TELEMEDICINE AND E-HEALTH COMMUNICATION SYSTEMS

Mobile e-Health monitoring: an agent-based approach

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Abstract: An ageing population is now the leading healthcare concern of many countries in the world. Aged patients need more healthcare efforts as they present more cases of chronic illnesses involving higher healthcare costs. e-Health systems based on modern information technology are expected to play a role in alleviating this problem. Fortunately, there have been dramatic advances in healthcare technology in terms of mobility, size, speed and communication. However, the main drawbacks of currently deployed e-Health monitoring systems originate from the fact that patients are ‘constrained’ within smart rooms and beds fitted with monitoring devices. Such monitoring is not ubiquitous in view of the privacy, mobility and flexibility issues concerning patients. On the other hand, health monitoring products strapped to the patient’s body provide no analysis or recommendations of results. A multi-agent architecture for mobile health monitoring is presented, involving a team of intelligent agents that collate patient data, reason collectively and recommend actions to patients and medical staff in a mobile environment.

1 Introduction

Health telematics can play a major role in improving the lives of patients, particularly in the weaker sections of the society including disabled, elderly and chronically ill patients [1]. However, mobile health-monitoring devices offer great potential help for such patients who may be able to afford good healthcare without having to regularly visit their doctor. These technologies bring potential benefits to both patient and doctor; doctors can focus more on priority tasks by saving time normally spent with consulting chronically ill patients [1] and patients can move about in their environment without having to make extensive trips to the doctor – especially if they reside in a remote location.

It has also been shown that rising hospital expenses are the main factor for rising costs in patient healthcare [2]. Many patients with non-life-threatening illnesses needing health monitoring do not necessarily require hospitalisations – they simply require monitoring via a mobile system that encompasses intelligent capabilities to detect abnormalities, provide temporary advice and send urgent alerts to medical staff in the event of an emergency. In the realm of chronic illnesses such as diabetes in remote areas, there is even a shortage of rural diabetic specialists, which has long been one of the most important problems facing most countries in the world [3]. The fact that mobile health monitoring can bring to these sufferers an increased contact with specialists in cities improves the overall quality of health service.

This paper presents a generic agent-based e-Health monitoring framework that is used to assist in the doctor-to-patient interaction spanning multiple remote locations and hospitals. The paper is organised as follows. Section 2 of the paper presents some background information into problem areas and related work. Section 3 discusses the current scenario of chronic illness management using episode-based healthcare and justifies the need for a multi-agent system for this purpose. Section 4 presents the network infrastructure for a multi-agent mobile e-Health system. Section 5 outlines a multi-agent application framework to achieve monitoring goals and Section 6 briefly discusses the implementation and operation of the mobile e-Health monitoring system. Section 7 discusses the evaluation of the system based on the given application scenario and finally Section 8 concludes the paper.

2 Related work

A major limitation for today’s healthcare is that vital signs cannot be measured often enough [1]. With the current assortment of health monitoring devices available in the market for purchase by anyone (such as the digital pulse oximeter by Nonin Medical [4] and the heart monitor by Alive Technologies [5]), vital signs may now be measured more often – but this leads to the problem of non-optimal analysis of results by the patient which normally would best be examined by a specialist or doctor.

Four major aspects of home health care involve [6]:

1. preventative health care programs;
2. physiological monitoring;
3. functional monitoring and
4. assessment of quality of life.

However, if the patient does not connect to the Internet at all, these systems would not be able to update their result and doctors cannot get access to the readings. Even more so, this system lacks the mobility that patients prefer – they currently would need to be at a computer terminal to upload the results. On the other hand, the provision of a basic intelligent agent on a mobile device to assist with
results and recommendations (e.g. if the patient’s body temperature is 37.8˚C, it reports a mild fever) would be ideal.

A multi-agent-based system can assist in better healthcare in the following ways [7].

1. Proactive healthcare with emphasis on prevention where patients with early symptoms can be attended to by the doctors before an acute attack occurs.
2. Enhanced patient–doctor interaction whereby agents can provide patients with information about their medication or treatment procedures which is not usually presented in a normal face-to-face consultation because of lack of time or the reserved nature of the patient.
3. Enhanced information exchange – agents can provide terminology at a level which the patient can understand. Often doctors may communicate information using technical healthcare terms which the patient may not fully comprehend.
4. Healthcare services to geographically remote patients whereby the Internet plays a major role in providing the back bone communication link between the doctor and the patient in a remote environment. Furthermore, a reduction in travel time and expenses for rural patients should be evident.

