multi-agent

1 Introduction

With the progress of information technology e-medicine has become popular in the last decade and numerous variants of e-medicine have appeared such as e-diagnosis, e-pharmaceutics, e-healthcare, telemedicine, telehealth, etc.

E-medicine entered as a part of the routine clinical as early as in 1990s [1]. E-medicine delivers healthcare by integrating the information, communication and human-machine interface technologies with health and medical technologies [2]. E-medicine relies upon the technology enabler to realise the vision for health [2] and its advantage is to deliver healthcare across geographic, temporal, social, and cultural barriers [3].

E-medicine has wide applications, from diagnostics (such as teleradiology), treatment, through telesurgery or telementoring where a specialist surgeon can guide a beginner [4]. The applications of e-medicine can be classified as four areas [2], i.e., (1) lifetime health and medicine, (2) personalized health information, (3) teleconsultation and (4) continuing medical education. Moreover, e-medicine also has great impacts upon the traditional healthcare system. The national/provincial/regional health systems, health regulation, clinical programs, health institutions/organisations, and so on will be affected by e-medicine systems [3].

New technologies and methods must be explored to release the full potential of e-medicine. Multi-agent system approach has been widely used in the development of large complex systems. Agents have the autonomy and social ability, and multi-agent

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system is inherently multi-threaded for control [5]. Therefore, multi-agent approach is very effective for tackling the complexity of e-medicine systems and suitable for the development of e-medicine systems.

2 Requirements and Taxonomy of E-medicine Systems

Medicine has four basic functions. Firstly, disease prevention—focuses on epidemical disease prevention, deadly diseases prevention (such as cardiovascular disease and AIDS), and emergent prevention (such as SARS Virus). Secondly, disease diagnosis—focuses on interview based diagnosis, instrument based diagnosis and collective diagnosis. Thirdly, disease treatment—focuses on clinic, prescription, medicine, surgery operation, emergent treatment and hearth care. Fourthly, health consultation—focuses on grouped consultation (such as pregnant consultation, children health consultation), individual consultation and health knowledge.

Accordingly requirements of e-medicine systems can be divided as functional and non-functional requirements. The functional requirements of e-medicine systems include providing distant medical service (such as telemedicine, e-healthcare and teleconsultation) and clinical practice (such as telesurgery, telementoring and training patient), establishing medical database (such as computer-based patient records) and exchanging medical information (such as physicians' education and sharing the medical experience or research).

The non-functional requirements of e-medicine systems include security and privacy (such as protecting patients' privacy and encrypting medical records), efficiency, convenience and reusability. Medical information security and privacy are very important. How to protect the system security and the privacy of patients becomes the focus with the wide use of e-medicine, because more and more data for patient treatment are exchanged through national networks or Internet [4]. For example, privacy can prevent disease or delay disease's offset [4]. E-medicine has to face the purposeful violations of privacy and the accuracy of medical knowledge for patient's benefit while it tries to provide more and more medical service on line. Moreover, medical information is dynamic because of the complexity of symptom. For example, fever is usually the typical symptom of cold, but it also is the one of symptoms of SARS Virus.

E-medicine is the digitalisation of medical process and service. It is a broad term and can include telehealth, telemedicine and other healthcare related activities, such as health education, administration, and training [1]. A taxonomy can be proposed for e-medicine as follows.

E-pharmaceutics focuses on the standard and evaluation of the functions of pharmaceutics, especially the biomedicine.

Telemedicine is the use of communications technology in the provision of healthcare. Telemedicine system aims at providing medical service over a wide area, especially remote rural areas, and sharing the existing medical experience and technique based on telecommunication and information technology.

E-healthcare is one of the clinical activities that focuses on the health knowledge and evaluation of health status. Information and communications technologies enable the interaction between professionals and patients and the mediation of clinical data across time and space [6]. E-healthcare has two models of t, i.e., asynchronous (store-and-forward)—that is non “real time”, e.g., digital recording, processing and storage of images and data; and synchronous (interactive)—that is “real time”, e.g., videoconferencing system, with parallel transmission of clinical data [6].

