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Abstract: Wireless technology based pervasive healthcare has been proposed in many applications such as disease management and accident prevention for cost saving and promoting citizen's wellbeing. However, the emphasis so far is on the artefacts with limited attentions to guiding the development of an effective and efficient solution for pervasive healthcare. Therefore, this paper aims to propose a framework of multi-agent systems design for pervasive healthcare by adopting the concept of pervasive informatics and using the methods of organisational semiotics. The proposed multi-agent system for pervasive healthcare utilises sensory information to support healthcare professionals for providing appropriate care. The key contributions contain theoretical aspect and practical aspect. In theory, this paper articulates the information interactions between the pervasive healthcare environment and stakeholders by using the methods of organisational semiotics; in practice, the proposed framework improves the healthcare quality by providing appropriate medical attentions when and as needed. In this paper, both systems and functional architecture of the multi-agent system are elaborated with the use of wireless technologies such as RFID and wireless sensor networks. The future study will focus on the implementation of the proposed framework.

1. INTRODUCTION

Wireless technology has the potential to change the way of living with many applications in healthcare of the dependent people, and emergency management. The wireless technologies such as wireless sensors, RFID and sensor networks combine with the research of pervasive informatics together have built the contribution in order to improve the healthcare quality by reliable detection of anomalies (Cook et al., 2009). Pervasive informatics refers to the study of information, which is pervasive, and the environment where information is or can be pervasive (Liu et al., 2010). In this scenario, pervasive healthcare represents the interactions between information of patient that can be pervasive and the pervasive healthcare environment. Besides, wireless technology based pervasive healthcare has been proposed in certain aspects such as disease management, accident prevention, cost saving and promoting wellbeing (Sneha and Varshney, 2009; Varshney, 2003, 2005, 2007, 2009). However, the emphasis so far is on the artefacts development with limited given attentions to guiding that how to develop an effective and efficient solution for pervasive healthcare.

This paper aims to propose a framework of multi-agent systems design for pervasive healthcare by adopting the concept of pervasive informatics and using the methods of organisational semiotics. In this paper, firstly the concepts of pervasive informatics as well as the theory of organisational semiotics that is used for the proposed framework are introduced. Secondly, the previous work and wireless communication technologies enabling pervasive healthcare solution are viewed. Thirdly, a multi-agent system for pervasive healthcare is proposed with its systems and functional architecture, as well as a detailed description of functionalities for the various intelligent agents that are tasked with analysing the monitored parameters. Lastly, the contribution of the proposed architecture and its limitations is discussed for future research.

2. RELATED WORK

The basis of this research is one of the projects "Co-ordinated Management of Intelligent Pervasive Spaces (CMIPS)" in the Informatics Research Centre at University of Reading. The project is conducted in collaboration with industry and it has several objectives such as automated personalization of the workplace, automated assessment of building environments in real-time and readily deployable sensors by use of wireless sensor networking technology (Yong et al., 2007). Besides, this project also has one key component that is to deliver a Multi-Agent System for Building cOntrol (MASBO) by using the methods of organisational semiotic in order to balance energy use and occupants' preference, and to learn/predict user's behaviour (Qiao et al., 2006). This paper adopts the concept of MASBO to provide a framework for multi-agent system for pervasive healthcare by using the methods of organisational semiotics. The proposed work aims to utilise sensory information to patient's health information in order to support healthcare professionals for providing appropriate care. The following sections review the MASBO and the supporting technologies for pervasive healthcare.

2.1 Overview of MASBO and Supporting Wireless Technology

Several projects in pervasive informatics have been conducted in the Informatics Research Centre and other schools in the University of Reading (Liu et al., 2010). One of the projects CMIPS is conducted in collaboration with industry. As mentioned that MASBO is a key deliverable of the project, which aims to balance energy use and occupants' preference as well as to learn behaviours of users. MASBO provides an agent-based framework, which utilises sensory information to determine the needs of users. In MASBO, mainly four agents (central agent, local agent, monitor and control agent, and personal agent) work with the Building Management System (BMS) and other devices in order to enhance the building performance. The central agent communicates with BMS to control the building; the local agent is to control a defined space, subject to the policies set for each space, and to coordinate with the central agent; the monitor and control agent communicates with devices such as sensors and actuators; and the personal agent analyses user's profile and preference to assist the personalised control of each defined space. The building assessment is to conduct a continuous assessment of building performance for adjustment of policies.