The next section presents a scenario of chronic illness management that is quite common for aged patients who utilise most of the emergency resources of healthcare providers in many countries.

3 Episode-based healthcare scenario

Fig. 1 shows eight stages of doctor–patient interaction in the context of the current episode-based care where the interaction between the patient and doctor happens only during patient visits [7]. In case the patient needs closer observation, he/she would need to be admitted to the hospital.

The stages shown in Fig. 1 are as follows.

1. Patient and doctor are brought together as a result of a patient complaint.
2. The doctor performs an investigation on the patient’s condition. This may require physical examination, test and specialist consultations.
3. The doctor diagnoses the condition. Specialist collaboration and negotiation may be required.
4. The doctor collaborates with specialists and the patient to design a treatment plan.
5. The treatment is carried to completion and the patient’s condition returns to normal.
6. The interaction concludes. Patient and doctor separate.
7. Occasional patient–doctor interaction:
   • Patient seeks information from doctor.
   • Doctor checks up on patient.
8. Until the next complaint when the cycle is repeated.

The main problem with chronic illness management lies with the sporadic contacts between a patient and the doctor, with the patient not being hospitalised. The patient could die of complications between these contacts and the doctor would not even know. On the other hand, the increasing pressure on the healthcare system because of an ageing population makes it impossible for patients to be hospitalised because of a lack of free beds in hospitals. If these chronically ill patients occupy all beds in hospital emergency departments, many severe cases (e.g. accidents) may be denied the required attention.

Our design overcomes the problem with multiple software agents where an intelligent agent assists each human role (patient, doctor, specialist and so on). This would allow the following advantages over the current episode-based patient care:

• The patient–doctor relationship is extended beyond the episodes of visits (continuous care).
• Proactive healthcare with emphasis on prevention (doctor would know before a fatal event occurs).
• Patients have access to high quality medical information (from medical teams at geographically remote locations).
• Patients are monitored at home or on the road.
• Patients often do not know if their symptoms are serious enough to see a doctor. Agents can help to identify patients who really need medical attention from those who only need information.
• Better completion of treatment.

This would mean that the body parameters of the patient would have to be first input to the electronic gadgets (e.g. computers) and then software agents could reason and interact with each other and with the human roles (e.g. patient, doctor). The discussion of this agent-based monitoring systems is presented in two subsequent sections as follows:

• The next section presents the communication and network perspective including the connectivity of body parameters to the agent-based monitoring software.
• The subsequent section presents the multi-agent-based application architecture followed by system evaluation.

4 Network architecture of mobile health monitoring system

Our system architecture consists of Java-based agents of each human role (e.g. doctors, patients) residing on the gadget (e.g. PDA or PC). Although the scenario in Section 3 discusses a one-to-one interaction between the doctor and the patient, we needed to design the system for a more generic many-to-many (multiple patients assisted by multiple doctors and specialists) scenario. Therefore we defined the network architecture consisting of clients (for doctors and patients) and servers that would provide communication and coordination between these clients. Although many users have personal computers (PCs) at home, getting these PCs to connect to body sensors would require patients to come to a fixed location and many users are not comfortable with that. Also PCs are still expensive for some sections of the population. Hence we decided to use mobile phones/portable digital assistants (PDAs) as the patient-side network client. Within the framework, the agents reside in three areas:

![Fig. 1 Episode-based patient care cycle [7]](image_url)
• the patient’s mobile device (e.g. smart phone or PDA with Internet connectivity),
• the healthcare personnel’s mobile device (e.g. for nurses or paramedics) and
• the mobile and static servers (which may be a wirelessly connected notebook or an enterprise server computer).

Smartphones/PDA Phones (client-side) receive transmitted patient data from Bluetooth-enabled health-monitoring devices connected to patients (Fig. 2).

The network architecture for mobile health monitoring that we have developed consists of three levels on networks, namely the body area network (BAN), the personal area network (PAN) and the wide area network (WAN) as discussed below with a case study for cardiac monitoring [2]:

4.1 Body area network (BAN)

This involves a Bluetooth-enabled wireless network of various body parameter sensors [e.g. blood pressure, electrocardiogram (ECG) and blood sugar] that can communicate with the mobile device (cellular phone or PDA). We used an Alive heart monitor (with Bluetooth interface) that has two electrodes attached to the patient’s body and it records ECG activity, body position and so on. The heart monitor is Bluetooth-compliant and transmits via the serial port profile (SPP) to the PAN, operating in a slave point-to-point configuration.

