ECS: Elderly Care System for Fall and Bedsore Prevention using Non-Constraint Sensor

G.Pongthanisorn[1], W.Viriyavit[2], T.Prakayapan[3], S.Deepaisarn[4], and V.Sornlertlamvanich[5]

[1]Department of Computer Engineering, Faculty of Engineer, Thai-Nichi Institute of Technology, Bangkok, Thailand
[2 3 4]School of ICT, Sirindhorn Internation Institute of Technology, Thammasat University, Bangkok, Thailand
[2]Department of Medical Engineering, Chiba University, Chiba, Japan
[5]Faculty of Engineering, Thammasat University, Bangkok, Thailand
[5]Asia AI Institute (AAII), Musashino University, Tokyo, Japan

***Abstract*—The Internet of Things (IoT) has become more practical nowadays. Various IoT applications are now being developed and deployed in order to attenuate our daily life problems. The global society is currently suffering problems associate to different aspects and ones that require our concern are regarding the aging society. Many and more countries are entering their aging society era while their healthcare sections have yet effective solutions to overcome the corresponding problems. Therefore, we propose the Elder Care System (ECS) for monitoring behaviours of elderly patients on the bed equipped with our designed system. The system includes notification system, in-bed position prediction system and real-time monitoring system. This paper demonstrates equipment, system architecture and dataflow. The result of our system deployment is discussed.**

***Index Terms*—Health Care, Internet of Things, Monitoring System, Posture Prediction**

I. Introduction

The global society has been gradually transforming into an aging society as the number of elderly population has dramatically risen while the fertility rate is significantly lower. In more-developed countries, the elderly, whose age above 60, is approximately 10% of the total population in 2010. This number is expected to go up to 21.2% by 2050 [1]. The falling fertility rate plays the major role of imbalance population aging which is an issue of concerned in most countries. Also, in Thailand, the National Statistical Office of Thailand reported as of 2017 that the percentage of Thai elderly population was increased to 16.7% in 2017 and that 10.8% of them lived alone [2]. This could imply that Thailand is currently facing a shortage of manpower,in every section including healthcare. Although, Thailand's health care section is considered effective, the rising number of elderly staffs would tremendously impact their performance in delivering services. One of the main reason for the cause is that Thailand's health care section expenditure is largely supported by the government. In addition, most of the low income elderly would certainly rely on the assistance provided by the government, which requires a high fiscal burden. The decrease fertility rate and senior citizen ratio altogether lead to a shortage of manpower as a result, especially in the healthcare section which supplies basic needs to people and therefore supports all other sections of the society.

The shortage of health care manpower leads to various problems. For instance, a reducing capacity of manpower in healthcare systems not only affects the working performance in general but could also arise unwanted technical errors. One of the problems to be addressed is that the main cause of injury in seniors is falling out of bed, resulting in as high lethality rate as 40.4in an inefficient monitoring of seniors in care. There is a high risk of fall when a senior attempts to get out of bed or lie close to the edge of a bed. Moreover, bedsores are also major problems in nursing home care. For bedridden people, lack of repositioning in every two hours is an important cause of bedsores due to the prolonged pressure on the body. In order to prevent accidents around the bed and bedsores, we have to consistently monitor the elderly activity on the bed. That means a huge number of caregivers are required. Therefore, the elderly care system becomes even more necessary to reduce the burden of caregivers.

Internet of Things (IoT) is considered an emerging trend as it is lately being implemented in broad domains in order to provide contextual services via IP-based network. Furthermore, a network of things of IoT provide such a potentially large amount of data and remote provisioning, enabling new challenges and business opportunities in the modern society. The things of IoT may be referred to as smart objects which are equipped with the following features – *i.e.* identification, sensing, communication, computation, service and sematic [4]

This paradigm promotes the existing internet usage to be more immersive and pervasive as newly developed services is provided such as home automation system, smart tracking system and even ICT-based solution for the future society; such that the quality of life is greatly improved. Although being diversely implemented in broad domains, medical and healthcare seem to be one of the most attractive application areas of IoT [5]. An example would be wearable devices which can be applied to a wide array of fields, including healthcare where users range from paediatric and senior patients. These devices could track and provide private health and fitness information of individuals [6]. Medical and healthcare-based

IoT is a promising solution for aging society with scarcity of manpower as discussed in this section. Thus, this work proposed a healthcare-based IoT system which is designed in order to attenuate such burdens, called Elderly Care System (ECS) using non-constraint sensor. The proposed system can be divided into three sub-systems, which are real-time monitoring, in-bed posture prediction and notification system via LINE application; a mobile messenger application which is widely used in Thailand. The details on the design and architecture are discussed as follows.

