Internet of Things for Sleep Quality Monitoring System: A Survey

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***Abstract*—Sleep quality is an important factor for human physical and mental health, day-time performance, and safety. Sufficient sleep quality can reduce risk of chronic disease and mental depression. Sleep helps brain to work properly that can improve productivity and prevent accident because of falling asleep. In order to analyze the sleep quality, reliable continuous monitoring system is required. The emergence of internet-of-things technology has provided a promising opportunity to build a reliable sleep quality monitoring system by leveraging the rapid improvement of sensor and mobile technology. This paper presents the literature study about internet of things for sleep quality monitoring systems. The study is started from the review of sleep quality problem, the importance of sleep quality monitoring, the enabling internet of things technology, and the open issues in this field. Finally, our future research plan for sleep apnea monitoring is presented.**

I. Introduction

In the recent years, internet-of-things (IoT) has become a popular subject in electronics and communication research field. IoT is a technology that interconnects people, computer, devices, and anything that is connected to the internet [1]. The emergence of IoT is stimulated by the rapid growing of wireless sensor network, cloud computing, and high-throughput network technology [2]-[4]. One of the most important aspect of IoT is the ability to operate machine-to-machine (M2M) communication without requiring human-to-machine interaction [5]-[6]. The M2M capability of IoT has become a fundamental aspect to develop a human control-less and continuous remote monitoring system. The system based on the concept of IoT has been developed in many fields, e.g. industrial automation [7]-[8], smart-city [9], smart-farming [10], many more applications.

Remote monitoring for health care is also a field that can maximize the capability of IoT technology. The research for this field has been performed for the last two decades. In 2000, Stephen J. Brown proposed a multi-user remote health monitoring system [11]. In his proposal, the data acquisition is performed manually by doctor or caregivers. From there, a smart health monitoring that utilizes wireless sensor network technology has been introduced [12]. In the recent years, many researches and developments have been done on smart health monitoring system based on the concept of IoT [13]-[15].

In this paper, we reviews the current state, open issues, and future research of remote health monitoring system, especially for sleep quality monitoring. Sleep plays an important role to maintain health, mental, day-time productivity, and safety of human being. The lack of sleep quality can potentially increase the risk of chronic diseases, depression, and the number of accident because of falling asleep. Therefore, sleep quality monitoring is important to maintain the physical and mental health of human. For this paper, we perform a research methodology as described by Fig. 1. Firstly, we gather the information and related reference about sleep quality monitoring and IoT technology. Secondly, we review the significance of sleep quality and sleep disorder and the monitoring aspect. Thirdly, we model the IoT system and the logical flowchart for sleep quality monitoring. We also review the component of the IoT architecture. Finally, we review the future research trend in this field and our research plan on sleep apnea monitoring system.

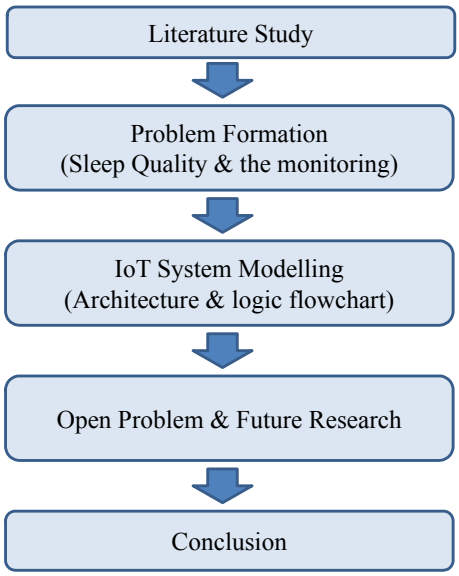

Fig. 1. Research Methodology

This paper is organized as follow. Section II reviews about the sleep quality, the sleep disorders, and the effect to human health and well being. Section III reviews about IoT system architecture, the component of the system, and workflow of the system. Section IV reviews about the future research trend on sleep quality monitoring and our research plan. Finally, the conclusion is presented in section V.

