



A novel framework for a remote patient monitoring (RPM) system with abnormality detection ☆☆☆

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ARTICLE INFO

Article history:

Available online 22 May 2019

Keywords:

Remote patient monitoring
Internet of Things
Machine-to-machine
Aging people

ABSTRACT

Objective: This research aims to build an effective and automated RPM system based on an information communication technology (ICT) framework that automatically triggers medical alerts, hospital visits, medications, and social support in a timely and precise manner, with specific attention to aging people. The goal of the proposed framework is to construct a safe, flexible, and manageable system containing multi-agent, auto-notice, sensor management, and secure transmission of data to allow an autonomous functioning of RPM.

Methods: The literature between 2002 and 2018 that introduces healthcare platforms with the technology of the Internet of things (IoT) is reviewed and compared in compliance with various technical and functional features. Eleven healthcare-based IoT platforms are compared. Eight of them utilize the Representational State Transfer Application Programming Interface (REST API), while ten of them have Message Queue Telemetry Transport (MQTT), seven of them have device management, and nine of them have security control. In addition, Kepware's KEPServerEX communication platform containing up to 250 communication protocols is included.

Results: The results confirm that the proposed framework reliably operates within the complex healthcare processes, taking into account the equipment management, security management, messaging and diversification of communication protocols. This study uses the concept of IoT 3-tier through which a complete sensor management mechanism is structured. Moreover, secure data connection protects the patient's privacy. Each sensor provides a distinctive notification to construct flawless authority management.

Conclusions: The proposed framework can not only reach the machine-to-machine (M2M) realm, but also provide support in emergency cases.

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Introduction

Increasing healthcare costs for aging people, growing numbers of chronic disease, need for new technologies in medical treatments, while at the same time the decline in the number of health professionals comparative to the population growth makes the

conventional healthcare model inadequate [1]. According to Bisbal et al. [2], most healthcare institutions rely on conventional information systems that are difficult to implement due to the inability to meet the demands of end-users. Hence, legacy information systems do not conform to recent developments in ICT [3]. Technological advances can better deal with operational problems in healthcare delivery with the application of computational tools to hospital activities [4]. In a healthcare system, ICT provides health services to anyone at any time and any location [1]. ICT advances enable patients, who are remotely located, to perform their routine activities in a daily basis.

The RPM system can help old and disabled patients to obtain timely healthcare service. Accompanied by a fast-increasing aging population, the increasing demand for RPM makes it an essential

* Conflict of interest: the author has no conflict of interest to disclose.

☆☆ Ethical approval: not required.

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part of the future healthcare system. The conventional RPM system uses fixed telephone lines to connect healthcare services to patients at home. The rapid developments in ICT, high-speed Internet and sensor network technologies increase the accessibility of the real-time monitoring of the health status of patients living in remote areas [5]. RPM involves acquisition data based on specific information, including vital signs and environmental elements, and transmission of the data to the principal server.

IoT is defined as “a global network of smart devices that can sense and interact with their environment for communication with users and other things (smart devices) and systems” [4]. Things or devices refer to cars, refrigerators, and others. Recent developments in the IoT and Cloud Computing (CC) have transformed the healthcare industry [6,7]. With increasing attention on efficiency and outcomes, the diffusion of IoT and CC could play an immensely important role in reducing healthcare costs without reducing the quality of care delivered to patients [8]. Although there are innovative implications of the integration of IoT and CC in modern health applications, RPM that integrates IoT and CC has received less attention [8]. However, IoT has the potential to bring about new medical applications such as remote health monitoring, chronic disease, fitness programs, and adult care. Hence, medical devices including diagnostic and imaging devices and sensors can refer to smart devices representing the core of IoT [9].

The introduction of Multi-Agent System (MAS) in the health industry led to interactive, self-intelligent, organized, distributed, and collaborative remote patient management [10]. Wooldridge [11] referred to software agents as entities employing Artificial Intelligence (AI) methods to select the optimal set of actions for achieving the goals defined by the users. These agents are able to communicate with one another and with users, while their proactivity, sociability, and autonomy allow them to support their users in daily activities [1]. Autonomy is a vital element of an agent in satisfying agents' goals [11]. Autonomy means operating without the intervention of humans or other systems, although the set of possible actions are pre-defined [4]. MAS refers to the combination and coordination of two or more agents with well-defined communication rules [12]. Henceforth, software agents can significantly assist healthcare professionals in exchanging healthcare information during the health tasks [13]. MAS can potentially meet crucial requirements in fast, mission-oriented, rich-in-content, and distributed information systems where a vibrant environment, ambiguity, and sophisticated control play integral roles [14]. It not only aids in awareness and knowledge sharing among patients and caregivers but also provides rapid response using distributed computing [10].

Isern et al. [15] collected 163 papers from various sources, such as ScienceDirect, PubMed, ISI Web of Knowledge, Citeseer, and others for further analysis of scientific publications related to the domain.

The purpose of this study is to design a new IoT framework for RPM system for aging people that automatically triggers medical alerts, hospital visits, medications, and social support in a timely and precise manner. Within this framework, patient data collected from various remote sensors and user devices are easily integrated, analyzed, and transformed into meaningful information for related users (e.g., physicians, nurses) to rapidly respond and take actions in accordance with their standard operating procedures.

Related works

In a modern health care, technological advances can better deal with operational issues, such as physician and patient relationship improvement owing to RPM possibilities, easy access to and sharing of information among medical care units and people who are close to patients (e.g., relatives), high mobility for uninterrupted

monitoring of patients' health status not limited to hospital facilities, involvement of external health care professionals in treatment and diagnosis of patients, emergency situation alerts to health care professionals, and so on [16,17].

Agent-based technology has recently emerged as relatively new concept that primarily focuses on designing, modeling, and developing complex systems [15]. In particular, MASs enable the modeling in more realistic and distributed environments, by assigning an agent to each part of the process or framework. Intelligent agents improve scalability, interoperability, and configurability in health care. In addition, main agent-based approaches are used in medical data management (processing electronic health/medical records), decision support systems that foster health care process execution by professionals in terms of diagnosis and treatment, resource allocation and planning (scheduling and management of human and material resources), remote care (remote monitoring of health status of patients), and composite systems (integrated health care management solutions).

The major focus of the current research is remote care. Remote care systems are mainly comprised of three components: (1) sensors; (2) signals received by sensors that analyze and identify the problems; and (3) reporting to health care staff. Wearable biomedical sensors are very useful due to the need for monitoring of vital signs, patients' activities, and real-time health parameters, and without hindering their movements [18]. Vital signs differ based on patients' activities, smoking, sleeping habits, temperature, and others [19]. If heart rate increases while a patient sleep, it is recognized as an abnormal case. While conventional health care assistant (HCA) systems are standalone applications that rely on local devices and servers, they are not flexible in monitoring different patients with distinctive health issues [20]. Henceforth, RPM can help health care staff, professionals, nurses and/or caregivers to dynamically and remotely monitor patients. Hassan et al. [18] proposed IHCAM-PUSH model that allows acquiring, storing, processing and analyzing big data collected by ambient assisted living (AAL) system. Gia et al. [21] proposed IoT-based continuous glucose monitoring (CGM) model that is integrated with sensor device monitoring real-time temperature and glucose level and presenting in graphical format for physicians and patients. The use of nRF communication protocol contributes to the energy efficiency. In another study, Morillo et al. [22] compared IoT and wireless sensor network (WSN) technologies to execute real-time meal distribution monitoring in hospital environment. Based on results, IoT has relatively less latency compared with WSN, while at the same time IoT-based system owns better battery life. However, their system is lack of functionality in terms of sending notification regarding the temperature increase and decrease in food trolleys. Li et al. [23] also developed IoT-based monitoring system solely for heart disease patients. The major drawbacks are that monitored data is predominantly stored at a patient side (e.g., handheld devices). Hence, data is only sent to the server, when the patient feels uncomfortable and requests for diagnosis. In addition, this system is only designed for the patients with lower heart attacks. The application of IoT is not limited to the above domains. Yacchirema et al. [24] utilized IoT and big data in monitoring and treatment of sleep apnea in elderly people. The use of fog computing by smart IoT gateway enhances interoperability, while at the same time Zig-Bee, BLE, and 6LowPAN systems create an intelligent operating environment. However, the authors suggested improving data analytics part, such as deploying sensors for assessing oxygen level, breathing rate and so on. Moreover, storing medical/health records and disease histories are recommended.