II. Methodology and System Design

A. System Design

There are several issues that must be taken into an account when taking care of elderlies patients with some kinds of special attention required, for example, those who live at home by themselves, or those with mental/physical disabilities. It is possible for them to cause unnecessary self-injuries – i.e. either accidents or bedsore as discussed previously. These can occur if they try to get out of bed without assistance of their caregiver, or staying at same posture for a long period of time. Or for the worst their chronic symptoms cause disability to get the help by themselves. In order to eliminate or attenuate these phenomena, we designed the ECS system that is capable of detecting in-bed postures of a patient, consistently monitor the patient and raise an alert when an abnormal event is detected. Thus, our proposed system composes of the following three sub-systems.

1) Real-time Posture and Signal Monitoring System
2) In-bed Position Prediction System
3) Notification System

In this section, we focus on the methodology design and cause of each sub-system. While the detailed discussion of subsystem implementation will be provided later.

As its name implies, In-bed Posture Prediction System is primarily designed to detect different postures of patient in the bed in order to predict their intention to leave the bed, since falling out of bed is one of the main cause of injury for elderly patients. After the system detected a leaving intention, the notification system will raise an alert for their caregiver. Furthermore, staying on same posture for too long, leading to bedsore, is also considered as an alert. The cooperation of these two sub-systems would reduce senior risk of injury caused by falling out of bed. Real-time Position and Signal monitoring system is designed in order to provide elderlies' caregivers a visualisation of each elderly's status, including raw signals from a sensor for the system administrator. Normally, for elderlies monitoring, the visual sensory such as video is used. However, for a larger group of patients, video streaming requires potentially large storage and processing power. Hence, we only present the posture that is detected by in-bed position prediction system instead. The last subsystem, Notification system, is designed to raise an alert to the caregiver if abnormal phenomena such as staying too long at same posture or trying to leave the bed is detected; the alert message is then put through. The implementation of notification system is on a cloud server. Currently, the notification sub-system is based on LINE application. Not only notify capability, the system can be equipped with a simple chat bot for command issues such as, subscribe for specific patient data (system administrator), report the current location, etc. Using all possible risks we have come up, the system usecase diagram is illustrated fig. 1.

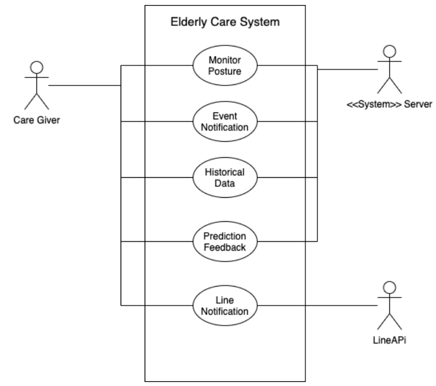


Fig. 1: The System Use-case Diagram

B. System Architecture

From the system aspect, it is designed to prevent elderly from falling out of bed as proposed. fig. 2 demonstrates an overview of system architecture which comprises of several service components cooperate together. Bed sensor is a combination of hardware that is capable of obtaining useful signals. The sampled signals are then passed to the mediator wirelessly. The mediator which classifies a current in-bed posture then make a request to the messaging service whether a notification should be made. While WebApp is designed for the system administrator for a sake of regulating and calibrating the system parameters. The messaging service is going to request a notification via LINE application using LINE's provided API. Then, a message will be relayed and sent to everyone that has token or already joined a specific group.

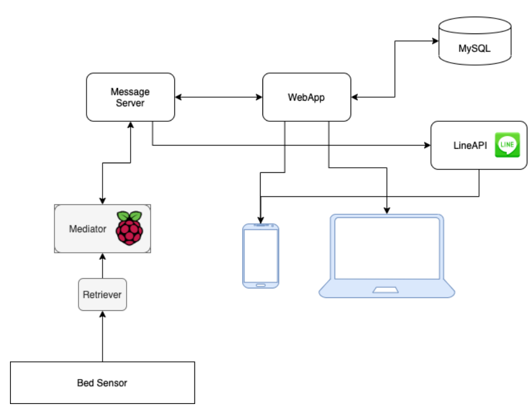


Fig. 2: The Overview System Architecture

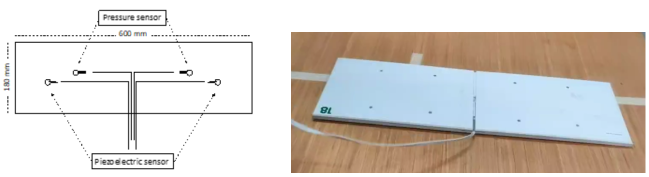
III. Devices

The proposed system devices that cooperate and communicate simultaneously with each other to form a ECS system is introduced. We categorized the devices as

- Sensor Panel
- Signal Retriever
- Mediator

A. Sensor Panel

A set of sensors – *i.e.* a pair of piezoelectric sensors and a pair of pressure sensors; are embedded in the sensor panel of size 60 cm x 18 cm. These sensors are aligned symmetrically as shown in fig. 3 [7].