E-diagnosis focuses on analysis and judgement of patients’ status in term of the medical information. Decision support provides the physician with medical knowledge that is pertinent to the care of the patient [4].

E-consultation focuses on the provision on consultation and delivery of health knowledge for individual patients.

E-clinic focuses on the clinical diagnosis and treatment, and acquires the practical information of the patients.

Computer-based patient record (CPR) is the collection of electronic data about a patient’s healthcare. Data entry and form of CPR are various. The data may be inputted by keyboard, dictation and transcription, voice recognition and interpretation, light pen, touch screen, hand-held computerized notepad, and other means [4]. CPR provides data presentation, storage, and access to the clinical decision maker (usually a physician or nurse). CPR may present data to the physician as text, tables, graphs, sound, images, full-motion video, and signals [4]. Moreover, CPR can provide the knowledge with proper context, i.e., specific data and information about the patient’s identification and conditions [4].

3 Multi-agent Approach to the Design of E-medicine Systems

Multi-agent approach is effective for tackling the complexity of e-medicine systems because of the properties of agents and multi-agent system.

An agent is a computer system that is capable of independent action on behalf of user or owner [5]. An autonomous agent has the following properties [7].

Autonomy—an agent encapsulates some state of its environment and makes decision about what to do based on this state;

Reactivity—an agent perceives its environment and responds to changes that occur in the environment;

Pro-activeness—an agent can exhibit goal-directed behaviour by taking the initiatives to satisfy the given design objectives; and

Social ability—an agent interacts with other agents via an agent communication language and engages in social activities in order to achieve goals or cooperate.

A multi-agent system is a system that consists of a number of agents, which interact with each other, typically by exchanging messages through some computer network infrastructure [5]. A multi-agent system is a dynamic society made up of a great number of “intelligent agents” [8], so it is an intelligent society.

The multi-agent approach to system development consists of four steps [5], i.e.,

- Identification of the agent’ roles
- Identification of the responsibilities and services for the roles
- Determination of the goal and plan to achieve the goals
- Determination the belief structure of the system

These four steps can be grouped as two stages, i.e., design of agent and design of agent society (structure) [9].

3.1 Design of Agents

The task in the design of agents is to identify the roles of all agents and their responsibilities and services in e-medicine systems. This can be elaborated as follows.

Interface agent provides guidance to an e-medicine system. Personal agent is one type of interface agents, which provides the user with a graphical interface to the multi-agent system and initiates a search or shows the results of a query to the user.

Broker agent is an agent that knows about all capabilities of the multi-agent system. Through the broker agent the user can communicate with agents or perform a general search among all agents.

Doctor agent maintains the schedule and appointment of a given doctor, and is aware of the doctor's times for visiting patients.

Administration agent implements the medical administration such as the assignment of task and the cooperation between departments and agents.

Controller agent controls the whole e-medicine systems and mediates the conflicts among the agents.

Department agent has the knowledge of a certain medical department and manages the medical affair in the department.

Monitoring agent, diagnosis agent, therapy agent, surgery agent, consultation agent, training agent and record agent carry out the functions of monitoring, diagnosis, therapy, surgery, consultation, training patient and medical record in a department, respectively. For example, training agent provides patients with instructions such as how to take medicine and how to take daily care.

Database wrapper agent is an agent that controls the access to a database that contains the medical records of patients. All the communications between database wrapper agent, patient agent and doctor agent are encrypted.

Education agent introduces the newest medical technologies and pharmaceutics, and provides e-learning for physicians or even for other agents in the e-medicine systems.

Decision support agent integrates various knowledge and provides diagnosis agent with effective decision approaches.

3.2 Design of Multi-agent Society (Structure)

Design of multi-agent society focuses on the establishment of the architecture of the multi-agent system and the interactions between the agents.

Multi-agent system has three architecture, i.e., deliberative, reactive and hybrid [7]. In e-medicine systems, the multi-agent system architecture tends to be hybrid. Different multi-agent systems are responsible for different specialist medical services of medical departments such as urology and cardiology.