Methods

This research identified general features and connection requirements for RPM devices and their applications. Earlier studies

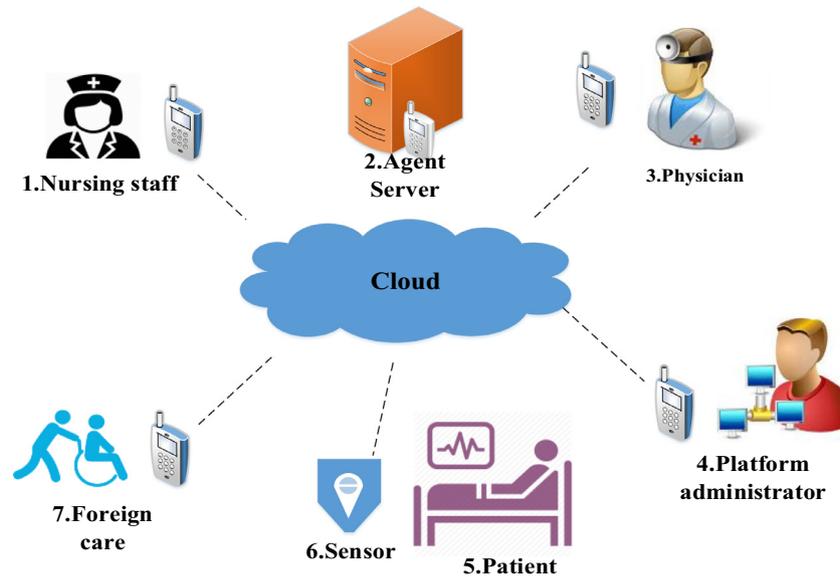


Fig. 1. The user role in remote care platform.

related to information technologies of IoT, agent, and AI applicable to remote monitoring and remote healthcare are reviewed. Then, the IoT framework is proposed as combinations of available technologies to fulfill these requirements.

Users involved in remote care

There are several user roles involved in the remote care platform, as shown in Fig. 1. They are mainly the nursing staff, agent servers, physicians, platform administrators, patients, sensors, and foreign care.

- Nursing staff: They frequently contact physicians and discuss appropriate medical intervention and referral, regular follow-up, and try to understand the changes in the disease, while also handle inspection reports, clinical plans, and other treatment stages. In addition, nursing staff conduct monitoring and tracking through telephone interviews. Moreover, they play a crucial role in distant care in the form of frequent contact with patients, as well as the tracking of personal health records.
- Agent Server: to ensure the system operates automatically, the agent server allows the message to automatically flow to the correct object, such as the monitoring of elderly people with diaper sensors, in which the guidelines can be set in advance. Thus, when the humidity of the diaper reaches the pre-defined level, the agent server sends a notification to change the diaper without informing the physician or caregiver.
- Physician: in abnormal physiological information, physicians along with nurses discuss and consult other relevant medical treatments to take appropriate intervention measures with the inclusion of the personal follow-up records of patients.
- Platform Administrator: is responsible for operating the platform, including abnormal message monitoring, network monitoring, software deployment, hardware sensor management, and data transmission.
- Patient: patients receive medical treatment with the use of a sensing device that helps measure blood pressure and pulses through an Electrocardiogram Sensor (ECG).
- Sensor: an instrument collecting the patients' physiological data, which refers to a blood pressure monitor or thermometer.

- Foreign care: they are responsible for the first-line contact with patients. Hence, through foreign care, patients are trained to wear the sensing devices in a correct way to ensure the system is connected, runs smoothly, and can receive the alert signal in the emergency.

Multi-agent in healthcare system

Following Isern et al. [15], this article used six common agents related to healthcare, namely *user agent*, *resource agent*, *physician agent*, *diagnostic agent*, *knowledge-based data service*, and *external services*. The advantages and main characteristics of each agent are described in Table 1.

Management features

The Internet service management platform IoT Platform as a Service (IoT PaaS) plays an important role in the ecological system. Thus, through IoT PaaS, enterprises can remotely monitor and operate equipment, and with the use of the equipment, data can be collected and analyzed, while the equipment itself can be maintained to provide innovative services. The Internet application support platform mainly contains the connection management, device management, and installation of the cloud, as well as other units.

- Connection Management: Due to the wide variety of sensing devices, different data formats produced by different devices are difficult to analyze and deal with. With the IoT PaaS Connection Management module, companies can retrieve different data formats collected from different devices, thus ensuring device interoperability. Currently, REST, MQTT, Constrained Application Protocol (CoAP), HyperText Transfer Protocol and others are common between Internet devices as well as Internet message protocols.
- Device Management: Device Management is able to carry out remote monitoring, diagnosis of network equipment to increase the equipment life and real-time operation (e.g., installed in the patient's equipment or sensor battery life, connection/offline status, firmware/software update status) to make preventive decisions and improve the efficiency of the equipment for other benefits.

Table 1
The classification of agents.

Agents	Major characteristics	Advantages
User agent	Stationary agent and user's intelligent gateway to a platform Bridge to interface between physicians and users Mechanism of access control which authenticates users before starting physician agent [25]	The easiest way of presenting the outcomes by physician agent or diagnostic agent directly to user [25]
Resource agent	Mediating access resources from physician agent to host computer Dynamic accelerator of resources in the MADIP Interface bridging users to the database Direct access to resources of the data server, since physician agents are restricted to communicate only with agent container and other agents in the platform [25]	Operating in higher level of trust Secure and granted to access resources of host computer Operating as websites to bridge users to the database [26]
Physician agent	Mobile agent used by medical staff Computer program helping medical staff to virtual monitor of patient conditions Provider of patient health-related data to diagnostic agent to examine health condition	Authenticating the incoming physician agent using its credentials and determining the privileges to be granted to it [26]
Diagnostic agent	PC, laptop, cell phone and PDA triggered agent for medical staff [25] Data analysis engine Analyzing the collection of health-related data and changes in patients Real-time alert to medical staff with mobile phone call or SMS Critical assistance such as call ambulance [25]	Advantageous in analyzing the data collected from a vital sign monitor or other types of electronic monitoring devices [26]
Knowledge-based data server	Information repositories (user status and user profiles) Utilization of physiological information collected by physician agent	Collecting vital sign data from user and transmitting to resource agent in order to store in data repository [26] Maintaining patient monitoring data, electronic data records as well as thresholds for monitored values [27]
External services	"User_Status" is monitoring physiological data from patients (heart rate, pulse oxygen saturation values) "User_Profiles" is up-to-date electronic records for patients [25] Environmental hardware and services including mobile phone, e-mail, and SMS Extensible component for various applications For instance, In case of user abnormality, with an analysis of physiological data, diagnostic agent along with external services will inform responsible physician in real time [25]	Simplifying the process of patient-to-physician interaction by informing physician via SMS text [27]

- Device Cloud: Device Cloud stores the data collected by the network endpoint. The system must have the time series of the data that can be used to access the application of the data type, to connect the Web APP and provide a hospital for pathological analysis at the same time. In this regard, the IoT industry is an innovative service and business model. Therefore, the implication of IoT cannot be summarized by the success stories, but it can be determined by the real value of things that provide information and services leading to an innovative business model.

Technology Stack

This study initially describes the technology needed for the remote care system and provides an overview of other platforms and their functions associated with the remote care system. Following that, the improved architecture for the actual implementation of remote medical care is put forward.

Protocol

The wireless sensor network (WSN) refers to wireless communication network that comprises of a number of automated sensory devices to help monitor the environmental or physical conditions of different locations. The transmission range (Communication range): data from the node through the wireless communication to the access range of the device. The node communicates the information collected through wireless communication and returns to the data collection site (Sink or Data collector) using the multi-hop method. The data collection site collects the data through the data network and sends it to the back-end server (server) that conducts network administrator analysis.

With the assistance of wireless communications applications, all kinds of mobile device can connect to the Internet at any time and any place. However, these devices require long hours of operation, ultra-low power consumptions, and transmission of a small amount of data, such as appliance control, object identification, medical care, and building automation, which is not suitable for high-power Wi-Fi transmission agreements.