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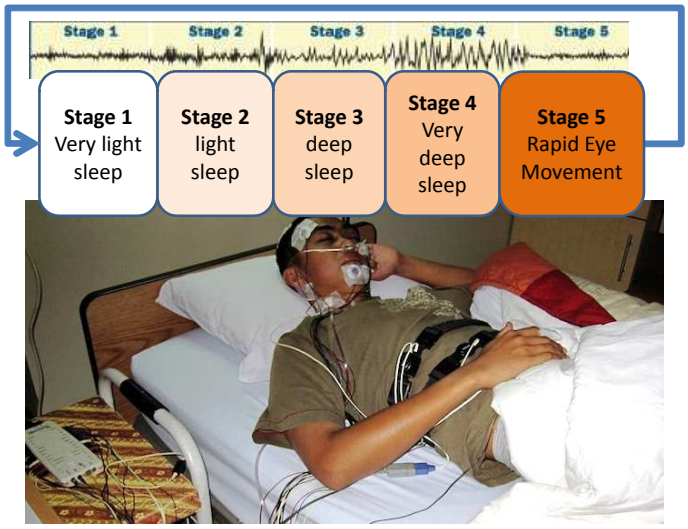

Fig. 2. Sleep Cycles

II. Sleep Quality and the Monitoring

As defined by William H. Moorcroft in his book, sleep is a reversible behavioral state when people have low attention to the environment. It is usually accompanied by an inactivity of nervouse system, a relaxed posture, minimal movement, the suspended consciousness.[16, p. 24]. There are five stages of sleep, i.e. stages 1, 2, 3, 4, and rapid eye movement (REM) [16, pp. 25-26]. These stages progress in cyclic manner, from stage 1 to REM sleep, then the cycle starts over again with stage 1. Stage 1 and stage 2 are called light sleep. People can easily be awaken in these stages. People spend almost half of their total sleep time in stage 2 sleep, 20% in REM sleep, the remaining time in other stages. The problem of sleep disorder is usually associated with the irregularity in sleep cycles. People need to get the right proportion of every stages and sufficient number of cycles to obtain a quality sleep.

A. Sleep Disorder

Sleep disorder is a medical disorder of the sleeping patterns. Sleep diorder potentially increases the risk of chronic diseases, mental problem, and number of accident. The most common sleep disorders include sleep apnea, narcolepsy, insomnia, and restless legs syndrome. It will be discussed more detail below.

- **Insomnia** refers to the deficiency of sleep quality and quantity. 10-30% of adult population is affected by insomnia [17]. This problem can result from jet lag, stress, diet, and many other factors. The insomnia can affect on the decrease of life quality, lost of productivity, increasing number of traffic accidents, and increasing load of general health care.
- **Narcolepsy** is a medical diorder when a patient has frequent "sleep attack" moments at different times of the day, even if they have had a sufficient sleep at the night before. It is also characterized by sleep paralysis (the inability to react, move, or speak that happens during awakening or when falling asleep), hallucinations, and some cases episodes of cataplexy (sudden loss of muscle tone) [18]. Narcolepsy is usually hereditary [16, p. 330]. It is also linked to brain damage from a head injury or neurological disease.
- **Restless legs syndrome (RLS)** is characterized by unpleasant crawling, tingling sensations from the legs, that create urgency to move the legs to relieve the painful feeling [16, p. 332]. It begins or worsens during resting period and becoming worse at night. Up to 30% of the cases are caused by iron deficiency. Therefore, iron supplementation can be helpful to cure this problem.
- **Sleep apnea** is a breathing disorder that is related to sleep. It is characterized by a pause in breathing or shallow breaths during sleep [19]. Due to sleep apnea, the patient wakes us requlary throughout the night in order to breathe. The frequents wake-up moments result in very poor sleep quality and excessive daytime sleepiness. The breaths of sleep apnea patient is usually accompanied by loud snoring.
  Sleep apnea occurs because the throat is shrinked during sleep that makes the patients get difficulty to breath during their sleep. The chest is moving, trying to pump the air to the lungs, but the air could not flow through the throat completely. Sleep apnea potentially causes hypertension and heart problems [16, p. 326-327], due to a drop in blood oxygen level and a considerable rise in blood pressure level during apneic moments. Patients that suffer sleep apnea for many years are in danger of dying during sleep due to heart failure.

B. Sleep Quality Monitoring

Many physiological parameters can be monitored during sleep in order to gain insight about the sleep quality of the patient. The monitoring method is performed by placing some sensor modules close to various body organs of the patient. The body organs generate few amounts of electrical energy during their work. These sensors can pick up some of this electrical energy, send it to computer, display it as a graphical representation on monitor, and store it in computer storage.