A multi-agent system is a dynamic system and is similar to a society. On the one hand, the multi-agent system interacts with its external systems. On the other hand, within the multi-agent system agents interact with one another. The interactions consist of internal communication and external communication, ciphered or non-ciphered [10]. So the interaction model in multi-agent system is divided into external model and internal model [9]. The internal interactions of e-medicine systems are those not only between agents within one department, but also between different departments. The external interactions of e-medicine systems are those with other systems such as medical instrument, psychology, medical university and institute, etc. Agent in the multi-agent society of e-medicine systems are grouped control, implementation and interface, as shown in Fig. 1. The internal communication is among the control, interface and implementation group, and the external communication is with the environment through the interface part. The kernel of multi-agent society is the implementation group where various implemental agents cooperate to fulfil the requirements from control group or patients.

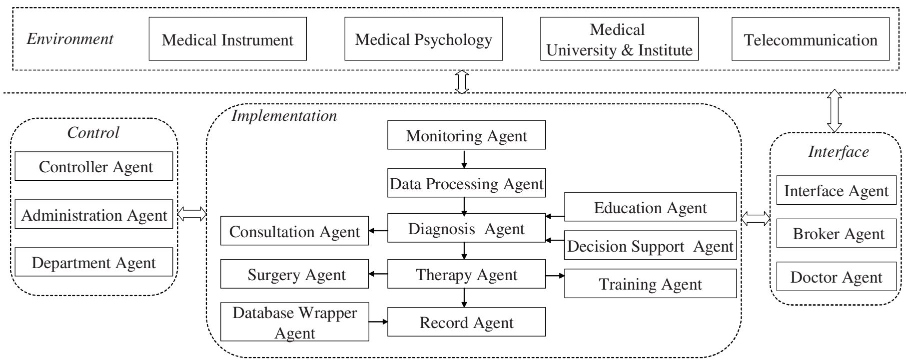

Fig. 1. The multi-agent society of e-medicine systems

4 A Case Study—Telemedicine for Diabetes

To illustrate multi-agent approach to the development of e-medicine systems, a case study of telemedicine for diabetes is presented below.

Diabetes is a chronic disease with a sustained elevated blood glucose level. The symptom of diabetes is that the metabolism can not work properly because of the reduction of insulin secretion [11]. The diabetic patients need to be injected with exogenous insulin to regulate blood glucose metabolism. Moreover, patients have to perform a daily strict self-monitoring of blood glucose level, such as measuring it before every injection and recording it on diaries, together with the amount of insulin injected and the information about diet and life style [12]. Using telemedicine system to manage this healthcare process can give diabetic patients real-time monitoring and immediate therapy. Telemedicine system for diabetic patients has been studied since early 1980s [11].

4.1 Requirement Analysis of Telemedicine for Diabetes

The telemedicine system must provide following services for diabetic patients on a daily basis.

- Visiting the patients and providing individual therapy.
- Monitoring the patients in real time and processing the monitored data immediately.
- Diagnosing the patients in term of the monitored data and making a proper therapy for the diabetic patients.
- Training the diabetic patient to monitor themselves and educating the physicians to update their skills.
- Establishing the patients' database the entry of which is ciphered.
- Providing the diabetic patients with consultation.
- The system needs to interact with other systems in e-medicine systems.

4.2 Identification of the Roles and Responsibilities of Agents

In the telemedicine system for diabetes, the medical services include monitoring the patient in real time and transmitting the information to physician, then providing the patient with a corresponding therapy, and consultation to enquiries. These services are implemented by monitoring agent, data processing agent, diagnosis agent, therapy agent, consultation agent, training agent, archival agent, department agent and interface agent, respectively. The agents and their responsibilities are detailed as follows.

Monitoring agent—monitors the diabetic patients in real time and transmits the monitored data to data processing agent.

Data processing agent—makes statistic and integrates the monitored data.

Diagnosis agent—analyses the situation and makes an accurate judgment for the patient.

Therapy agent—determines a proper therapy method.

Consultation agent—provides consultation to the enquiry of patients and contacts with diagnosis agent.

Decision support agent—provides decision support and cooperation for diagnosis agent.

Training agent—trains patients about how to take medicine and how to care himself. It implements the method of therapy agent.