In the wireless sensor network, many internal networks use industry-based standard wireless transmission protocol, such as ZigBee, 6LowPAN, WirelessHART, WIA-PA, ISA100, and others, while wearable devices mainly use ANT and low power Bluetooth, and the storage, access control systems and the electronic wallet uses Radio Frequency Identification (RFID). Finally, traditional remote control systems use infrared transmission and Near-field communication.

The basic architectural design of the sensor network system is shown in Fig. 2. A large number of sensors (Nodes) are randomly dispersed in the sensor field to collect various environmental data, such as temperature, humidity, blood pressure or carbon dioxide concentration. Then, through the wireless network (RFID, LoRA, infrared, radio waves, and fiber media), the information collected through the wireless data collector returns to the data manager or the user. Since the relative position of a sensor with any of the sensors is not known, the sensing network must use a self-organization protocol to automatically communicate a communication network between the sensors, so all sensing areas in the sensing data are utilized through the self-configuration established by the network, and the information is sent to the wireless data collector. The wireless data collector functions as a gateway that transfers information from the sensing network to the back-end server application or management through the Internet or satellite, or another transmission medium.

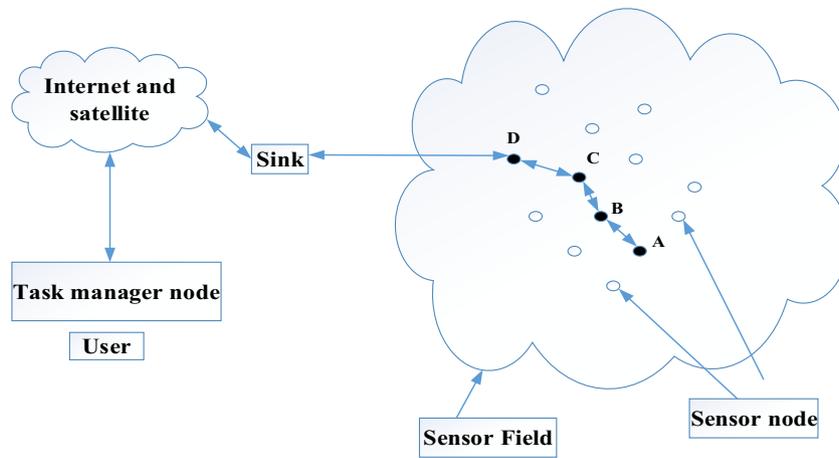


Fig. 2. Sensor network.

Message Queue Telemetry Transport (MQTT)

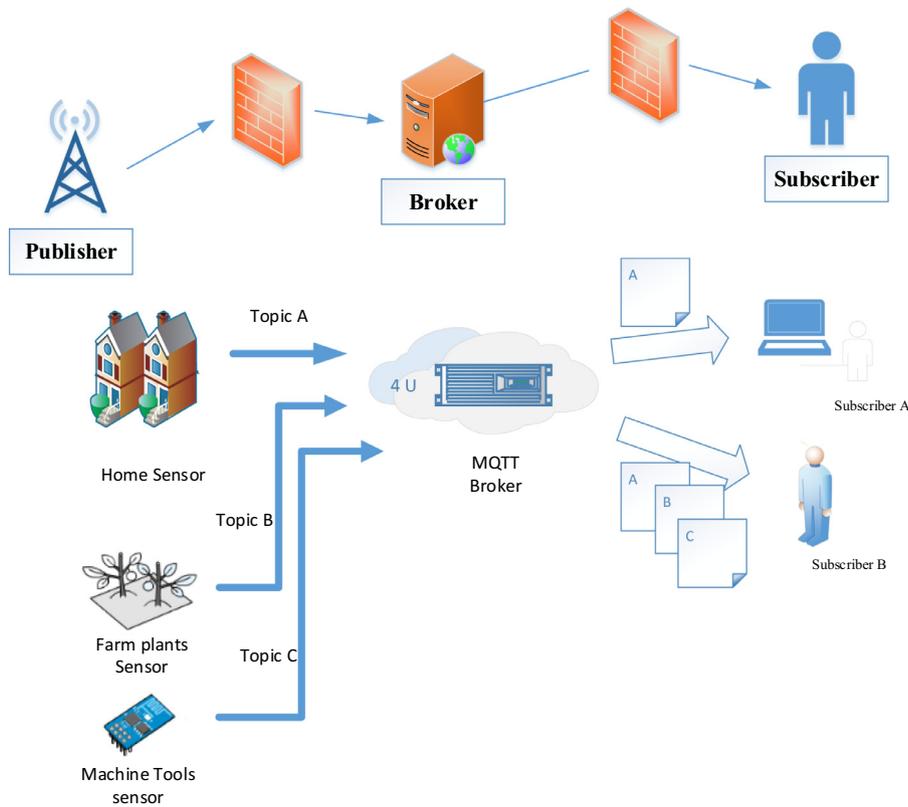


Fig. 3. MQTT structure.

Existing IoT technologies

Message queue telemetry transport

MQTT refers to ISO standard publish-subscribe-based or so-called lightweight message protocol, which is intended for constrained devices with low level of bandwidth, high-latency and/or erratic network. The design practices minimize network bandwidth and device resource requirements, while also ensure reliability and delivery assurance to some extent. The above principles make MQTT ideal for the connectivity of IoT or M2M devices and for mobile applications. MQTT requires a message broker and can provide reliable connections for remote/cloud communications,

and therefore this study adopts MQTT for connections through the Internet (see Fig. 3). However, this study does not use this protocol for communication between devices because the broker requirement makes MQTT not particularly efficient. For direct communication on the local network part, this study utilizes REST API as an alternative.

As of March 2013, MQTT is in the process of undergoing standardization at Organization for the Advancement of Structured Information Standards.

The protocol specification has been amenable published with a royalty-free license for many years and companies such as Eurotech (formerly known as Arcom) have implemented the protocol in their products.

Representational State Transfer (REST)

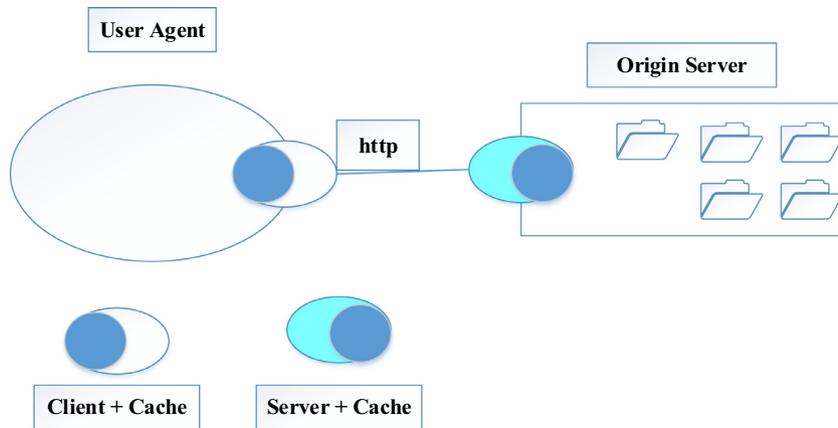


Fig. 4. REST state transfer.

Representational state transfer

REST is a style of web service design providing stateless operations. REST-compliant (or RESTful) web services are more tolerant of networking quality and are preferable for low-powered and frequently roaming small devices where the connection is not always strong or stable (see Fig. 4). They can provide relatively better reliable services in a poor network environment than those implemented in heavyweight styles like Simple Object Access Protocol.

However, due to the challenge-response feature of HTTP/HTTPS and the device need to keep polling, use long polling, or use a web socket for new updates, REST is relatively unsuited to cloud communication.

JADE

By considering the major concern of applications being open-source, the proposed framework uses JADE, which is a set of Java architecture for proxy systems. Java JADE is an open source software.¹ Moreover, JADE is added to technology layer along with REST API and MQTT.

In addition, REST is a global information network software architecture style proposed by Dr. Roy Thomas Fielding in 2000, in order to facilitate different software/programs in the network. REST layer is a set of constraints and attributes based on the HTTP. It is a software build style designed to provide global information network services.²

OPC unified architecture (OPC UA)

OPC UA is an M2M messaging protocol developed by the Open Platform Communication (OPC) Foundation for industrial automation. The major features are as follows.

