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The Development of IoT Tele-Insomnia Framework to Monitor Sleep Disorder

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ABSTRACT

The development of the Internet of Things for medical use has helped many medical practitioners to perform treatments remotely. Insomnia or sleep disorder is one of the most common medical conditions that could happen to the person who is living in the urban or remote area. This condition requires a clinical test through a monitoring process that includes EEG, BP, Pulse and Stress status. Due to limited sleep laboratory facilities and medical equipment for insomnia. This paper proposes an initial Tele-insomnia framework that enables the rural patients to be tested for sleep disorder remotely. The framework is tested through a well-developed tele-insomnia proto-type by way of pilot test through case study patients in three hospitals of Jakarta. The physicians and patients were interviewed regarding diagnose time, accuracy and conveniences. The proposed framework provides convenience for the patient as they did not need to commute from home to the hospital and takes up less time to complete the diagnosis.

Key words: Insomnia, Internet of Things, Telemedicine, Telemonitoring

1. INTRODUCTION

The use of the Internet is increasing massively where more than 2 billion users worldwide have been browsing the Internet for content, exchange messages both e-mail, and instant messages, or to socialize through social media or play online games, and now it feels like a basic necessity in the community. The use of the Internet that was once only between humans and computers or with Artificial Intelligence but today, the Internet has also made communication between machines that are presented as a global platform that connects physical objects or 'Things' with other physical objects that allow new ways to work and communicate [1,2]. These developments brought a significant change to what we call the Internet of Things, where objects of different shapes and places can communicate and exchange information with one another to improve functionality and performance of business processes. [3,4].

The Internet of Things has a broad spectrum of uses, ranging from security, plantations, animal husbandry, vehicles, and their use in the health sector, which is called the Internet of Medical Things IoMT). In the Internet of Medical Things, monitoring of the health of a patient's vital organs is monitor by the use of biological sensors that are attached to the limbs. This sensor installation allows patients to be in any different location by staying connected to the internet, such as at home, offices, public places, and on vehicles. Biological sensors installed remain connected and send information to the relevant medical service provider [5, 60]. Advances in the development of Information and Communication Technology are providing increased mobility in biological sensors to provide solutions for many medical applications such as remote monitoring of patient activity, diagnosing chronic diseases experienced by patients [6], monitoring health and processing data online [7,8,9, 61]. In addition, the Internet of Medical Things has played a role in revolutionizing the care of the elderly with the concept of distance care, so that the elderly does not need too much mobility in getting health care services [10]. However, there are significant concerns in the development of IoT systems such as data security [11] and energy efficiency [12]. Some applications of the Internet of Things in the medical field, among others, are used for centralization and early detection of insomnia using electrocardiography remotely [13], to conduct cardiac monitoring and patient's heart attack [14, 15,16], to monitor patient with Parkinson disease [17,18]. Furthermore, the IoT applies in remotely monitoring patients diagnosed with chronic kidney failure [19], monitoring the health of pregnant ladies, as well as monitoring the vital condition of the pregnant woman [20] which includes detecting potential miscarriage, [21] the body temperature [22] and long-distance monitoring of blood pressure using the concept of the IoT [23, 62].

Sleeping is a natural state of rest carried out by living things, both animals and humans alike. It is also a mandatory requirement that humans need to survive. Sleep quality influences human health and mental state. Poor sleep quality can result in sleep disorders that have a direct or indirect impact on daily activities. There is a tendency that patients who have sleep disorders to be prone to chronic diseases such as obesity, hypertension, and diabetes [24]. Meanwhile, Obstructive Sleep Apnea is a risk factor for systemic hypertension [25]. Some of the direct effects caused by some sleep disorders can be serious enough to disrupt the physical, mental, and emotional functions of the patients. Patients will complain about experiencing fatigue during the day or even sleepiness that was felt during the day can also result in an inability to concentrate, which could lead to accidents [26]. In recent years, several countries such as in European, American, and Asian countries such as Japan, sleep disorder have become one of the main focuses in public safety.