Archival agent—edits and archives the patient record and therapy methods, and updates the database of the individual patients. Moreover, it integrates with the medical database and encrypts the important database.

Department agent—implements the control of the telemedicine system.

Interface agent—provides search service and information service.

4.3 Identification of the Goal and Plan to Implement

This telemedicine service is implemented by diabetes department in a hospital. The telemedicine system must not only provide the diabetic patient with immediate medical services through distant monitoring, diagnosis, therapy and consultation, but also integrate with other e-medicine systems for the functions of education, training, management, security and database.

How to achieve the goal by the multi-agent system? The multi-agent system consist of three groups, i.e. interface, implementation and control. In the implement group, there are many agents to individually and orderly carry out different responsibilities. The proposed architecture of multi-agent system is depicted in Fig. 2.

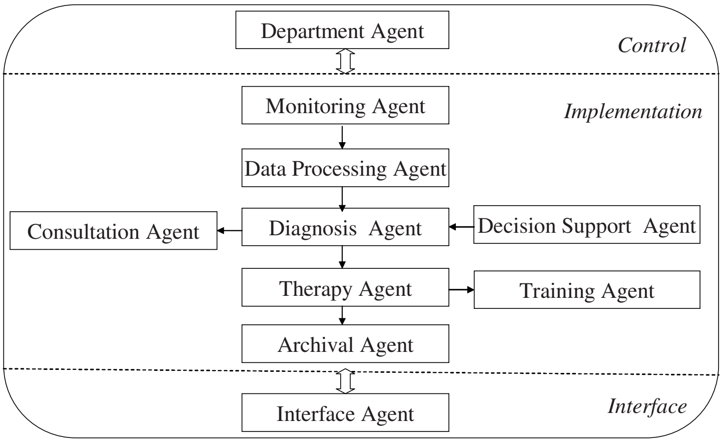

Fig. 2. The architecture of the multi-agent system of telemedicine

In the multi-agent system, the control group assigns the work and mediates the conflicts between agents. The interface group keeps the link with patients and other e-medicine systems. The implementation group implements the monitoring, diagnosis, therapy, consultation and archival functions to achieve the goals.

4.4 Determination of the Belief Structure

This is to determine the information requirement for each plan and goal in the interactions between agents [5]. In the multi-agent system, the external interactions focus on the integration with other e-medicine systems and its environment, while the internal interactions focus on the cooperation between agents to realize the telemedicine process, as shown in Fig. 3, where the bi-directional arrow represents the interactions.

In Fig. 3, the bigger dashed ellipse indicates the range of telemedicine while the smaller dashed ellipse indicates the range of the implementation group of the telemedicine system. So arrow 1 and 2 indicate that the telemedicine system interacts with its environment and other e-medicine systems, respectively. And arrow 3 and 4 indicate that the implementation group interacts with the control group and interface group in the telemedicine system, respectively.