The physiological parameters include heart rate, respiration rate and amplitude, central nervous system activity, muscular activity, etc. The signal recordings can be utilized for e.g. detecting sleep staging, detecting various sleep disorders, and other analysis applications.

- **Polysomnography** is a comprehensive recording of physiological changes that occur during sleep, which includes brain activity, heart ryhtm, eye-movement, and skeletal muscle activation [20]. Despite its extensive capabilities, polysomnography is very troublesome to be implemented because many sensor modules need to be placed on the body surface of the patient.
  Following are more detail parameter that is recorded by polysomnograph.
  - **Brain activity** is measured with electroencephalogram (EEG). EEG is a visualization of the waveform of electrical activities of large groups of brain cells.

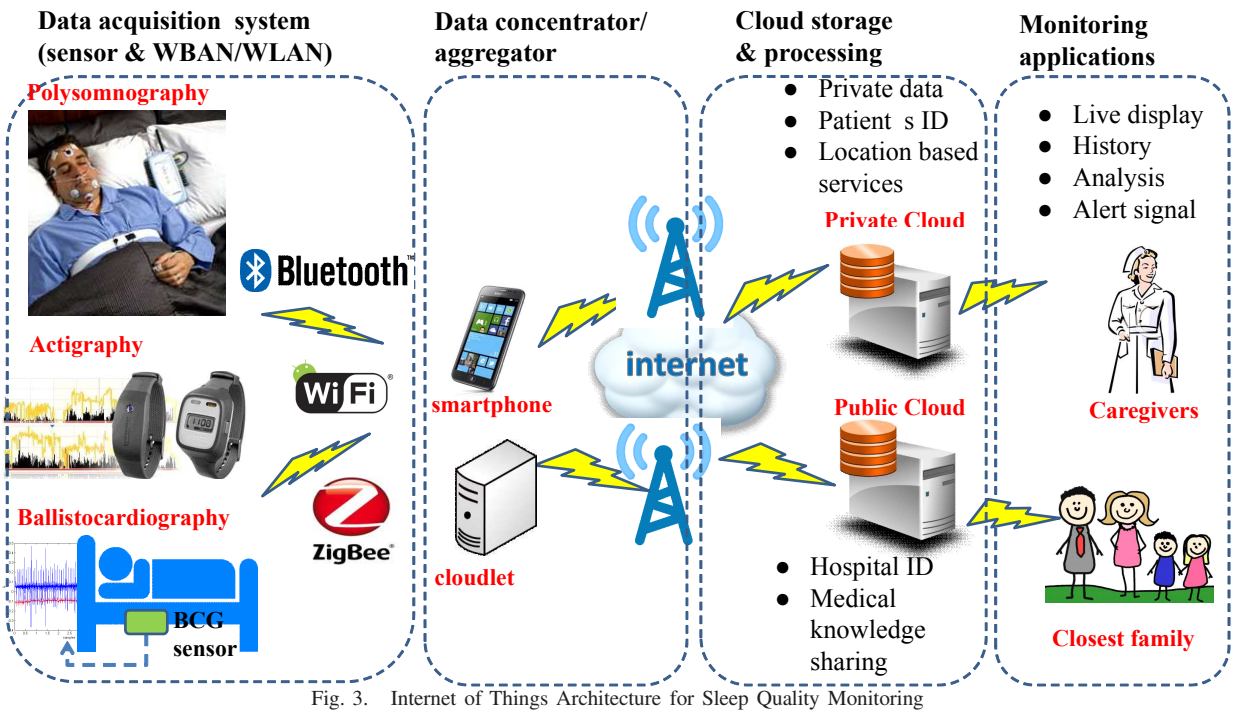

Fig. 3. Internet of Things Architecture for Sleep Quality Monitoring

EEG is recorded for the determination of sleep stages [21].

- **Eye movement** is measured with electrooculogram (EOG). Eye movement measurement is possible because the front of the eye is electrically positive. Therefore, the sensor measures the change of its distance to the positive poles of the eyeball. EOG is recorded to determine the presence of REM stage [22].
- **Muscle activity**, e.g. teeth grinding, face twitches, and leg movements is measured by electromyogram (EMG) [23]. It helps to determine if the REM stages is present during the sleep. Detected frequent leg movements may indicate symptoms of restless leg syndrome (RLS).
- **Heart activity** is recorded by measuring electrical activity of the hearts at it contracts and expands. These can be analyzed for any abnormalities that might be indicative of an underlying heart pathology.
- **The blood oxygen level** is measured with oximetry. Low oxygen levels may indicate a symptom of sleep apnea [24].