In one study it was found that sleep disorder, often overlooked and missed by primary care physicians until or unless requested by the patient, with a prevalence of about one in three subjects in the study that has a sleep disorder. Chronic diabetes and increasing age are also factors that increase the tendency to develop sleep disorders [27]. Insomnia is most often defined as a sleep disorder with reports of individuals having trouble sleeping. For example, with survey studies, insomnia is diagnosed by definite answers or approval of questions such as, "Are you having trouble sleeping?". However, in other literature insomnia is also defined as a term to describe the results of polysomnographic testing of disturbed sleep, where there are symptoms of a long latency of sleep, often waking up at night or having a long period of wakefulness during sleep periods [28,29].

There are several methods and devices used to conduct sleep monitoring and assessment to determine sleep quality such as using Polysomnography [30], Photoplethysmography [31], Ballistocardiogram [32], and Actigraphy [33]. he most preferred monitoring method is by the Polysomnography device for sleep assessment in clinical use [28] because the Polysomnography tool can provide more detailed information for sleep monitoring and offer more accurate sleep assessment results [34].

Treatments and assessments of sleep disorders using polysomnographic gold standards turn out to have socio-economic problems, for some cases, the use of polysomnographic treatments is not good enough for patients who have difficulty in mobility [35,36]. Especially for some developing countries, treatment for sleep disorders is still only in big cities and cannot reach the whole country, therefore there is a need to travel from the patient's home town to a big city that has sleep laboratory facilities for the assessment of insomnia. Current treatment will increase the patient's cost and time needed to assess insomnia sleep disorders.

Therefore, a conceptual tele-insomnia framework is needed to remotely examine insomnia sleep disorders that can reach patients far from the sleep laboratory and for patients who have difficulty mobilizing where the concept still involves medical devices that meet the needs assessment of insomnia sleep disorders. The concept is to save time and money on the part of patients as well as health care providers, both nurses and expert doctors.

This paper contributes to proposing a new conceptual framework that will promote the reach of insomnia sleep disorder patients far from the sleep laboratory field to accelerate the distribution of services in remote areas using the Internet of Medical Things to help break through barriers that occur between patients and healthcare providers.

This paper structure into four parts, where this introduction is the first part of this paper. In part, II will discuss similar studies such as the use of the internet in the treatment of other sleep disorders or similar cases to make a basis for consideration of the concept of the framework that we propose. Part III is the core of this paper; where we explain the concept of the framework we propose to overcome the problems that occur in the lack of equitable access to insomnia sleep disorders testing. Part IV, Discussion of our conceptual tele-monitoring framework. Finally, part V is the conclusion of our paper.

2. RELATED WORK

The presence of the Internet of Things as a technological innovation that functions to connect a collection of sensors and devices to collect, record, transmit and share data that can provide for analysis that may have been used in a wide field of application [37,46]. In recent years, the Internet of Things technology has been used in the health industry by developing a simplified standard protocol between medical devices, both wired and wireless [47]. Some have become potential applications in monitoring health, where patients' data will be collected from a number of sensors installed on their bodies both invasive and non-invasive which are then analyzed and delivered through a network and shared with several parties who need the data such as doctors, officer medical practices suitable for patient care, as well as for patients and their families if needed [38,40,44, 45, 48, 49].

In the field of treatment and assessment of sleep disorders, there have been several studies that have been carried out previously such as Matar and colleagues in 2016 [50]. They have innovated the Internet of Things to monitor patient's sleep disorder remotely. The remote sleep monitoring is used to get sleep position recognition, whereby the sleeping position can be used for clinical findings in sleep studies, such as non-partial anesthesia surgical procedures that involve determining the position of the body on the mattress. In this study, the distribution of body pressure is used to place the mattress under the patient's body. The data then obtained from the pressure sensor and sent to the computer for further processing. The results obtained from the patient's body will be sent for monitoring and diagnosis purposes. This study is to carry out an introduction to human posture, which consists of providing an optimal combination of signal acquisition, processing, and storage of patient data to perform the task of recognition in a quasi-real time manner. By utilizing the machine learning algorithms, a model is formed based on the synthesized data to obtain accurate results with the use of Kappa Cohen's coefficient value of 0.886.