2.2 RFID Technology and Applications

A Radio Frequency Identification (RFID) system generally consists of tags and readers. The tag is composed of an integrated circuit for processing data, modulation of radio frequency signal and its transmission. The reader is used to retrieve data from tags. The RFID technology plays an important role in pervasive healthcare environment. It provides location-based healthcare services with the main objective of real-time monitoring indoor and outdoor patient's healthcare condition and information collection. The patient's healthcare conditions such as body temperature, blood sugar, heart rate etc. are generated as monitoring criteria which can be used for defining thresholds. For example, healthcare professionals located in the hospital or care home can remotely monitor the real-time health information of the tagged patient. On the other hand, the RFID tag is mounted on patient's wrist bracelet and can communicate with the healthcare sector identifying the patient without requiring additional interrogation to the central repository. In addition, the detailed information of the patient is stored on HIS database to maintain a consistent profile of each patient for further diagnosis. The wireless infrastructure of the medical facility can provide web-based communications among patient, healthcare professionals and caregivers.

Furthermore, other applications in addition to monitoring stakeholders and equipment have been proposed for pervasive healthcare based on RFID, like the surgical procedures applications using for reducing medical errors. For example, Bacheldor (2007) develops the Smart Sponge System using RFID tag in surgical operation for recognising if some of the sponges have been inadvertently left in the patient after the operation, and the VeriMed tag which can be implanted on the patient for collecting information such as allergies and medical directives.

2.3 WLAN and Mesh Networks

Wireless Local Area Network (WLAN) is an infrastructure-based wireless network that distributes a number of access points (AP) located in fixed positions for supporting control of the network usage in transmission range. The WLAN acts as a router providing internet connection for transmitted data packet. The reference standard is represented by IEEE 802.11 family (a/b/g) which is based on definition of a service differentiation on transmission in order to set priorities for packets (Ni, 2005). Access categories are defined for several services i.e. real-time services are associating with higher priorities. These parameters during the transmission enhance the network adaptability and improve the quality of services. The traffic prioritisation can significantly support pervasive healthcare while it is applied inside a single service. For example, it can prioritise the data transmission related to alarm message or urgent responses of clinical analysis.

In addition, another approach to extend WLAN coverage is represented by Mesh networks (Bruno et al., 2005) which root from the concept of Mobile Ad HOC Networks (MANETs) (Conti and Giordano, 2007). The MANETs consists of a set of self-organised mobile nodes in a multi-hop network topology where the mobile node does not need pre-existing infrastructure for communication and data exchange. Mesh networks allow the mobile nodes to connect the internet and access through multi-hop path established in wireless backbone. Each mobile node can act as a mesh router: static node can communicate to each other through multi-hop paths. It also can be configured with gateway to enable internet access to other networks. In order to allow mobile user obtain multi-hop connectivity to communicate with others and access the internet, several mesh networking protocols have been defined (Bruno et al., 2005). These protocols overcomes the interoperability issue i.e. IEEE 802.11s working group (Hiertz et al., 2008) is constantly working on standardisation of mesh network capabilities in Wi-Fi technology.

3. METHODOLOGY

This section reviews the concept of pervasive informatics and applies the semiotic framework which roots from organisational semiotics in pervasive healthcare environment to articulate the interaction between the pervasive healthcare environment and stakeholders.