4.2 Personal area network (PAN)

The PAN component of the framework (based on GPRS/3G) connects the BAN to users who communicate through the local cellular network. The PAN includes intelligent agents as midlets on a Java-based Symbian smartphone to enable communication between body sensors and local nurses and doctors.

If the agent is to forward the patient’s data to the hospital servers, the agent will commence the transfer via GPRS or 3G technology. To transfer data, the smartphone agent begins to encode data into a format which the server agent can understand. The message is then transmitted to the servers servlet as the body of an HTTP POST request. The messages may also be transmitted via web services via SOAP messages encoded in XML.

4.3 Wide area network (WAN)

In this case, the WAN provides connectivity between the patient and remote healthcare personnel who might be geographically far apart. Through the operation of web application servers such as WebLogic running at hospital and mobile sites, we are able to program servlets (server agents) to collaborate with smartphone agents.

4.4 Scalability

Scalability is achieved with web-based applications running on the three levels of interconnected networks – BANs, PANs and WANs. This design is flexible enough to be used in a range of health monitoring situations including disasters.

The only drawback to this framework, however, would be the remote chance of Internet dysfunction altogether since it relies on the Internet as a data and information carrier. This would mean that communication to hospital servers would fail and data being transferred onto the smartphone would be temporarily stored locally.

In summary, Fig. 3 shows the entire architecture of the network consisting of Bluetooth-enabled body sensors that are connected through Bluetooth (that work for very short distances) protocols to the smartphones on the client side (patients, doctors, nurses and so on). The mobile phone is connected to a GPRS-based gateway to a server that connects to the Internet and other remote devices through various types of wireless networking protocols, such as Wi-Fi and WiMAX. Service provider roles (e.g. doctors, nurses and paramedics) can connect to the network at various levels as shown in the diagram. We did come across some problems that will be discussed in the section on evaluation towards the end of this paper.

![Fig. 2](image-url) Network architecture of agent-based mobile health monitoring system [14]

5 Multi-agent application framework for mobile e-Health

Fig. 4 shows the scenario for multi-agent application framework used in this system. Essentially each human role is assisted by a type of intelligent software agent, such as patient agent, doctor agent, paramedic agent and specialist agent. These agents need to interact continuously as shown in the diagram. Before we discuss the application in more detail, the next section gives a brief overview of multi-agent systems.

5.1 Multi-agent systems

Jennings et al. define agents as ‘There is no universally accepted definition of the term agent, but there is something much extended. An intelligent agent is defined as one that is capable of flexible autonomous action to meet its design objectives’ [8]. Agents have the intelligence to react to situations; they can act proactively and also may have some social abilities (e.g. negotiation) to achieve desired objectives. Intelligent agents are being increasingly used to support networked enterprise services in various sectors, such as healthcare [9].

The last two authors of this paper have presented a holistic model to design cooperative management systems based on multiple agents in a top-down fashion [10]. These authors have been working on multi-agent systems using static and mobile agents for various applications in healthcare, finance and telecommunications for many years [11].

Development of multi-agent systems presents a number of problems, such as differences in ontologies that determine the behaviour of agents and differences in infrastructure (particularly in a networked environment) for these agents. This paper focuses on the networked infrastructure aspects of the multi-agent system for e-Health illustrated in this paper with a case study on cardiac monitoring. The next section discusses the operation of an agent for mobile e-Health monitoring. There are two types of agents:

- Smartphone or client agents.
- Server agents.

5.2 Operation of smartphone client agents for mobile e-Health monitoring

The client agent captures patient heart beat readings and surveys the patient environment. The agent first performs a device inquiry to discover the heart monitor which it connects to via SPP. The agent then establishes an Internet connection to allow communication with hospital servers later if required. It then begins to stream the patient’s data from the heart monitor.

As the Bluetooth-enabled mobile heart monitor transmits packets to the smartphone by reading the patient’s ECG
signals (via attached nodes on the patient’s body), the mobile agent (deployed on the smartphone) decodes the incoming packets and displays the current heart rate (in beats per minute) on screen along with the health status (e.g. healthy) indicating whether the current rate is abnormal or not. In the background, however, the patient’s mobile agent is connected to the server agent via general packet radio service (GPRS). The patient agent is constantly forwarding the monitoring packets to the server agent for persistent storage and trend analysis (Fig. 5).