Veiga and friends [51] conducted a study on the use of smart pillows to monitor sleep quality in the Ambient Assisted Living environment. This study was conducted due to many people suffered from sleep disorders that drastically affect the quality of sleep and daily life. Moreover, the problem of time constraint for patients to get the opportunity to do sleep testing to diagnose their sleeping pattern. The study proposed a smart pillow that is used to monitor sleep quality by using the Internet of Things to collect data such as the temperature, humidity, luminosity, sound, and vibration. The data will be sent to central computer server via a router with a static NAT configuration. The data on the server will then be used by medical personnel to obtain information and get results of the patient's sleep quality.

Yacchirema and friends [52], conducted a study of Obstructive Sleep Apnea (OSA), in which they created a smart system for monitoring sleep using the Internet of Things and big data analysis. In this study, detection and treatment support for elderly Obstructive Sleep Apnea patients by monitoring the sleep environment, sleep status, physical activity, and physiological parameters. The difference is obtained by analyzing the big data from the data obtained with an effectiveness of 93.3% in predicting the air quality index to guide the treatment of OSA.

Surrel and colleagues [53] conducted a study to detect online Obstructive Sleep Apnea using wearable medical sensors. The problems are due to the lack of medical devices as well as monitoring of Obstructive Sleep Apnea in inpatient care. These devices are still relatively expensive and cannot be used for long-term monitoring for outpatient care. The study has used the Internet of Things to reduce the balance of healthcare in hospitals and supervision of professional officers such as Medical Specialists. Patient monitoring is used as a single channel electrocardiogram signal, which then analyzed and calculated the sleep apnea scores. The impressive results had shown that 88.2% classification accuracy.

Han and colleagues conducted the study regarding [54] smart devices to conduct real-time sleep monitoring. The system is made using ECG, orientation, audio, and acceleration signals in real-time to get the data needed to monitor sleep in real-time. The main objectives of this research are to gather the above information and the collected signals data are used to analyze sleep quality, sleep apnea, and stroke.

Furthermore, Jayarathna and colleagues [55], conducted a study by developing a sleep testing device called "Vital Core" in which the device is a polymer sensor mounted on a t-shirt for long-term use for sleep disorders that caused by breathing. The created device uses electro resistive polymer sensors and an accelerometer to measure breathing, heart, and actigraphy information. The Bluetooth 5 connectivity is used to transmit the data. Based on the study, it was found that their device significantly improved the user experience with five-day battery life as well as local storage that is capable of more than one-year storing sleep data of the wearer.

3. A PROPOSED FRAMEWORK FOR SLEEP DISORDER MONITORING THROUGH IOT TELE-INSOMNIA

Based upon analysis and comparison from the previous models regarding sleep disorders diseases, this research proposes initial framework for Sleep Disorder Monitoring using IoT Tele-Insomnia Framework. The framework aims to maximize the medical device for insomnia sleep testing by combining the Internet of Things that is useful for monitoring sleep disorder between distance patients/rural folks and healthcare providers. By having this system, the limited professional staff such as specialist doctors would be resolved and the Internet of Medical Things will play an essential role in the concept of the framework that we propose in this paper. The proposed framework consists of4 parts. First, Section C1 - Human Device Interaction is a part that deals directly between patients and professional staff with medical devices and software involved for testing and evaluating insomnia sleep disorders. This process produce data sets from the results of sleep testing conducted by the patient. Second, Section C2 - Telemonitoring Medical Devices is a part where there is preparation for sending data from medical devices before heading to the data server in the cloud and the tele-communication. Third, Section C3 - Telemonitoring Insomnia Management Systems is a process that occurs on the server, starting from storing data and processing medical data obtained from the previous process. Fourth, Section C4 - Standard and Policy is a part which discusses the standards and policies that underline how this system works. This section will involve the whole process that has occured. The proposed conceptual framework is depicted in Figure 1 and the explanation of each part of the framework will be described as follows.