- Communication with equipment as well as system for control and collection of data
- Open-source with no fees or restrictions for implementation
- Cross-platform, meaning that it does not rely on a single operation system (OS) or programming language
- Service-oriented architecture (SOA)

- Solid in terms of security
- Fundamental information model in which the infrastructure has been built that is essential for information integration. Moreover, vendors and firms can integrate complex data into an OPC UA namespace, which is beneficial for rich SOA of OPC UA. Currently, the OPC Foundation is collaborated with more than 35 businesses. Main industries are oil & gas, pharmaceutical, industrial robotics, building automation, and others.

FIPA2000 standard

The Foundation for Intelligent Physical Agents (FIPA) refers to an entity that helps develop and set computer software standards for multifaceted and networking agents as well as agent-based structures. It has been established in 1996 as a Swiss not-for-profit organization aiming for the development of a full set of standards for both systems implementation through which agents could perform agent platforms, while at the same time specify the standard way of communication between the agents. The most widely used FIPA standards are considered the Agent Management and Agent Communication Language specifications.

Comparison of IoT platforms

A detailed study of the current IoT software platform discovers every single feature of it has been applied to differing extents. This study lists the relevant platforms in Table 2 with a comparison of the features adopted from Dayarathna [25]. Careful investigation of IoT software platforms shows each functional category has its typical degree of implementation, and at the same time, this study identified eleven of them (see Table 2).

System design

This study proposes a system framework that can be applied to elderly people in need of medical care, while different interfaces can be designed for different system users.

Data flow

The flow of data is shown in Fig. 5. It starts with the registration of the sensor in the system and sets the criteria for the collection of information. The system allows the sending of message A to user A, and message B to user B. Each sensor has a rule that different sensors will notice the behaviors of different users. User-agent

¹ <http://jade.tilab.com/>

² <https://zh.wikipedia.org/wiki/%E8%A1%A8%E7%8E%B0%E5%B1%82%E7%8A%B6%E6%80%81%E8%BD%AC%E6%8D%A2>

Table 2
The comparison of IoT platforms (data source: [25]).

IoT software platform	Device management	Integration	Security	Protocols for data collection	Types of analytics	Support for visualizations
2lemetry—IoT analytics platform**	Yes	Salesforce, Heroku, ThingWorx APIs	Link encryption (SSL), standards (ISO 27001, SAS70 type II audit)	MQTT, CoAP, AMQP, STOMP	Real-time analytics (apache storm)	No
Appcelerator	No	REST API	Link encryption (SSL, IPsec, AES-256)	MQTT, HTTP	Real-time analytics (titanium)	Yes (titanium UI dashboard)
AWS IoT platform	Yes	REST API	Link encryption (TLS), authentication (SigV4, X.509)	MQTT, HTTP1.1	Real-time analytics (rules engine, Amazon kinesis, AWS lambda)	Yes (AWS IoT dashboard)
Bosch IoT suite—MDM IoT platform	Yes	REST API	*Unknown	MQTT, CoAP, AMQP, STOMP	*Unknown	Yes (user interface integrator)
Ericsson device connection platform (DCP)—MDM IoT platform	Yes	REST API	Link encryption (SSL/TSL), authentication (SIM based)	CoAP	*Unknown	No
EVERYTHING—IoT smart products platform	No	REST API	Link encryption (SSL)	MQTT, CoAP, websockets	Real-time analytics (rules engine)	Yes (EVERYTHING IoT dashboard)
IBM IoT foundation device cloud	Yes	REST and real-time APIs	Link encryption (TLS), authentication (IBM cloud SSO), identity management (LDAP)	MQTT, HTTPS	Real-time analytics (IBM IoT real-time insights)	Yes (web portal)
ParStream—IoT analytics platform***	No	R, UDX API	*Unknown	MQTT	Real-time analytics, batch analytics (ParStream DB)	Yes (ParStream management console)
PLAT.ONE—end-to-end IoT and M2M application platform	Yes	REST API	Link encryption (SSL), identity management (LDAP)	MQTT, SNMP	*Unknown	Yes (management console for application enablement, data management, and device management)
ThingWorx—MDM IoT platform	Yes	REST API	Standards (ISO 27001), identity management (LDAP)	MQTT, AMQP, XMPP, CoAP, DDS, websockets	Predictive analytics (ThingWorx machine learning), real-time analytics (ParStream DB)	Yes (ThingWorx SQUEAL)
Xively—PaaS enterprise IoT platform	No	REST API	Link encryption (SSL/TSL)	HTTP, HTTPS, sockets/websocket, MQTT	*Unknown	Yes (management console)
Our proposed platform	Yes	JADE, REST API,	Link encryption (SSL/TSL), identity management (LDAP)	HTTP, HTTPS, sockets, MQTT	Real-time analytics, machine learning	Yes (user manager platform)

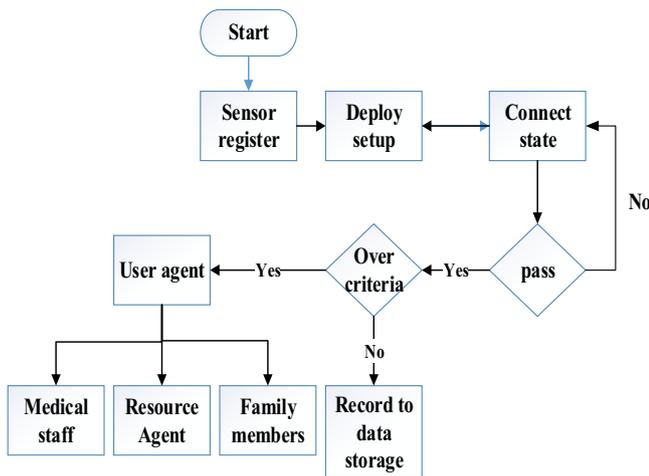


Fig. 5. Data information flow.

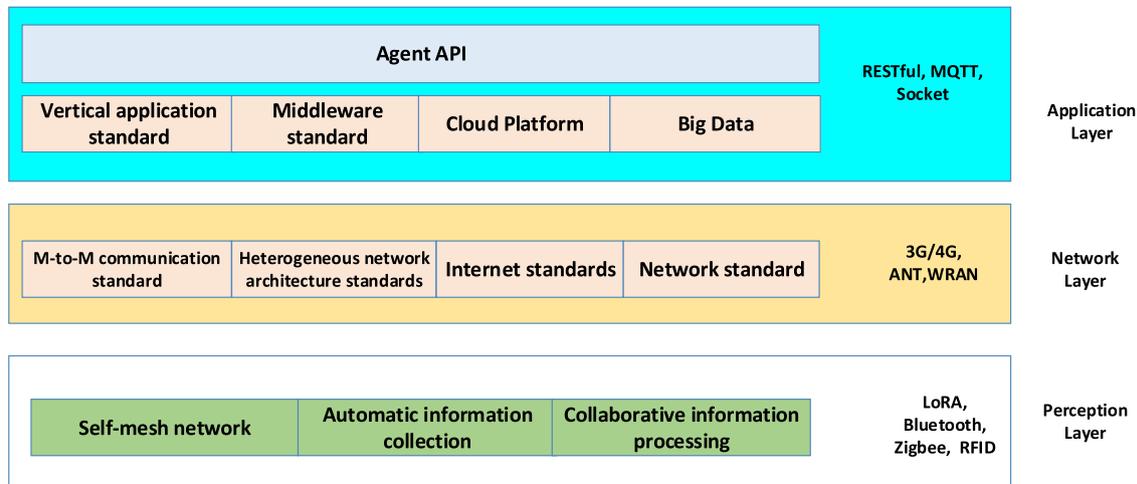
refers to our program to check the destination of each sensor ID. The destination will be identified from the database by sensor ID. A resource agent helps detect abnormal situations, and if it reaches

a critical emergency level, the agent automatically sends a notice to the ambulance and other first aid units.

IoT layer mapping in involved technologies

According to the structure of IoT, there are three different layers (See Fig. 6).

- Perception layer: This is comprised of devices that can sense the signal, monitor the physical or environmental conditions of the location, such as temperature, humidity, speed, etc., support the remote settings, operation, control, management, and must have low power consumption and cost, as well as support a large number of network node characteristics.
- Network layer: This provides a reliable network transmission function and includes wireless or wired Internet and cloud technology so each object (device) has an IP address, which is the IP sixth edition (IPv6) to develop a number of IP addresses. The information collected by the device can be integrated into the data management center of the IoT. Therefore, the communication protocols at the network layer must be compatible with the service quality mechanism and device mobility management to provide a secure and stable network environment.