3.1 Pervasive Informatics

Pervasive informatics is an emerging interdisciplinary study that focuses on how information affects human interaction with their environment (Liu, Nakata and Harty, 2010). It is different from the concept of pervasive computing as the focus of pervasive informatics is on ICT-enhanced physical and social spaces, rather than just on the technology itself. Informatics has been given many different definitions, and the term has been used in varying domains. Here, the focus in on the nature of information itself and on the interaction between people and information, in this sense, the healthcare environment and involved people like patients, professionals and caregivers. The definition of informatics in this paper which is defined and used by Informatics Research Centre at the University of Reading is the study of information through its lifetime, relating the creation, management, distribution and utilisation of information in scientific and economic activities. On the other hand, the word "pervasive" is the adjectival form of pervade. Hence, pervasive informatics refers to the study of information which is pervasive and the environment where information is or can be pervasive, in this context, the information of patient which can be pervasive and the pervasive healthcare environment.

As defined by Liu (2008), an intelligent pervasive space covers social and physical space with enhanced ICT for humans to interact with the environments. An alternative definition of intelligent pervasive space is "an adaptable and dynamic area that optimises user services and management processes using information systems and networked ubiquitous technologies" (Moran and Nakata, 2009). In order to meet the business purposes i.e. care quality improvement, patient's safety in healthcare environment, the spaces should be adaptable and automated to provide more intelligent services. Such services included automatic patient monitoring (e.g., health records, vital signs and security) through the use of information and communication technologies. The intelligent pervasive spaces can be implemented by embedding pervasive computing devices and using communication technologies in healthcare environment to improve the care quality for living patient. Thus the information of patient can be sensed and communicated with pervasive devices such as RFID tag and sensors through wireless networks, and patient can be treated in a more convenient, seamless, transparent and pleasurable environment.

3.2 An Organisational Semiotics Perspective of Pervasive Healthcare

Semiotics, as a branch of the philosophy related to linguistics, is the study of signs and symbols. As a sub-branch of semiotics with a particular emphasis on the functions and use of information in organisational setting, Organisational semiotics (OS) is the study of organisation using concepts and methods of semiotics (Liu, 2000; Liu et al., 2002; Zhang and Liu, 2009). The study is based on the fundamental observations of the communication and interpretation of signs between people and the environment. There are six aspects of organisational semiotics defined by Ronald Stamper, physic, empiric, syntactic, semantic, pragmatic, and social world, namely to semiotics ladder, which is a theoretical framework in information system development. The semiotics ladder has been widely used in design information systems and analysing business organisation. Furthermore, its relevance can be also used in the development of pervasive healthcare. The analysis in figure 1 describes relevant issues that should be addressed in the design of pervasive healthcare:

- At the physical level, the material dimension identifies the basic form of signs and serves the requirements such as functionality, durability and protection. In this context, the physical properties include sensors, media and signals.
- The empiric level examines that how signs are used and transmitted, and it covers transmission of signals and supporting protocols.
- The syntactic level is used to describe the structure of signs, such as language, coding methods and the data records.
- The semantic level represents the meaning of the sign. In this sense, readings from sensors should be understandable and meaningful for healthcare treatment.
- At the pragmatic level, where it provides recommended actions based on the understanding of readings.
- The social level is where the social consequences happened, and it relates to the diagnosis, obligations and commitments for patient.

Pervasive healthcare environment is a complex sign system. Organisational semiotics can help to understand the relationships between the healthcare stakeholders and the healthcare environment. Methods and techniques developed from organisational semiotics are used to examine that how the complex signs of pervasive healthcare can be best designed to improve the care quality of the patients and to meet the requirements of the stakeholders. The next section introduces the proposed multi-agent system for pervasive healthcare, including its system architecture and functional architecture.