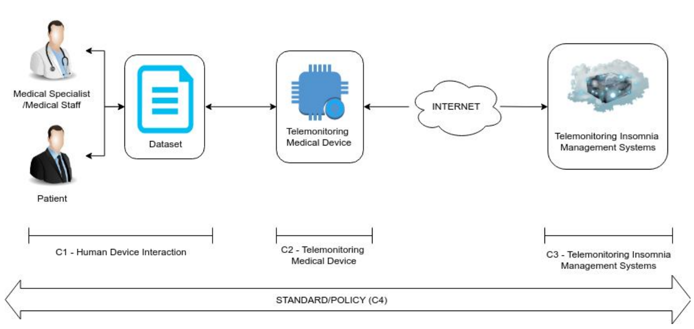

Figure 1: General description of the proposed conceptual framework

3.1 C1 - Human Device Interaction Section

The Human Device Interaction Section is the only part where there is direct involvement of humans (both patients and professional officers) with the system of testing and evaluating the sleep quality of insomnia sleep disorders (medical devices whose task is to collect data from patients as well as integrated software).

The Human Device Interaction section has two major parts, namely the sleep quality testing medical device, and the software integrates with the medical device system. In the medical device, there are several biopotential sensors ECG, EEG, EMG, EOG, respiratory effort, pulse oximetry, blood pressure, and other sensors needed in some instances. The software is included several procedures such as inputting patient information such as medical records, filling out questionnaires both before and after sleep testing, as well as information about the test environment.

The medical device will retrieve the patient's vital signs data, such as the patient's brain waves using a biopotential Electroencephalographic (EEG) sensor. The patient's heart rhythm during testing both before going to sleep, during sleep and after sleep using a biopotential electrocardiogram (ECG) sensor. The movement of the cheek muscles, and other body parts needed to retrieve the vital data using an electromyographic biopotential sensor (EMG). Eye movements is also captured when the patient falls asleep using a biopotential Electrooculography (EOG) sensor. Moreover, to find out if there is a respiratory disorder that is involved that could lead to sleep disorders, patients could opt for respiratory support devices to overcome the condition. The oxygen level in the blood and heart rate are captured using pulse oximetry devices. Some tests are carried out occasionally at the beginning and end of the device in contrast to other biopotential devices or sensors that are always recorded during testing. This is to determine the pressure of the blood using a blood pressure device. Meanwhile to find out other vital tools necessary for diagnosis, the biopotential sensors are required to follow the considerations and directions of a medical specialist.

The software integrates with medical devices that have the duty as a compliment that is required to create a data set. The tasks of the software are to safe keep the t information about the patient such as name, age, gender, blood type. In this case, if the system that stores the patient's medical record is already interconnected and integrated with other health care providers, then the only requirement left is to enter the medical record number of these patients. The next task is giving questionnaires to patients both before and after the sleep testing. Questionnaires submitted before the sleep test are questions that surveyed sleep quality which were derived from the Insomnia Severity Index questionnaire [56], Epworth Sleepiness Scale [57] Pittsburgh, Pittsburgh Sleep Quality Index [58], Sleep Condition Indicator [59], and others according to the needs of patients or agreements between the health care providers and patients. On the other hand, the questionnaire after sleep test is a set of questions that is focused more on the development of health care services by collecting feedback from patients. This will provide additional information to support other data like the environment of the remote test site which includes the room temperature before and after the test; the duration of the sleep test, the location, and other data.