IoT Platform Technical standards

Fig. 6. IoT platform layer.

- Application layer: IoT applies different areas, such as a smart grid, smart city, smart home, eHealth, intelligent traffic, environmental monitoring, and others. Users can obtain services at any time and anywhere and even link to the cloud service platform. In terms of the application of IoT, many information processing and different services must be integrated to work together and collect the sensory data from each object (device), which is further used in business classification and the provision of related services.

Traceability matrix of technologies

Following the idea of the three-tier architecture of the IoT, this study proposes a system design with abnormal values as the alarm transmission. The system design contains the scheduling, modeling, analytics, connectivity and other modules placed on the bottom of the system (see Fig. 7). The sensor returns the data through the Wire Data Communication to the cloud database via the WSN or uses web services to return the self-built web platform. Since the sensor needs to define the transmission criteria in advance, only the exception values (e.g., abnormal signal) will be sent, so this study can ensure it will not take up too much bandwidth. This study uses the IoT API and REST API, MQTT, and JADE for the data access and status transmission, so this study can use Parse to store the data in the cloud. Data can also be saved to the Local DB via the Microsoft API for further analysis.

Compared with the eleven platforms discussed above, this study includes device management encompassing the REST API, HTTPS, Secure socket layer (SSL), and Lightweight directory access protocol (LDAP). As for the protocols of data collection, this study uses MQTT and HTTP. For visualization support, this study uses JADE because the software mentioned above is in commercial use. Hence, our proposed system design is superior to the software architecture of Fernandes and Lucena [4] in terms of messaging or data storage security, and data analysis.

The description of conceptual framework

The framework contains three layers:

- Technology layer: The Open Platform Communications (OPC) specification is based on Microsoft Object Linking and Embedding (DDE), Component Object Model (COM), and Distributed

COM (DCOM) technologies for Microsoft Windows operating systems. The specifications define the objects, interfaces, and methods required for process control and factory automation to achieve interoperability. In addition to the OPC DA specification, the OPC Foundation maintains specifications for OPC Historical Data Access (OPC HDA). OPC DA accesses real-time data, while OPC HDA allows access and retrieval of archived historical data. The OPC Foundation also maintains specifications for OPC alarms and events, defining warning and event type message information, similar to variable status and status management messages. OPC is designed to provide a common bridge between Windows-based software applications and program control hardware.

- Among the mainstream Web service implementations, REST mode is more concise than complex SOAP and XML-RPC, and many web services have recently started to implement it. For instance, Amazon.com provides a RESTful web service to perform book queries.
- MQTT is useful for connections with remote locations where a small code footprint is required and/or network bandwidth is at a premium.
- JADE system supports coordination between several agents, such as FIPA and provides a standard implementation of the communication language FIPA-ACL (Agent Communication Language, ACL). It is recognized as a standard language for Agent communications utilizing the communication between agents and allowing the service detection of the system.
- IoT API comes in different formats, including SOAP, REST or XML/JSON. A web service is a piece of software, or a system providing access to its services via an address on the web, so-called URL. This web service offers its information in a format that other applications can understand or parse through.
- Microsoft API: The Azure IoT is a collection of cloud services managed by Microsoft that connects, monitors, and controls a vast number of IoT Devices. The IoT Solution consists of one or more IoT appliances and back-end services that execute in the cloud and communicate with each other. The IoT device SDK API allows building applications that execute on a device, allowing to perform a task. With the SDK (Software Development Kit), telemetry can be transferred to the IoT hub and messages, as well as updates from the IoT hub, can be received.
- Management layer

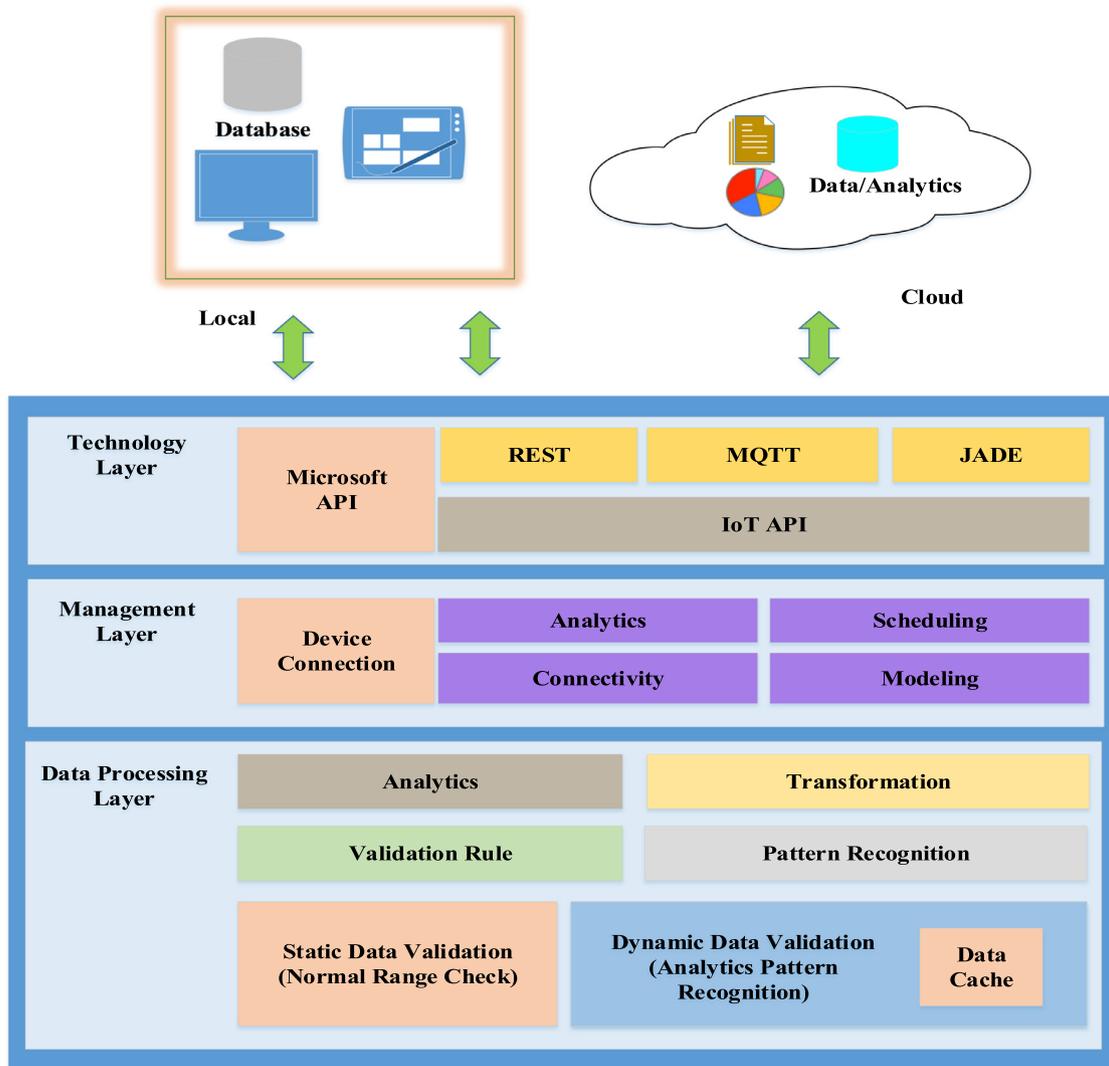


Fig. 7. Data collection platform.

- **Device connection:** As the terminal device is placed on the user end, the connection of the device must be detected and maintained through detection function. Therefore, the connection management of the device is necessary for the framework.
- **Analytics:** This module provides statistics on the usage frequency of the connected devices and transmission volume.
- **Connectivity:** This module provides a variety of connectivity options, such as Wi-Fi, ZigBee, RFID, and Bluetooth.
- **Scheduling:** This module provides pull/push of timing data, and the management platform can set time history to access data of remote devices.
- **Modeling:** It is based on historical data to build models and make corrections at any time.
- **Data processing layer**
 - **Analytics:** This module is to analyze the frequency and statistics of the occurrence of data, (e.g., the rate and frequency of diaper replacement).
 - **Validation:** It refers to verification and tracking of data entering the system.
 - **Transformation:** The data conversion module can convert different types of data, such as, text file, csv, pdf, xls.
 - **Pattern recognition:** The identification module of the model (e.g., the sleep breathing module receives a set of continu-

ous data and compares it with the existing data to determine whether there is a symptom of respiratory arrest).