On receiving this data, if the agent is asked to analyse the data locally, it will consult with its database of rules the criteria to analyse the incoming data. Simple rules are programmed into the smartphone agent such that it can reason for irregular heart beats and falls. For example, a rule would be if the beat is far less or greater than the average human heart beat of 72 beats per minute [12] (the condition), the agent will react to the situation and ask the patient whether he/she may be exercising or needing immediate help.

Typically, client agents running on smartphones are capable of:

1. allowing patients to decide whether to have results analysed by the server agent or locally,
2. relaying any alerts or suggestive actions to the end-user from the server agent,
3. analysing recorded parameters to give patient instructions if analysing locally,
4. providing alerts and suggestive actions to the end-user if analysing locally,
5. relaying patient data back to the hospital for further analysis,
6. locating the patient via the global positioning system on the smartphone,
7. allowing experts to visualise the current condition of the patient via a built-in VGA camera and
8. informing response personnel such as paramedics to respond to a situation.

5.3 Operation of server agents

Any given message that is received by a server agent may involve processing associated with several service roles such as contacting a doctor or specialist. On receipt of patient data, a server agent unpacks the message and consults its database of rules to analyse the heart rates. An underlying rule may be based on the entire history of collected patient data. For example, if the patient’s heart beat has been rising ever since their data was first collected, the agent will inform a doctor to examine and confirm the trend and diagnose that this may be because of a heart disorder. After the data has been analysed, it is written to a database such as PointBase (WebLogic’s internal database).

The server agent is connected to a backend database that stores all patient data and results. A doctor can log in to the system to view the patient’s monitored progress in real time. In the event of an abnormal reading, the doctor on duty is notified of the situation by the server agent. If the patient needs attention, a confirmation is set by the doctor on the system. Moreover, the server agent performs a number of key tasks to assist patients and medical staff which include:

1. processing incoming patient data and comparing it with the patient’s historical data,
2. storing patient data for medical history,
3. informing medical staff of abnormal readings or forming trends,
4. replicating and communicating information to other servers as a fail-safe mechanism,
5. sending advice and recommendations to the patient and medical staff and
6. tracking down the availability of resources.

The next section presents the configuration issues of a networked multi-agent system for e-Health.

5.4 Configuration of the multi-agent system

Once a confirmation is set, the response personnel, for example paramedics on duty, receive a notification to respond to a case. In the background, the response personnel agent is constantly polling the server to check whether a patient requires attention. If the response personnel respond to the case, the server agent marks the patient case as being attended to – otherwise, other response personnel who may also be polling the server agent will receive the notification. Once the response team has attended to the patient, they are able to relay a comment back to the server agent, so that the doctor may know of the diagnosis or treatment undertaken (Fig. 6).

In this way, agents at the smartphones and servers can jointly look after the patient by simultaneously performing multiple tasks. They are also able to monitor the patient’s

![Fig. 5](image-url)
environment through an integrated VGA camera to track patient actions and relay images back to medical staff.

This section presents the topology of the multi-agent systems in this application of mobile e-Health monitoring as shown in Fig. 7. The root level agents (at the servers) are the team leaders that communicate with each other via intermittent messages initiated by the lower level agents (except for the specialist agents who are able to communicate directly with the server agents as they may be using wireless PDA’s within the hospital for communication). This is because the agents on the smartphones must initiate the first contact to the server in order that the server may know where to reply to those agents.

The root level agents are the main agents that provide suggestive decisions to the patients and health professionals. The lower level client-side agents (which includes patient and response personnel agents) generally forward information provided by the server agents to their end user who can in turn respond. If the patient agent is not connected to the Internet, it will take charge of the situation and provide simple suggestive actions in the event of a problem – the suggestions are simple because the processing capability is limited on mobile devices compared with servers. Again, there will be data synchronisations occurring between top-level mobile agents and static server agents.

6 Implementation

We implemented this architecture for a prototype using Bluetooth-supported e-Health sensors for heart and weight monitoring and GSM mobile phones (smartphones). The software was developed using Symbian operating system used in many mobile phones today. We used Java 2 Micro Edition (J2ME) as the mobile programming environment to program our mobile agents and Java 2 Enterprise Edition (J2EE) for server-side agent programming [8]. Because of space constraints we are unable to provide more details here. Interested readers may see [8].

7 Evaluation

The preliminary evaluation involved the following [8]:

- Assessing the suggested architecture with respect to the remote health-monitoring scenario described in Fig. 4.
- Performance of the system using simulated data.
- Contextual interview of healthcare professionals.