The process flow of the Human Device Interaction section is shown in Figure 2. The details are as follows.

a. The health workers will register the patient by entering the information of the patient or by entering the medical record number. However, the medical record number requires the data of the patients to be well integrated between health center.
b. Patients fill out the questionnaire before the sleep monitoring test for sleep disorders diagnosis. The type of questionnaire that will be provided depends on the needs determined by the health service provider.
c. The patient will then undergo a sleep test at night whereby the patient's body is fitted with a biopotential sensor on vital organs followed by the placement of the biopotential sensor, which has been set up by the health worker in a remote location. The duration of this test usually ranges from 7-9 hours.
d. During the sleep test, health workers will monitor and enter any findings such as the duration of the sleep test and other fundamental data relating to the environment of the test where it was conducted.
e. Post sleep test, the patient is required to answer a questionnaire to gather their feedback.
f. Essentially, the whole process will form a complete set of data that could be an integral part of the concept that we propose to diagnose sleep disorder. This set of data will be sent to the Telemonitoring Medical Device section for file adjustments, which will then have transmitted to the Telemonitoring Insomnia Management Systems section.

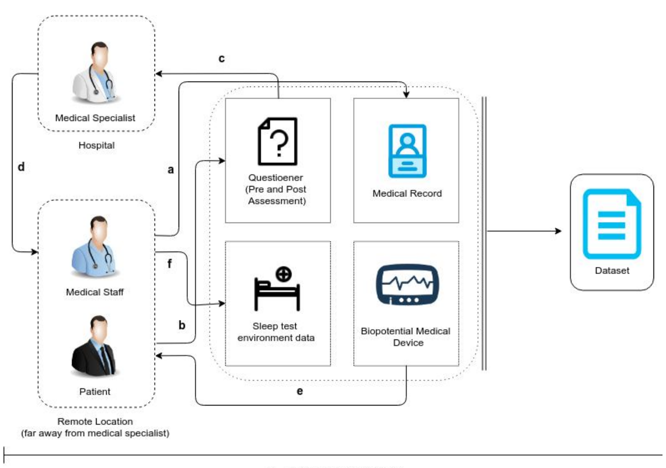

Figure 2: Process Flow of Human Device Interaction section

Medical specialists would have access to the results and the entire data set will be displayed both in the form of a questionnaire and reading of the vital of patient's biopotential data for further analysis. The Human Device Interaction section for medical specialists is indirectly linked to Telemonitoring Insomnia Management Systems to visualize the data, getting initial diagnostics with the help of artificial intelligence and produce reports of sleep disorders testings from patients.

3.2 C2 - Telemonitoring Medical Device Section

The primary function of the Telemonitoring Medical Device section is to change the data set obtained in the previous section (the Human Device Interaction section) into a medical report derived from the biopotential data of patients. However, before sending, there are several processes to be carried out which includes sufficient resources to validate the diagnosis.

We propose several device requirements that can outline all the processes required in the Telemonitoring Medical Device section. A device used in Telemonitoring Medical Devices in this framework concept must have the following minimum requirements such asmicrocontroller or microprocessor, internal storage, and connectivity to the internet either wired or wireless. All these function needs to carry out the processes contained in the Telemonitoring Medical Device section.

The dataset received from the previous process and the Human Device Interaction section will go through the process of collecting biopotential data where the biopotential data will be stored in the internal storage of the Telemonitoring Medical Device. After the biopotential data from the patient has been recorded and collected fully in one sleep test session, the next process is to process the data before the data send to Telemonitoring Insomnia Management Systems.

The stages in processing data are the responsibility of the microcontroller or microprocessor. Such as the conversion of raw data obtained from internal storage where data derived from internal data is from data sets obtained from the Human Device Interaction section into the appropriate biopotential data. Other processes that occur in Data Processing, this process is to do data packaging into smaller data and more accessible to send and file archiving and provide additional security such as providing a password in the archive file.

The next stage is to perform data integrity validation, in this process the microcontroller or microprocessor has the task to do a checksum checking of a file, using an algorithm such as MD5, SHA1, or BLAKE. The results obtained at this stage is a file checksum information that is useful for validating data sent by Telemonitoring Devices and received in the Telemonitoring Insomnia Management Systems section. The entire checksum and archive password are stored in a file that will be sent by the ability of Telemonitoring Medical Devices to access the Internet, therefore Telemonitoring Medical Devices must have internet connectivity capabilities.