- **Static data validation (Normal range check):** Setting and checking the normal value range of data collection.
- **Dynamic data validation (analytics pattern):** Analysis and comparison of dynamic data models.

Comparison with current platforms

The proposed system design is based on the RPM, which helps monitor the patient's physiological data, while a message can be sent to the relevant health care workers, compared to the IoT4Health system architecture proposed by Fernandes and Lucena [4]. Although the author's design is effective, in real situations, it is important to ensure the transmission is 100% correct, which IoT implements, so the device and network management system construction is vital. Previously proposed designs can only meet laboratory conditions but not meet market competition. This study improved the framework by combining FIPA2000 Standard and considering the interface with different WSN transmissions (e.g., Bluetooth, ZigBee), so different brands can use the FIPA2000 Standard to expand the market entry of the new framework.

Energy-saving and low-energy IoT design has always been the goal of engineers. The Bluetooth and ZigBee mentioned in WSN

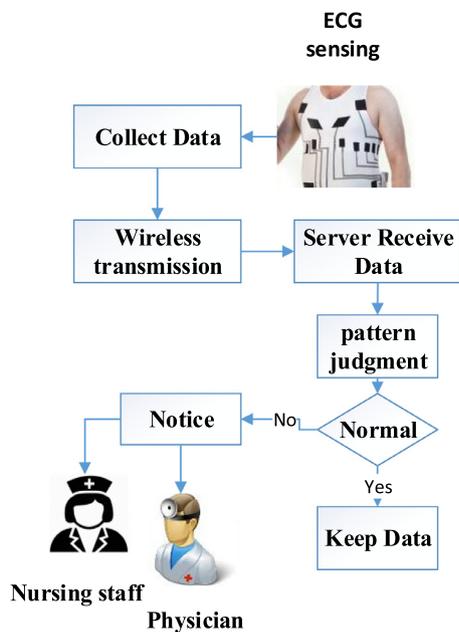


Fig. 8. ECG sensing scenario.

are designed for low power consumption. The IoT framework adds IEEE p2413 Standard, which can be expanded to numerous industries and consumer devices as well, although it will not replace the existing data format. Hence, it can effectively reduce the burden of promoting data sharing.

Further, the newly designed framework can help overcome various challenges, such as long-term care for urinary incontinence, since it is inconvenient to take care of elderly people that need their adult diapers replaced. Thus, aligned with sensory chips, the device can alert the replacement time without the doctor control, by informing family members or caregivers. In the case of a single elderly person living alone, by considering some adults do not want to get help from others, the device can help detect when the elderly person falls down in the bathroom, while also sending an alert to the neighbors of community managers for assistance. In addition to this, sensory devices could also notify elderly people when to measure blood pressure or take medicine. The sensory device and a reminder of blood pressure measurement become relatively important. Hence, the data can be returned to doctors on a quarterly basis to provide consultation and medication with the aim of better medical care.

Based on the above analysis and description, it is obvious the RPM platform can not only be considered in the form of laboratory design. However, as Isern et al. [15] pointed out, most studies are in the experimental stage, and there is a lack of consideration of deployment of the devices in actual situations. Henceforth, the current study draws on the actual platform operation of industrial networking based on real situations. Note, the deployment of the actual platform needs time and frequent adjustments to handle unexpected cases.

Description of the scenario

This study adds three scenarios to describe the overall process. In the context of the first scenario (see Fig. 8), the ECG is installed to collect data from patients while the data is sent to the server via the wireless network sensor, and the patient's health condition is verified by Pattern judgment. If the health condition is normal, the data is preserved in the database, whereas in an abnormal situation, a notification is sent to a physician or nursing staff. The



Fig. 9. Philips VM6 physiology monitor (data source: [28]).

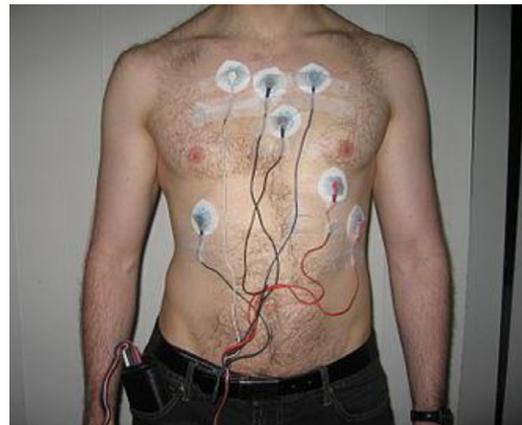


Fig. 10. Holter monitor [29].

Philips SureSigns VM6 is used to make patient care more friendly and efficient (see Fig. 9). The device has already been installed in the Intensive care unit of Chang Gung Hospital. Another product is the Holter monitor (see Figs. 10 and 11), which is a small wearable device that tracks a patient's heart rhythm. It helps in monitoring a patient's blood pressure, respiration, heart rhythm, and others. Hence, based on the proposed framework, this study can use this device to make the RPM more effective, as well as save on labor and additional costs.

The second scenario is designed to measure the pulse of the patient's blood pressure (see Fig. 12). Hence, the measurement criteria can be set on the sensor. The patient can initially set the measurement criteria to define the level of normality as well as abnormality. Then, the notification target can be selected as either nursing staff, caregiver or physician.

Finally, the third scenario helps measure the diaper humidity in elderly patients (see Fig. 13). The sensor accepts the normal level of diaper humidity to be in the range of 60–70%. When the humidity exceeds the defined level, a notification is sent to family members or caregivers to replace the diaper. In addition, the system can record the frequency of diaper replacement for future medical reference.

Simulation results and discussion of main findings

Figs. 14–16 illustrate the simulation for the IoT application in the hospital intensive care unit. The patient needs to be cared for by a caregiver (e.g., external caregiver). Therefore, the nursing staff



Fig. 11. Holter monitor (data source: MAYO CLINIC [30]).

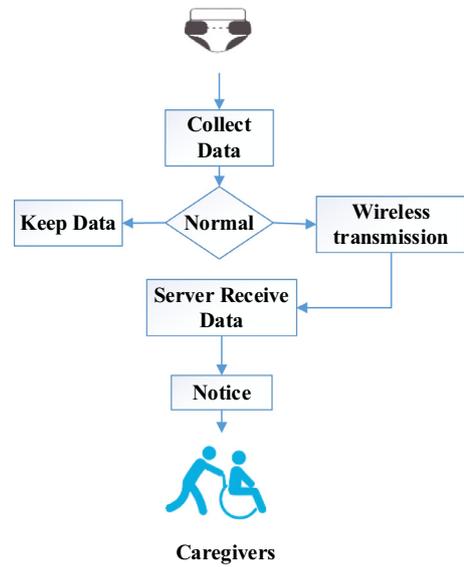


Fig. 13. Diaper sensor.

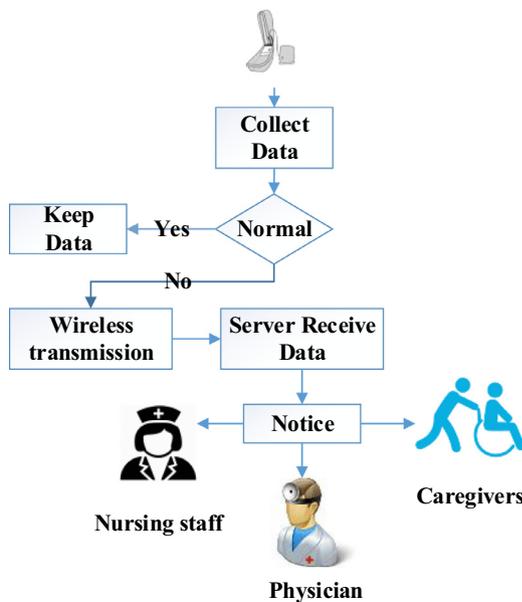


Fig. 12. Blood pressure and pulse measurement.

needs to notify the caregiver through the system. Fig. 14 shows the software interface for monitoring of patient’s health status. Following each action taken for the care of a patient, the caregiver needs to confirm the action on the E-INK panel.