Because of space constraints, we next discuss only the first two of the above evaluations.

7.1 Scenario-based testing

The interactions in the scenario shown in Fig. 8 are described sequentially as follows:

1. The patient has their body signals sent via Bluetooth to the patient agent.
2. The patient agent forwards this data to the server agent.
3. The hospital agent performs some processing and analysing and sends the results back to the patient.
4. On comparing the patient’s health history, the agent detects an abnormal pattern and alerts the doctor.
5. The doctor has a query to ask regarding the problem.
6. The server agent informs the correct specialist agent.
7. The specialist receives the query.
8. The specialist responds to the query.
9. The answer is forwarded back to the server agent.
10. The answer is received by the doctor.
11. A response is sent to the server to notify the agent of a necessary check-up.
12. The paramedic agent polls the server for a check-up.
13. The server agent sends out a notification to the paramedic agent.
14. The notification is noted by the paramedics.
15. The paramedic is able to respond to the situation.
16. The response is forwarded back to the server agent.
17. The server agent informs the patient agent that help is arriving.
18. The patient is notified of the diagnosis and arrival of help.
19. The paramedic reaches the patient.

Clearly, it can be seen that routine monitoring and checks of patient conditions can be performed by agents, freeing up the time of healthcare personnel (e.g. doctors) to focus on more serious situations. We are able to simplify the agent software design by having one agent for every type of human role in a typical scenario of e-Health for chronic illness as described above. All the human roles could be mobile not only within the hospital but also outside the hospital premises. Agents can collaborate over distance using this architecture.

7.2 Performance testing with simulated data

We tested the GPRS component of the implementation on the NetBeans phone emulator (which was mainly used to contact the server to do processing on the database). While combining the GPRS component with the existing midlet (running Bluetooth), we ran Bluetooth and GPRS components in a single thread. We read one frame of data from the input stream, sent the ECG data over GPRS and then waited for the server to send back proper ECG values to be displayed on the patient’s screen. On average, it took roughly 3 s to read data from the input stream and to post the data over GPRS, and then receive data from the server [8]. Sometimes the Bluetooth interface data from sensors in BAN was too fast compared with the rate at which the data could be offloaded by PAN through GPRS. Consequently, there was a buffer overflow at the smartphone after about 15 min. A PDA would withstand this speed mismatch for a longer duration. However, this would be a limitation on the number of BAN sensors that can be simultaneously monitored by a smartphone/PDA.

One problem with GPRS technology at the time of this study (2006) was cost. For a patient to continuously send out ECG values over a period of time, say a couple of hours, the cost would add up to a couple of hundred dollars – clearly not worthwhile for anybody to use over a long period of time. The technology is still not used widely enough and it is not feasible to transfer large amounts of data. It would better suit applications such as transferring simple diagnostic readings to the doctor on a daily basis where the data would not normally exceed 100 KB.

During the testing phase of this project, since the patient-side smartphone was both connecting wirelessly to the heart monitor and to the remote server via GPRS, the battery life did not last very long. When Bluetooth itself is switched on, the phone’s batteries may not last long – possibly for a maximum of a day or two depending on whether it is used in standby mode or constantly streaming data. Add GPRS connectivity to this, and surely the phone’s battery life would be reduced further. Hence battery life may constrain the mobility of the patient and doctor, as they have to recharge the phone after a period of usage [8].

8 Conclusion

This paper has presented a networked multi-agent architecture for monitoring of human health conditions based on emerging wireless mobile technologies. This architecture provides the basis for the use of intelligent agents to deliver better healthcare to patients, especially in the case of home-based care of chronic illnesses, the cost of which is increasing because of the ageing population in the world. The application of this framework can be applied to many e-Health service scenarios. This can range from doctor-to-patient monitoring from a remote location for chronic illnesses such as diabetes, to responding to emergency situations such as earthquakes and tsunamis, and tele-consultations.

As the telecommunication infrastructure improves in the future, we should see enhanced communication quality and faster transmission of data such that quality video and voice content can be captured by agents to allow healthcare professionals to provide better patient services. More trials are needed to establish mobile e-Health that can help solve some burning global healthcare problems caused by the ageing population and the increase in chronic illnesses.

This paper has discussed the network infrastructure for a
simple multi-agent system for mobile e-Health. As the capabilities of mobile devices improve, agents will be able to perform more and more sophisticated functions in future. However, the security of mobile agents will be a major problem not discussed in this paper [13].

9 References