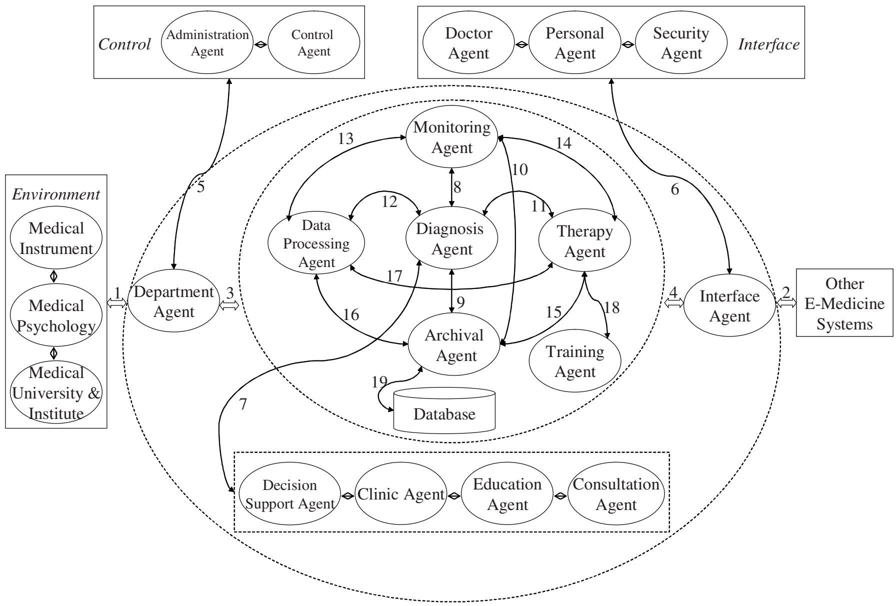

Fig. 3. The interactions in the multi-agent system of telemedicine of diabetes

Arrow 5 represents the interaction between department agent and the control group in e-medicine such as administration and control agent, while arrow 6 represents the interaction between interface agent and the interface of e-medicine systems such as doctor agent, personal agent and security agent. In the implementation group, diagnosis agent plays an important role. Because diagnosis is a complex process, diagnosis agent not only interacts with other agents in the implementation group, but also integrates with decision agent, clinic agent, education agent and consultation agent, as show by arrow 7.

Arrow 8-17 represents the internal interactions between agents in implementation group of the telemedicine system, respectively, which can be described by a matrix, as shown in Table 1.

Moreover, training agent implements the method of therapy agent, as shown by arrow 18, and archival agent directly interacts with the database, as shown by arrow 19.

The interactions in the matrix are explained in a symmetrical order as follows.

Entry <1, 2> represents monitoring agent transmits the monitored data to data processing agent. And entry <2, 1> represents data processing agent may require monitoring agent to provide other related data.

Entry <1, 3> represents monitoring agent may transmit the monitored data to diagnosis agent if required. And entry <3, 1> represents diagnosis agent may require monitoring agent to further monitor the patient's activities and symptom.

Entry <1, 4> represents monitoring agent may transmit the monitored data to therapy agent if required. And entry <4, 1> represents therapy agent may emphasise further monitoring the patient's improvement after making the treatment.

Table 1. The matrix of interaction of the telemedicine system for diabetes

	Monitoring Agent	Data Processing Agent	Diagnosis Agent	Therapy Agent	Archival Agent
Monitoring Agent		1, 2	1, 3	1, 4	1, 5
Data Processing Agent	2, 1		2, 3	2, 4	2, 5
Diagnosis Agent	3, 1	3, 2		3, 4	3, 5
Therapy Agent	4, 1	4, 2	4, 3		4, 5
Archival Agent	5, 1	5, 2	5, 3	5, 4	

Entry <1, 5> represents monitoring agent may transmit the monitored data to archival agent if it needs the further data. And entry <5, 1> represents monitoring agent acknowledges the requirement from archival agent.

Entry <2, 3> represents data processing agent will transmit the summarised data to diagnosis agent, such as graph, table and related medical historical records. And entry <3, 2> represents diagnosis agent may require data processing agent to reprocess the data if it does not feel the summarised data are sufficient.

Entry <2, 4> represents data processing agent may transmit the summarised data to therapy agent if required. And entry <4, 2> represents therapy agent may require data processing agent to reprocess the data for further information.

Entry <2, 5> represents data processing agent may transmit the summarised data to archival agent if required. And entry <5, 2> represents archival agent may provide more data for the data integration required by data processing agent.

Entry <3, 4> represents diagnosis agent will report the conclusion of the diagnosis, implying the treatment, to therapy agent. And entry <4, 3> represents therapy agent may require diagnosis agent to diagnose again or require the integration with other agents such as decision support agent.

Entry <3, 5> represents diagnosis agent may search the related medical history record of the patient through archival agent. And entry <5, 3> represents archival agent will require diagnosis agent to archive the diagnosis conclusion.

Entry <4, 5> represents therapy agent may require archival agent related records. And entry <5, 4> represents archival agent will require therapy agent to archive the therapeutic data.

5 Conclusion

Multi-agent system can not only integrate the medical knowledge and clinical experience and make decision support, but also adapt the system rapidly to the change in environment. So multi-agent approach can effectively tackle the complexity of e-medicine systems.

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