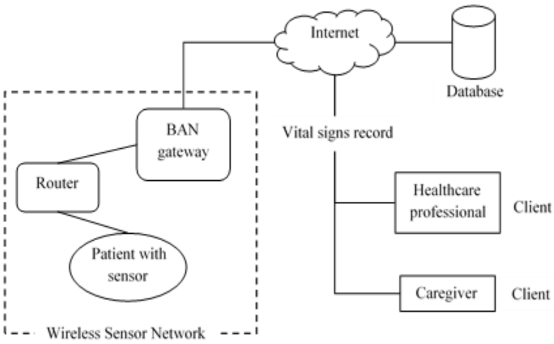

Figure 1: Scenario of system implementation

4. DESIGNING MULTI-AGENT SYSTEM FOR PERVASIVE HEALTHCARE

The design of the multi-agent system for pervasive healthcare consists of a Body Area Network (BAN) gateway, routers and a body sensor equipped with RFID tag. The body sensor constantly measures vital sign such as body temperature, bold sugar, heart rate etc. of the patient and the routers relay the data to the BAN gateway which links to the WLAN A Java program is developed for transmitting sensory data from BAN gateway to the database server via internet using method of client-server access (Chang and Huang, 2011). Besides, the RFID tag is used for location tracking, i.e. which room the patient is. In this way, when an emergency situation occurs, the location information helps caregivers and healthcare professionals to indicate where the patient is and result in taking a prompt action. In addition, this design can be extended by adding sensors embed in buildings, i.e. room for delivering more extensive information such as video images, humidity and room temperature, and smart home appliances can be used in the living environment. Sensors with computing and communication capabilities are deployed at specific locations in patient's home to monitor compliance

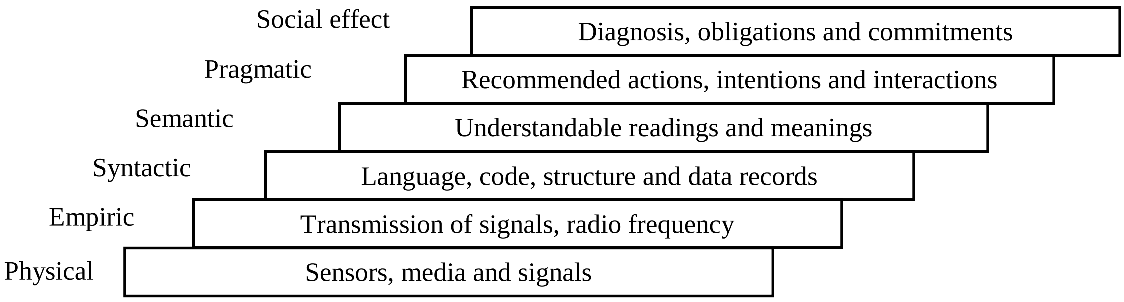

Figure 2: Applying the semiotic framework in developing pervasive healthcare (based on Stamper, 1973)

tasks. The sensors are communicated with intelligent agent who analyses the sensory data and sends to corresponding healthcare professionals. The frequency of reporting the health conditions of the patient is adjusted by a healthcare professional as deemed suitable. For example, if the patient is observed to be sitting on the coach in front of the television of personal PC at medication time, then the system will get informed by agent and send a reminder to the hand devices of patient via either internet or cellular network. The scenario of the system implementation is given in the figure 2.

4.1 System Architecture

Technically, an implementation of the multi-agent system is an assisted care facility using sensors technology and database. Facility professionals can be alerted when patients need immediate care. RFID plays a key role for communication among patients and staff members and allows long-term health monitoring and easy retrieval of information. Figure 3 is the system architecture describes that how the designed multi-agent system fits into the existing healthcare information system. The system architecture consists of three key layers: 1) software, 2) communication and 3) devices. The software layer contains three contents:

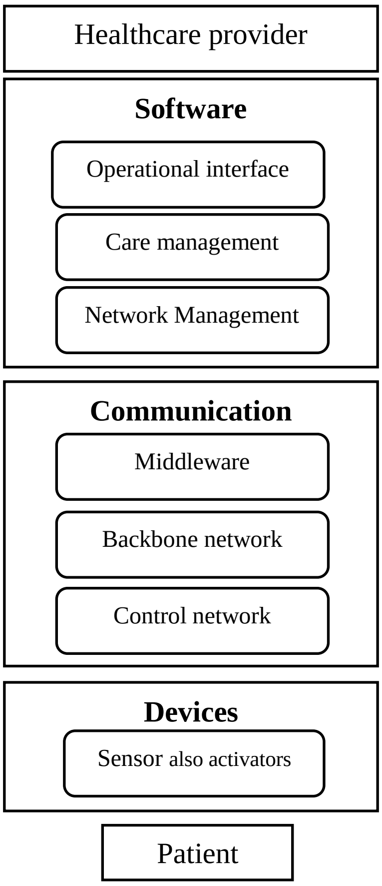

Figure 3: System architecture (based on Qiao, et al., 2006)

a) Operational interface – to provide operational interactions for healthcare provider
b) Care management – to provide intelligent analysis for agents
c) Network management – to manage network transmission in communication layer

The communication layer has the elements of middleware, backbone network and control network. This layer focuses on providing stable quality of communication. The device layer is where hardware such as sensor resides in and connected the patient.