- **Actigraphy** is a non-obtrusive method to record sleep-wake schedule and measure sleep quality from body movement data [25]. Acceleration sensors are typically worn on the wrist, jaw, ankle, calf, or around torso to determine activity pattern. The weakness of actigraphy is on its accuracy. Because it is difficult to distinguish if the patient is sleeping or resting while stay awake. However, despite its weakness, it has several advantages, i.e. cost effective and easy to setup for long term monitoring
- **Ballistocardiography (BCG)** is another unobtrusive method for measuring heart rate, heart rate variability, respiration rate, and relative blood stroke volume based on the body movement induced by heart's pumping mechanism [26]. Recent development in sensor technology and signal processing have made it possible to install BCG under the bed or mattress of the patient for totally unobstrusive measurements. Therefore, BCG appears as the most user-friendly option among the sensor technology.

III. IoT Design Modelling

This section discusses about the IoT architecture, the components, and the logical flowchart of the sleep quality monitoring system. There are some references of IoT architecture that are introduced in [13]-[15]. In this paper, we propose the architecture for sleep monitoring. We also explain the mechanism of the proposed architecture by logical flowchart.

A. *IoT Architecture & workflow*

Fig. 3 displays our proposed architecture for sleep quality monitoring. There are four components of the architecture, i.e. data acquisition system, data concentrator/aggregator, cloud storage/processing, and monitoring applications. The workflow of each component in architecture is shown in Fig. 4. The medical data and real-time location of the patient is acquired by data acquisition system through the wireless sensor and location based detection service. Medical data from sensor is then transmitted to network through intermediate data concentrator/aggregator, which is typically a smart phone that is located around the patient. Then, data is transmitted to cloud service for storage and processing. Finally, the medical data is displayed in application that can be accessed by caregivers or closest family. In case of emergency, the system will deliver

warning signal to caregivers and closest family, therefore a rescue action can be carried out immediately.

B. Data Acquisition System

Data acquisition system consists of sleep monitoring sensor and the connection. We have discussed about the type of sleep monitoring sensor in subsection II-B. The connection in data acquisition system means the wireless connection between the sensor and data concentrator/aggregator. The wireless connection module is usually integrated into an embedded system. The type of connection used for health monitoring is usually wireless local area network (WLAN) or wireless body area network (WBAN). The WLAN refers to the IEEE 802.11 standard, i.e. WiFi standard [27]. The WBAN was created to answer the challenge of low power consumption issues in health monitoring sensor [28]. IEEE 802.15.4 or well-known as ZigBee is a low power consumption and low data rate wireless networking protocol for communication between low power devices that operates around 10 meter space distance [29]. Bluetooth low enery (BLE) is another low power wireless communication protocol suitable for the special applications, e.g. health monitoring, sports, and home entertainment. BLE achieves higher energy efficiency in terms of ratio of energy per bit transmitted compared to ZigBee [30].

C. Data Concentrator/Aggregator

Data concentrator is used to collect and organize data collected by sensor to be transmitted to cloud service in internet [31]. The data concentrator usually comes in the form of mobile phone of the patient that contains application connected to the wireless sensor. In case the resource in mobile phone could not support the application, cloudlet can be used as data aggregator [32]. The cloudlet can be local processing unit and temporary storage prior communication to cloud service in internet. The cloudlet can also be used to run time critical tasks in monitoring application.

D. Cloud Storages & Processing

Mobile cloud computing (MCC) has emerged as a promising solution for healh remote monitoring system. MCC can provide powerful, scalable, and flexible high performance computing, storage, and sofware services at low cost [33]. Developer can develop and deploy numerous mobile applications for sleep quality monitoring by accessing larger and faster data storage service and processing power from the cloud.

For sleep application, we adopt the hybrid MCC architecture from [33] which consists of public and private cloud. Sensitive data, e.g. patient identity, location based services, real-time monitoring status can be carried out on private server to guarantee the security. On the other hand, other insensitive data, e.g. hospital identity and medical knowledge sharing can be deployed on public cloud service.