In the case of the simulation in nursing station, patient’s information must be entered into the system, and the time interval must be set for each movement of the patient. The near-end Bluetooth transmission is used in this project. Moreover, access point and router use power directly, while E-INK uses AAAA battery, which can be valid for 3 weeks. E-INK is only used in transmission process. Electricity is generally in a dormant state. The project is to push the message from the nursing station to the designated bed E-INK. After the caregiver receives the E-INK message, the delivery action is completed. “Confirmation” button is then pressed to return the message to the platform system of the nursing station.

Table 3
The comparison of platforms.

	REST API	MQTT	Device management	Security control	Visualization
11 platforms	8	10	7	9	9
Proposed framework	Yes	Yes	Yes	Yes	Yes
Fernandes and Lucena [4]	No	No	No	No	No

The platform system can identify whether the connected devices in the platform are active or inactive, while at the same time it can be used for immediate status elimination. This project is currently being tested in a regional hospital in northern Taiwan, since December 2018. The patient has been transferred to the general ward after receiving proper care for 1–3 weeks (in intensive care unit), and the result has been confirmed.

Overall, the results confirm that the utilization of IoT-based automated RPM system can help to reduce manpower, while can increase the effectiveness of the medical care that everyone, particularly elderly people can benefit from it.

Implications

This study considers the actual deployment of the platform along with its management and future maintenance. It identifies eleven platforms in Table 3 and compares them with the study of Fernandes and Lucena [4]. Table 3 illustrates most system development is accomplished by the use of REST and MQTT because, in each of the documented M2M message communication processes, the lost sensor should be focused on.

When the sensor is faulty, this study must be able to identify where there is a problem. The privacy of patients should also be taken seriously, so the data, as well as the transmission process, must be encrypted to prevent hackers from taking advantage of the wireless network. Overall, the visualization design can allow users to track the changes in the data, so they can make a decision, such as the time for changing the diaper if the degree of moisture in the adult diaper reaches 80%.

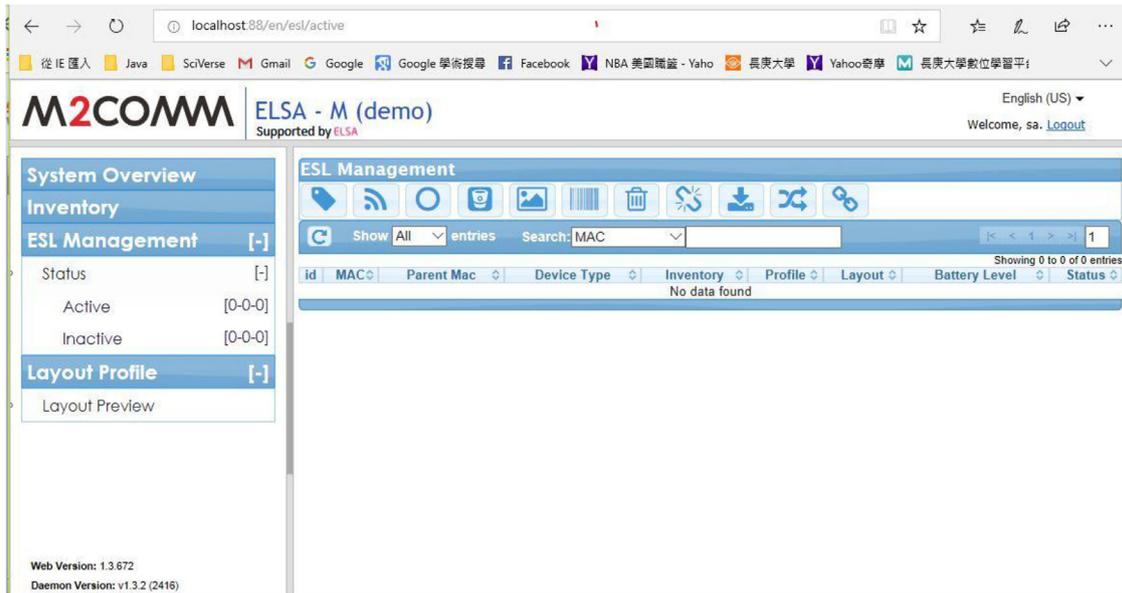


Fig. 14. Control platform.

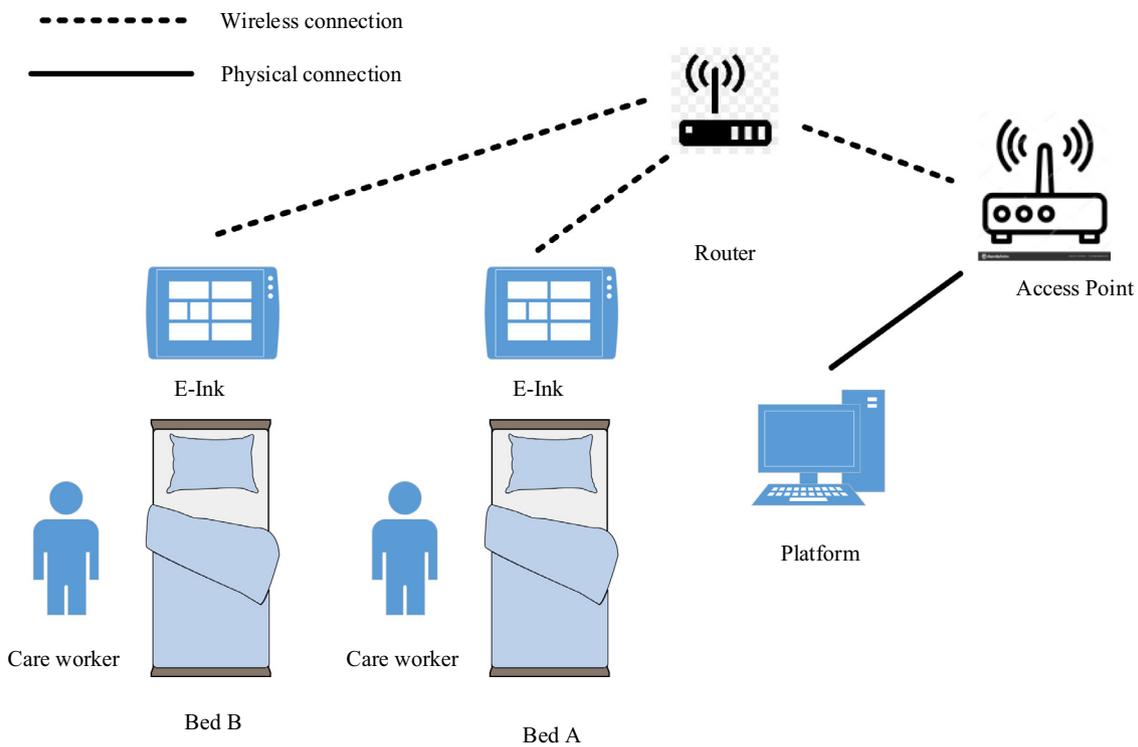


Fig. 15. The simulation description of real environment.

Conclusion and suggestions

Our research can be extended with the inclusion of diagnostic and knowledge-based agents to provide a responsive and rapid M2M automatic transmission of data. However, combining Knowledge Management and AI, as well as other technologies, is needed. Further, this study aims to build a medical knowledge-based system in the next stage to establish a connection between the patient’s family and physician/doctor and reduce the visiting time to the patient by extending the role of the physician agent.