The architecture is designed by using agent and wireless technology to support healthcare professionals for providing appropriate care. Its capabilities include access to diverse wireless networks and location tracking which supports the system functionalities such as patient position and intelligent emergency response. In addition, the architecture is potentially aiming to reduce long-term cost of healthcare by reducing the burden of healthcare professionals and enhancing the efficiency. Furthermore, a list of commercial applications summarised by Alemdar and Ersoy (2010) are supporting the multi-agent system for monitoring patient. There are five categories of them: 1) location tracing and medication intake reminder – can support monitoring system to provide constant healthcare for patient; 2) daily living activities monitoring – identifies and records patient's routine and anomalies; 3) medical status monitoring – captures healthcare status of patients including heart rate, blood sugar, temperature etc. by using wireless sensor; 4) fall and movement detection – focuses on support for patient who requires special care i.e. patient recovering from an operation.

4.2 Functional Architecture

The intelligent agent is developed to perform the task of monitoring and analysing the conditions of patient. The use of the intelligent agent with relevant knowledge has the capability of assisting the healthcare professionals in on-going analysis and diagnosis of sensory data, and it can also support the continuous patient monitoring and alerting in care of anomaly via multi-agent communication (Sneha and

Varshney, 2005). The intelligent agent has helped the healthcare professionals to reduce the cognitive overload and promoted timely intervention of healthcare structure as required. The agent carries a large amount of data analysis and communicates with other agent or sends reminder to devices only when required thereby reducing traffic on the wireless networks and enhancing the performance of the healthcare system.

The intelligent analysis is managed by the content of care management at software layer in system architecture. Prior to the first use, the intelligent agent tasked with analysing patient's healthcare condition is configured by professionals based on their expertise and the patient's past condition, thus providing specific personal care. The agent analyses the sensory data derived from sensors equipped on patient, looks for violations of pre-defined thresholds, and alarm patient or healthcare professionals when and as needed. The ontology which categorises different messages is built by specialist. Figure 4 is the functional architecture which elaborates the care management and depicts how agents work on providing continuous care for individual patient.

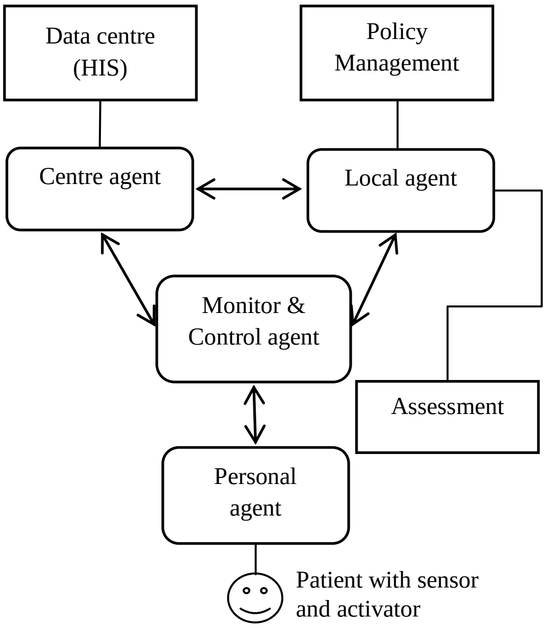

Figure 4: Functional architecture of care management (based on Yong et al., 2007)

The intelligent agents are categorised into four agents (Centre Agent, Local Agent, Personal Agent and Manage & Control Agent) for this architecture. With the support of policy management and seamless network connectivity such as WLAN and RFID, the architecture is proposed in order to improve healthcare delivery by timely and reliable detection of anomalies and enhance the efficiency of the clinicians by assisting them in providing medical attention when needed. Figure 4 depicts the agent-based functional architecture for pervasive healthcare environment and the four categories are presented as followed:

- Personal agent: includes a number of agents such as patient data agent, medical information agent and location which are used for information management and updates.
- Local agent: plays a central role as a mediator, policy enforcer and information provider. It reconciles patient's behaviour in different contexts, enforces policies and provides structural information for their respective coverage and updates information as needed.
- Monitor & Control Agent: consists of a list of agents such as medication agent, blood sugar agent and weight agent which are used for collecting and monitoring patient's personal information and behaviours. It enforces the operation request given by the patient according to decisions made by the Local Agent.
- Central agent: has two major functions which are decision aggregation and interface to internal/external services required by other agents. The typical services provided by central agent include agent system configuration and interface to data centre.

In a data centre, a large amount of stored healthcare data which supports the healthcare decision making process is accessed, analysed and updated by the multi agent system. The use of the updated data in the data centre can help related industries such as pharmaceutical authorities, research organisations in analysis of specific health conditions and cost saving. Patient's information including monitored data can be accessed by healthcare professionals, nurses and carers. In particular case, they also can be accessed by the third party with authentication. To be aware that following to related data protection acts, the patient's individual healthcare data would not be disclosed to others.

The mechanism of knowledge representation and reasoning in the agent adopts the EDA (epistemic-deontic-axiological) model which is rooted in organisational semiotics (Filipe and Liu, 2000; Stamper et al., 2000). The EDA model exemplifies the agent informational states, and meanwhile it simultaneously classifies the relationship between them (Booy et al., 2008). As depicted in the figure 5, the EDA model has four basic component modules: Perceptive Interface (P) which is the initial element perceiving the data that has been sensed by agent or other devices; the epistemic (X) element contains knowledge of the domain (each defined space) and updates tis knowledge and beliefs of the state in the domain through the information received by the perceptive interface; the axiological (Y) element holds the norms, rules related to business process, cultural and personal practice to determine which signs the agent should perceive and what actions are

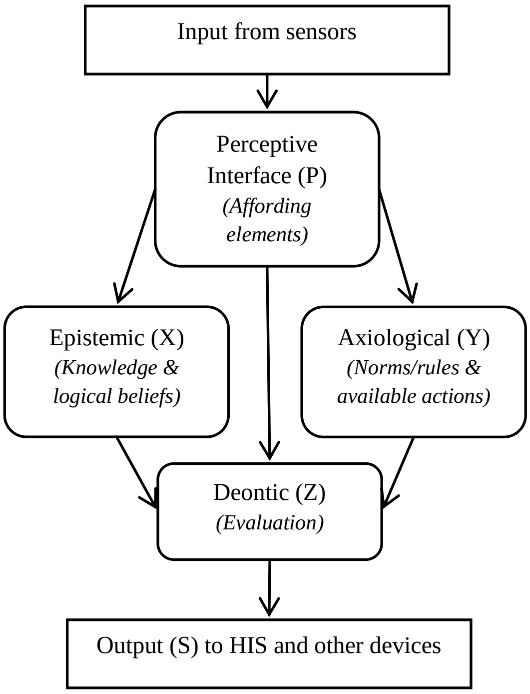

Figure 5: The EDA model of agent design (adapted from Duangsuwan and Liu, 2010)

currently available for enabling the evaluation of the current state of the domain using the norms; the deontic (Z) element performs the evaluation and generates commands for actuation through the agent. It determines what actions the agent can perform based on the combination of the perceptual interface, epistemic knowledge and axiological norms. The outcome (S) of the deontic evaluation can result in the health information system for performing recommended actions to the patient.