E. Monitoring Application

The result of data sensing and processing will be reported to caregivers or relatives of the patient through mobile application. The data will be displayed in form of live data streaming,

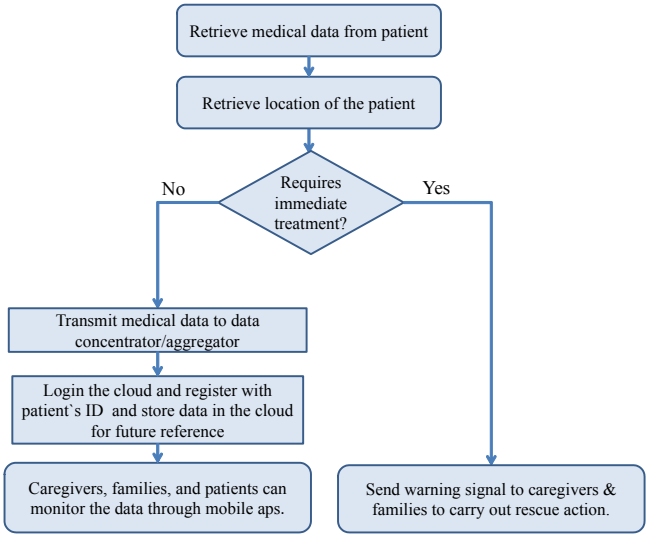

Fig. 4. Sleep Quality Monitoring System Workflow

data history, data analysis from the history, and the warning signal. The data streaming gives a real-time live medical data of the patient, e.g. heart rate, respiration rate, etc. All the recorded data is stored by cloud server to keep the history of the patient. Based on recorded history, application performs an analysis of patient sleep quality. Whenever it is analyzed that there is an irregularity in patient condition then the warning signal is released to notify caregivers and relatives to give an immediate action to the patient.

IV. Future Research

A. Future Research Trend

There are several open issues and challenges for sleep quality monitoring with IoT concepts.

- **Standardization**
  In the health remote monitoring system, there are many vendors that manufacture various products and devices. We predict, there are more vendors will continue this trend because there is still many room for innovation and improvement in this field. However, there is no default standard that can regulate the interoperability among each device. Therefore, the standardization is required to regulate about communication and protocol, including phy and media access control (MAC) layer, data aggregatiion, device and gateway interfaces, value added services and many more.
- **User-friendly data sensing method**
  In sleep quality monitoring, it is important to do measurement or monitoring that does not disturb the convenience of the sleeping patient. Polysomnograph appears as the most comprehensive sensing method with extensive capability and high accuracy [20]. However, since many electrodes needs to be attached to the patients body, then they disturb the convenience of the patient. It is not appropriate for regular monitoring method at home