The results of the data processed in the Telemonitoring Medical Device section we call Medical Data. In the final stage after the whole process to get the entire file checksum obtain, the next step is sending Medical Data to the Telemonitoring Insomnia Management Systems section through an internet network that is available through protocols such as HTTP/S, FTP/S, MQTT, CoAP depending on the capabilities of the device and protocol available on two sides that are interconnected. Sending the file in a queue with a maximum number of records of medical data sent no more than eight files, but depending on the quality of the internet connection. It might be better if there is a configuration that can be arranged by medical personnel in the Human Device Interaction section to set the number data delivery connection. However, by default, this step is done automatically by sending four files simultaneously. In the big picture, the process flow that occurs in the Telemonitoring Medical Device section shown in Figure 3.

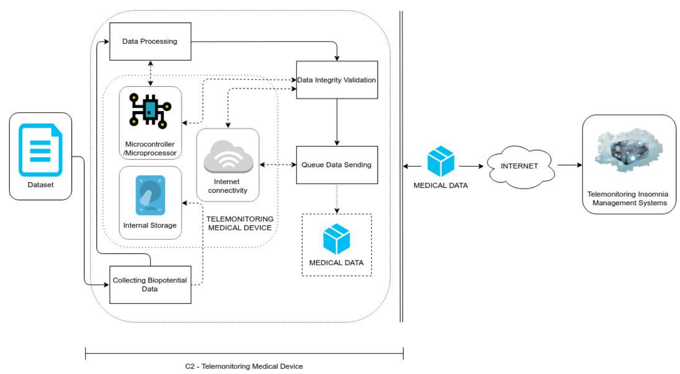

Figure 3: Telemonitoring Medical Device section

3.3 C3 - Telemonitoring Insomnia Management Systems Section

Telemonitoring Insomnia Management Systems is a significant part of data storage and processing. There are at least two major parts involved in this section This includeData Warehouse section (which was previously carried out by Data Integrity Validation) and the Notification Systems section. The Telemonitoring Insomnia Management Systems section has contact to all parts that are hardware (medical devices) and software, such as Notification Systems that will make contact with the software, Human Device Interaction and medical devices, as well as the Telemonitoring Medical Devices. Data Integrity Validation will contact the medical device and Telemonitoring Medical Device. Moreover, the doctor will make the diagnosis through the Human Device Interface that makes contact with the Telemonitoring Medical Device.

Telemonitoring Insomnia Management Systems section can be seen in Figure 4 and the details will be explained as follows.

a. Medical data received from the existing database will be transmitted through the Telemonitoring Medical Devices which will then be checked for data integrity. After checking the file checksum, it compares it with the original file checksum which was derived from the medical data archived with a password. If the file checksums are not similar, the Notification Systems will send a signal to the Telemonitoring Medical Device to resend the intended file to the last queue, until the entire file checksum is the same for up to 3 times before notifying the medical staff to send the file checksum manually.
b. Once the data is validated, the next step is to carry out the data storage procedure that involves the data warehouse stage. Validated data remerge into a complete data set and transmitted into an appropriate database, for example, ECG data into the ECG table in the Telemonitoring Insomnia Management Systems database. The strategy for storing data in files is not covered in the explanation of this framework concept.

c. Data that has been stored in the Data Warehouse stage can be obtained according to the desired format of the users. For instance, a medical practitioner who requires a set of data from the sleep test conducted in a form of graphic can easily do so by accessing the patient's ECG data visualisation graph.

e. The last stage is if the doctor wants to make a report on insomnia sleep disorders testing, a process that has been carried out at the stage of Visualization of Data and Pre diagnostic Insomnia Levels using Artificial Intelligent present to the medical specialist. Medical specialists carry out this process through the Human Device Interaction section related to Telemonitoring Insomnia Management Systems remotely with internet connectivity. After the Medical Specialist has completed with the results of the diagnosis, it will be stored on the Telemonitoring Insomnia Management Systems and Notification Systems will provide information to the Medical Staff at the remote location that the doctor has completed the diagnosis of the patient concerned. The medical staff will then contact the patient to receive results and explain these results. It could also be in terms of explaining results remotely, such as using voice over the Internet or video calls made between patients and medical specialists.