With an aging society being an emerging issue in every country, the ultimate goal of this study is to promote the use of technology to strengthen the scale of care for elderly people. However, due to the increasing cost of investment in the provision of government subsidies, it is recommended governments provide a free medical control device, such as a smart wearable device to connect the patient with family members in case of basic medical needs. In addition to this, when the emergency case occurs, family physician/doctor can be alerted to provide consultation without loss of time. Thus, it can massively save on medical resources, while

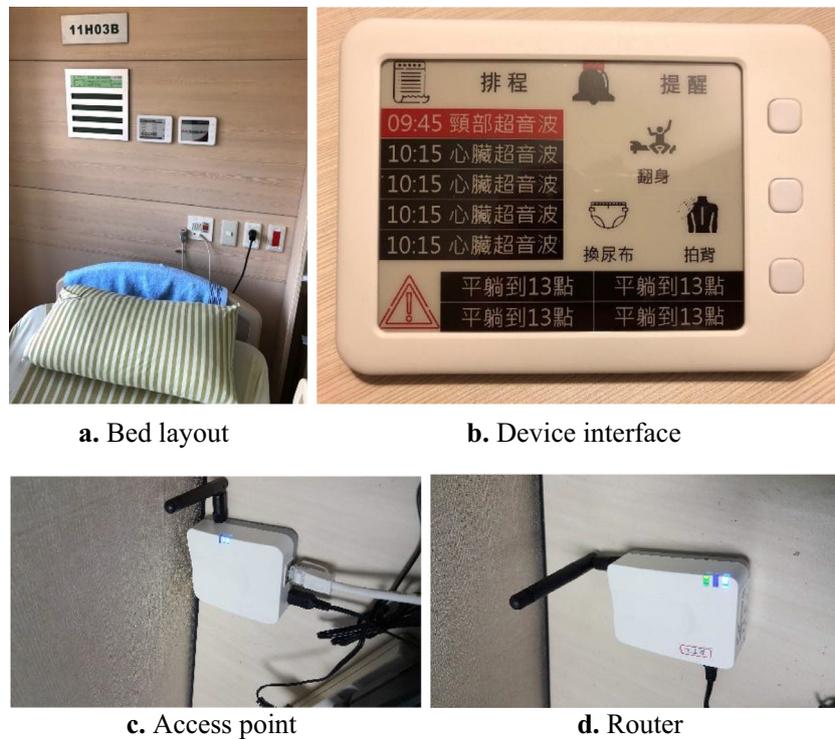


Fig. 16. The demonstration of device usage.

helping patients avoid queuing in medical centers for medical treatment.

Author statements

Funding

This work was supported by the Ministry of Science and Technology of Taiwan under the grant MOST 106-2410-H-182-004 and Chang Gung Medical Foundation (BMRPA79) during the study completion.

Competing interests

None declared

Ethical approval

Not required

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.hlpt.2019.05.008.

References

- [1] Moraes JLC, Souza WL, Pires LF, Prado AF. A methodology based on openEHR archetypes and software agents for developing e-health applications reusing legacy systems. *Comput Methods Programs Biomed* 2016;134:267–87.
- [2] Bisbal J, Lawless D, Wu B, Grimson J. Legacy information systems: issues and directions. *IEEE Softw* 1999;16(5):103–11. URL: <http://dx.doi.org/10.1109/52.795108>.
- [3] Nguyen MT, Fuhrer P, Pasquier-Rocha J. Enhancing e-health information systems with agent technology. *Int J Telemed Appl* 2009;2009:279091. URL: <http://dx.doi.org/10.1155/2009/279091>.
- [4] Fernandes CO, Lucena CJP. A software framework for remote patient monitoring by using multi-agent systems. *JMIR Med Inform* 2017;5(1):e9. doi:10.2196/medinform.6693.
- [5] Khan JY, Yuce MR, Karami F. Performance evaluation of a wireless body area sensor network for remote patient monitoring. *EMBS 2008. 30th Annual International Conference of the IEEE. Engineering in Medicine and Biology Society; 2008*.
- [6] Ray BR, Chowdhury MU, Abawajy JH. Secure object tracking protocol for the Internet of Things. *IEE Internet Things J* 2016;3(4):544–53.
- [7] Chowdhury M, Abawajy J, Kelarev A, Jelinek HF. A clustering-based multi-layer distributed ensemble for neurological diagnostics in cloud services. *IEEE Trans Cloud Comp*. 2016;4(2):1–12. doi:10.1109/TCC.2016.2567389.
- [8] Ghanavati S, Abawajy J, Izadi D. An alternative sensor cloud architecture for remote patient healthcare monitoring and analysis. *2016 IEEE Int'l. Joint Conf. Neural Networks Vancouver, Canada; 24–29 July 2016*.
- [9] Islam SMR, Kwak D, Kabir H, Hossain M, Kwak K-S. The Internet of Things for health care: a comprehensive survey. *IEEE Access* 2015. doi:10.1109/ACCESS.2015.2437951.
- [10] Chan V, Ray P, Parameswaran N. Mobile health monitoring: a computer supported cooperative work (CSCW) approach. In: *Proc. 40th Hawaii Int. Conf. Systems Sciences (HICSS2007)*; January 2007.
- [11] Wooldridge M. *An introduction to multiagent systems*. 2nd ed. West Sussex, England: John Wiley and Sons, Ltd.; 2009.
- [12] Hsieh F-S. Collaborative workflow management in holonic multi-agent systems, in agent and multi-agent systems: technologies and applications, lecture notes in computer science 6682. Berlin Heidelberg: Springer; 2011. p. 383–93.
- [13] Hudson DL, Cohen ME. Intelligent agents in home healthcare. *Ann Telecommun* 2010;65(9–10):593–600. URL: <http://dx.doi.org/10.1007/s12243-010-0170-6>.
- [14] Gasser L. MAS infrastructure definitions, needs, and prospects. In: Wagner T, Rana O, editors. *Infrastructure for agents, multi-agent systems, and scalable multi-agent systems*. Berlin, Germany: Springer Verlag; 2001. p. 11.
- [15] Isern D, Sanchez D, Moreno A. Agents-applied-in-health-care—a review. *Int J Med Info* 2010(79):145–66.
- [16] Annicchiarico R, Cortes U, Urdiales C, editors. *Agent technology and e-health, whitestein series in software agent technologies and autonomic computing*. Basel, Switzerland: Birkhauser Verlag; 2008.
- [17] Fox K, Beveridge M, Glasspool D. Understanding intelligent agents: analysis and synthesis. *AI Commun* 2003;16(3):139–52.
- [18] Hassan MK, El Desouky AI, Elghamrawy SM, Sarhan AM. Intelligent hybrid remote patient-monitoring model with cloud-based framework for knowledge discovery. *Comput Electr Eng* 2018;70(70):1034–48.
- [19] Das SK, Cook DJ. Designing smart environments: a paradigm based on learning and prediction. In: *Int Conf Pattern Recognit Mach Intell.* Springer; 2005. p. 80–90.
- [20] Oresko JJ, Jin Z, Cheng J, Huang S, Sun Y, Duschl H, Cheng AC. A wearable smartphone-based platform for real-time cardiovascular disease detection via electrocardiogram processing. *IEEE Trans Inf Technol Biomed* 2010;14(14):734–40.

- [21] Gia TN, Ali M, Dhaou IB, Rahmani AM, Westerlund T, Liljeberg P, Tenhunen H. IoT-based continuous glucose monitoring system: a feasibility study. 8th International Conference on Ambient Systems, Networks and Technologies (ANT-2017); 2017. p. 327–34.
- [22] Morillo P, Orduna JM, Fernandez M, Garcia-Pereira I. Comparison of WSN and IoT approaches for a real-time monitoring system of meal distribution trolleys: a case study. *Future Generation Comput Syst* 2018;87(87):242–50.
- [23] Li C, Hu X, Zhang L. The IoT-based heart disease monitoring system for pervasive healthcare service. In: *International Conference on Knowledge Based and Intelligent Information and Engineering Healthcare Service*; 2017. p. 2328–34.
- [24] Yacchirema D, Sarabia-Jacome D, Palau CR, Esteve M. Systems for monitoring and supporting the treatment of sleep apnea using IoT and big data. *Pervasive Mobile Comput* 2018(50):25–40.
- [25] Wang B. (2014). The internet of things world forum unites industry leaders in Chicago to accelerate the adoption of IoT business models. [Online]. Available: <http://www.marketwired.com/press-release/internet-things-world-forum-unites-industry-leaders-chicago-accelerate-adoption-iot-nasdaq-csco-1957407.htm>
- [26] Dayarathna M. Comparing 11 IoT development platforms 2010. URL: <https://dzone.com/articles/iot-software-platform-comparison>.
- [27] Su CJ, Wu C. JADE implemented mobile multi-agent based, distributed information platform for pervasive healthcare monitoring. *Appl Soft Comput* 2011;11(1):315–25. doi:10.1016/j.asoc.2009.11.022.
- [28] http://www.winningmedical.com/products_open.asp?id=71.
- [29] https://en.wikipedia.org/wiki/Holter_monitor.
- [30] <https://www.mayoclinic.org/tests-procedures/holter-monitor/home/ovc-203>.