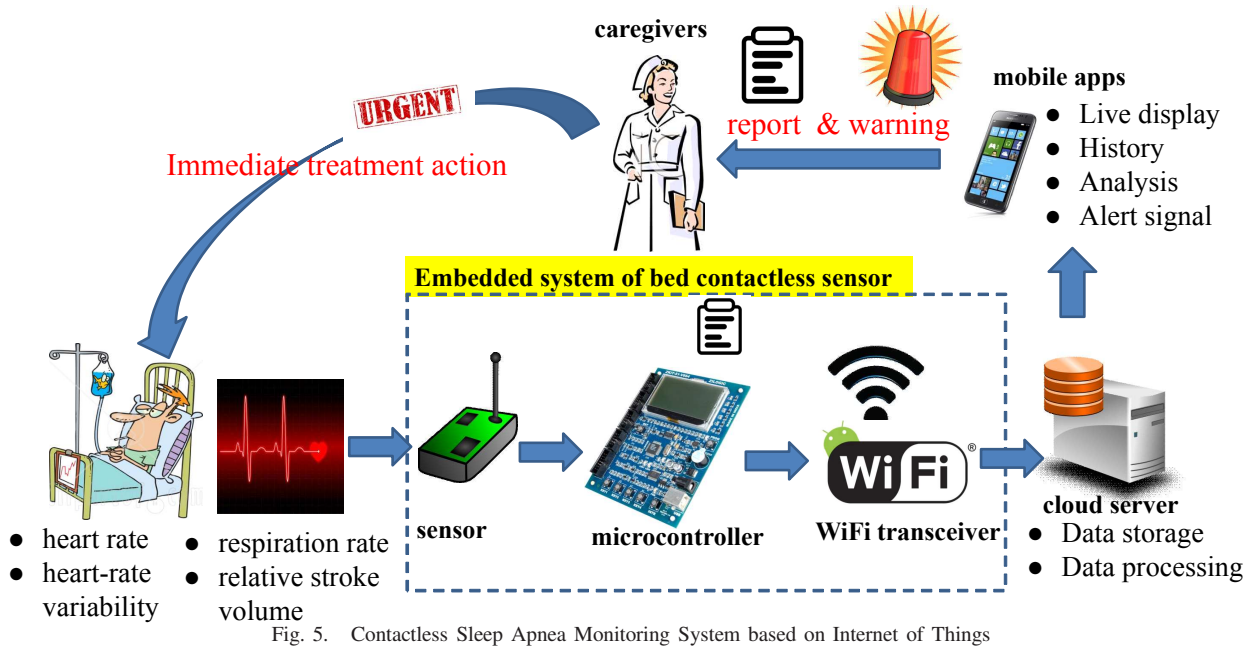

Fig. 5. Contactless Sleep Apnea Monitoring System based on Internet of Things

because of the lack of conveninence and troublesome setup. It is also not appropriate to monitor elderly and infants that are very sensitive to interference during their sleep. Two unobtrusive methods, i.e., Actigraphy and BCG might appear as the promissing candidate for this problem. However, the accuracy and the range of capability of these methods still need to be explored to obtain the most accurate result.

- **Reliable and low-power communication protocol** For IoT systems, low-power communication has become the major issues. Reliable MAC and routing protocol must support multihop communications, low end-to-end delay, low packet-delay, and low-power communication. Eventhough, a study reports that the existing routing protocols can work with minor modifications in IoT scenarios [2], IETF ROLL workgroup claims that the existing protocol, e.g. OSPF, AODV, OLSR does not satisfy the lossy networks specific routing and low power requirements in their present form. The specific routing requirements for example optimization for energy saving, restricted frame sizes, etc. Therefore, there is a need to define low energy communication protocol for the system.

- **Data security** Since there are many sensitive informations, e.g. patient identity, medical data, patients location are involved in this system. Therefore, data security becomes one of the main concern for this monitoring system. Firstly, secure routing protocol is required. The proper routing and forwarding methods are vital for real-time communication in this system. Secondly, the security of handling IoT big data is also important. The sleep quality sensor generates huge amounts of medical data continuously and there is a need to securely store such data, without compromising privacy, integrity, and confidentiality of the data. Finally, since resource (memory and power) has become main constraint for IoT system, therefore the data security system should be designed to maximize security level while minimizing resource utilization.

B. Future Research Plan

To answer the user-friendly challenge in sleep quality monitoring system as described by subsection IV-A, our future research plan is to propose a contactless sleep apnea monitoring system based on the concept of internet of things. Our proposed system is depicted by Fig. 5. There are three main components of the system, i.e. an embedded system, cloud server, and mobile apps. An embedded system will be utilized for data acquisition. The embedded system consists of some components as mentioned below

1) **contactless ballistocardiography sensor**
   The "contactless" term means the sensor is not be attached to the body, but it is be attached to the bed, therefore it does not disturb the convenience of the user. It become possible because the emergence of ballistocardiography technology[26]. The ballistocardiography sensor enable the system to do real-time monitoring of vital sign of user, e.g. heart-rate, respiration rate, heart-rate variability, and relative stroke volume.
2) **microcontroller**
   A microcontroller is used to read data from sensor and send them via a WiFi transceiver unit.
3) **WiFi transceiver**
   A WiFi transceiver is used to transmit the acquired data from the embedded system to cloud server for storage and processing

. The result of data processing will be reported to caregivers through mobile application. The data will be displayed in form of live data streaming, data history, data analysis from the

history, and the warning signal. The warning signal indicates an irregularity in user condition that requires an immediate action

V. Conclusion

Sleep quality is one of main factor to determine human health and well-being. Sleep quality monitoring is one the solution to maintain the quality of sleep and prevents chronic diseases, mental problem, or accidents caused by sleep disorder. The emergence of IoT technology offers a great solution for real-time and continous monitoring system due its M2M nature and high capacity cloud storage and processing. In this paper, we have reviewed the importance of sleep quality monitoring. We have also proposed an architecture and workflow for sleep quality monitoring based on IoT concept. Finally, we have discussed about the open issues and our future research plan in sleep apnea monitoring with IoT system.

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