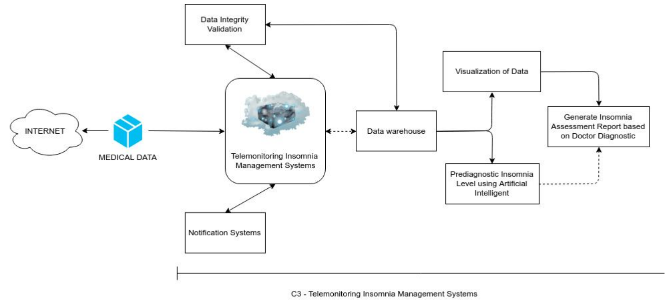

Figure 4: Telemonitoring Insomnia Management Systems Section

3.4 C4 – Standard and Policy Section

This section serves as a guide to enable the proposed framework to be implemented in other countries. The overall process meets the minimum standards that include the utilisation of Human Device Interface, sending and receiving data via HIPAA and other stipulated regulations. The regulations in the Standard and Policy section are useful for protecting all stakeholders involved especially for health workers, medical staff, and medical specialists. As for the personal information of the patients we are bounded and governed by the Personal Data Protection Act (PDPA). While some other studies was using Blockchain [62], IPv6 addressing scheme, Blowfish algorithm and Wireless Body Area Network [63] for securing patient data. This approach can we use as security standard of this proposed framework.

4. DISCUSSION

Limitations on health services in the form of sleep laboratories for diagnosis of insomnia or sleep disorders are still limited, both in terms of facilities and human resources. The problem that often occur is that patients are hindered from taking the test due to restricted means to travel and high cost. Therefore, the concept of this framework is by minimizing the limitations of the lack of experts involved and enable patients to undergo the sleep test remotely. Medical devices and software become a unified system that is explained earlier in this framework, starting from the Human Device Interface which acts as a bridge between Medical Specialists who are at the health service center and Medical Staff who are stationed in rural areas. Then, the Telemonitoring Medical Device Section is tasked with preparing the data set from the patient for further processing and sending it to the internet so that the Medical Specialist can make the diagnosis seamlessly.

Furthermore, the Telemonitoring Insomnia Management Systems Section is for Data Warehouse, Notification Systems, as well as testing the severity of sleep disorders based on artificial intelligence to help doctors diagnose the level of severity. The doctor will then remotely analyze the results of a patient's sleep test with seconded results from the initial diagnosis of artificial intelligence to help doctors make documents more accurately to measure the severity of insomnia currently experienced by the patient. In conclusion, by using the concept of the framework in this paper it certainly benefits patients by enabling them to take the sleep test without the need to travel far and in doing so, it will save their time and costs. Furthermore, health care providers can also shorten the time to read patient data because they have the pre diagnosis results recorded from the initial diagnosis of artificial intelligence which can also increase the income of hospital service providers. In short, with the application of this framework, it can increase the accessibility of the community to take up the sleep disorders test and resolved their issues for a better quality of life.

5. CONCLUSION

Accelerating the distribution of services in remote areas for Insomnia sleep disorder monitoring using the internet of medical things to help break through barriers that occur between patients and healthcare providers will be achieved by this conceptual framework. Using this conceptual framework tele-monitoring of Insomnia sleep disorder will help reduce the cost and time on every side, on the health provider side and especially the patient side. On the health provider side, they can get more helping patient, which mean this can make more revenue of the health service. On the patient side, without travel to a big city which has the sleep laboratory make they reduce the time and cost which they need before the conceptual framework of tele-monitoring for Insomnia sleep disease applied. Using the four-part of this conceptual framework of tele-monitoring for Insomnia sleep disease can increase the accessibility of the sleep disorders test and resolved their sleep issues for a better quality of life.

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