This scenario depicts that a patient suffering from diabetes living in his/her own house, and this house can be seen as a pervasive healthcare environment monitored by intelligent agents. The pervasive healthcare environment also includes hospital and the social care such as care home. The patient's health conditions are monitored by the embedded sensors, and the sensed data will be immediately transmitted to the healthcare professionals or care givers once anomalies have been detected. In this example, in order to maintain the patient's health condition, a multi-agent system is proposed to monitor the patient's vital signs by timely and provide pertinent care. The system deployed the central agent, local agent, monitor & control agent and personal agent. The personal agent has a list of functions (Blood sugar agent, medication agent, weight agent and sleep agent etc.) to monitor the patient's health condition. The function of blood sugar monitoring is set for frequent detection and alarms once the monitored data exceeds the specified threshold; the function of medication monitoring is to inform the patient to take medicine in every 30 minutes and a weight agent keeps the record of the patient's body weight for intensive diagnoses; the function of sleep monitoring is to detect the anomalies of the patient's sleep which can be reported to clinician in care if they are caused as side effect by mismanagement of diagnoses. As introduced previously the functionalities of the intelligent agents which are responsible for carrying out certain pre-defined tasks and the protocols and functionalities of intelligent agents tasked with the process of analysis. A detail description of each function of the various intelligent agents that are tasked with analysing the monitored parameters and the protocols is given as followed:

- Medication monitoring – the agent set specific time to inform patient to take medicine, and will reminder the patient in every 30 minutes until the patient has confirmed the medication intake. Otherwise, the agent will count the times that patient missed medication intake and send alarm to corresponding healthcare professionals if it exceeded the threshold.
- Blood sugar monitoring – the agent set a list of blood sugar levels and defines the thresholds for each level. If the sensed reading of blood sugar has significantly increased or dropped, the agent will request intensive monitoring which reports two consecutive readings, and the agent will send alarm to healthcare professionals if the readings still reveals the anomalies of blood sugar situation.
- Weight monitoring – the agent watches patient's body weight and advice the patient on healthy habits if the change in weight is more than 10kg. If the change is more than 15kg, the agent will send alarm to healthcare professionals for further treatment.
- Sleep monitoring – the agent observes patient's sleep condition and will send alarm to healthcare professionals if the patient has sleeplessness or too much sleep for more than two consecutive days.

This section mainly represents the proposed multi-agent system for pervasive healthcare, including its system architecture and functional architecture. The mechanism of the multi-agent system has been discussed, yet limited applications have been considered. As this paper is to propose a multi-agent system for pervasive healthcare from both semiotic and social perspectives, the applications of the system will be discussed in the implementation of the system.

5. CONCLUSION AND FUTURE RESEARCH

This paper proposed a framework of multi-agent system design for pervasive healthcare by adopting the concept of pervasive informatics and using the methods of organisational semiotics. The purpose of the proposed multi-agent system for pervasive healthcare is to utilise sensory information from sensors to patient's health information in order to support healthcare professionals for providing appropriate care. The key contributions of this paper contains theoretical aspect and practical aspect: in theory, the paper articulated the interactions of information between the pervasive healthcare environment and the involving stakeholders by using the methods of organisational semiotics, and proposed framework for guiding the design of multi-agent system; in practice, the proposed work improved the healthcare quality by reliable detection of anomalies and enhance the efficiency of the healthcare professionals by providing appropriate medical attentions when and as needed.

To sum it up, the concepts of pervasive informatics as well as the theory of organisational semiotics that is used for the proposed framework have been introduced at first in this paper. The previous research related to MASBO and the supporting wireless technologies for pervasive healthcare have been reviewed, and both system and functional architecture of the multi-agent system have been elaborated with the use of supporting wireless technologies such as RFID and wireless sensor networks.

However, the proposed multi-agent system still requires to be validated more comprehensively by the implementation in practical. The future work will help to address the issue of interoperability of the proposed system along with existing health information systems, as well as the issues of acceptability of the system along with the level of trust of the stakeholders in the pervasive healthcare environment. Another important concern is the security and reliability of the information transactions over the system. The future research also needs to elaborate the mechanism of the multi-agent system that can be utilised as a decision support tool for healthcare professionals. Furthermore, from a technology perspective, the existing issues of providing a stable and reliable wireless data transmission are imperative to be overcame, and the feasibility of using new technologies in the system needs can be explored in the future work.

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