(a) The Blueprint (b) The Actual

Fig. 3: The sensor Panel

Fig. 3b shows an image of the actual sensor panel. The sensor panel detects vibrational signals via piezoelectric sensors, and pressure signals via weight sensors. Both sensor types are used for in-bed posture detection as described. While being deployed, the sensor panel is placed underneath the mattress of the target patient's bed in order to obtain these signals

Fig. 4: The Signal from Sensor Panel

Outputs from symmetric sensor array which is placed under the mattress, is shown in fig. 4 Pr and Pl represent signals acquired form the two piezoelectric sensors which resides in both right and left sides of the panel, respectively. Similarly, Wr and Wl represent signals from the two weight sensors on the right and left,, respectively. The variety of waveforms are generated when different sensors are activated, which will be used later to classify a position. Nevertheless, the sensor panel is not integrated with any kind of microcontrollers. Thus, the sensor panel must be connected to the signal retriever first. When they are connected, sensor panel signals can be sampled using a 12 bit analog-to-digital convertor (ADC) of the signal retriever to digitize the signals before transferring to the mediator. The process of information emission will be discussed further.

B. Signal Retriever

The signal retriever is implemented using ESP32 board which is embedded with Xtensa single/dual core 32 bit processor, capable of WiFi and Bluetooth communication including an amplification circuit. Since, signal from piezoelectric is relatively small. The signal retriever must be connected to the sensor panel before an in-bed posture can be classified. Signal retriever samples emitted a signal from the sensor panel using two 12bit ADCs at the sampling rate of 30 Hz [7].

Fig. 5: The Encased Signal Retriever

A digitized signal is then emitted to the mediator via WiFi communication where the classification of position is perform using Neural Network and Baysian Network based method of [7]. Not only used for information retrieval, the signal retriever also host a web-based real-time signal monitoring system which is capable of displaying a signal waveform. Moreover, the signal retriever also host a web-application for real-time signal monitoring. Despite being such a heavy duty controller, the signal retriever still operates without any jitter and can complete every task perfectly thank to the provided SDK which is based on FreeRTOS. .

C. Mediator

Mediator can be considered as the brain of the system since it is embedded with the posture classification system. The mediator is implemented using Raspberry Pi Model B+ which is equipped with wireless communication module together with Raspbian OS.

The mediator is capable of the proposed system network management which comprised of one or more mediator and signal retriever. Multiple signal retrievers can be wirelessly connected to a mediator. This is easily executed using integrated services that are designed to automatically or manually give pairing information of mediator and signal retrievers. Once the signal retriever is connected, the in-bed position prediction system is then invoked and pairing information is stored to the local database.

Fig. 6: Raspberry Pi Model B+

IV. In-bed Position Prediction and Notification

The in-bed position prediction is adopted from position classification model [7], [8].

The model classifies 5 positions; *i.e.* off-bed, sitting, center lying, left lying, and right lying. Signal normalization is used to eliminate the offset between different panel sensors.

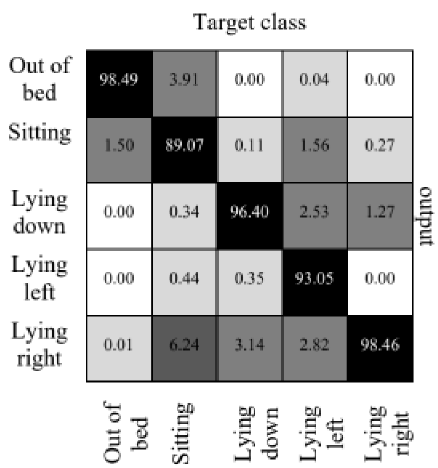


Fig. 7: Accuracy of Combined Neural Network and Bayesian Network for Position Prediction

The performance matrix on the left define a prediction from the algorithm while the bottom is target class. As fig. 7, the accuracy of algorithm is considerably high. Sensor signals of off-bed position are used as the based offset which is adopted to be the zero set as in eq. (1).

$$W_n = W_i - W_{offbed} \tag{1}$$

where Wi is current pressure signal, Wn is normalized pressure signal, and W_{offbed} is off-bed weight signal. Ideally, piezoelectric signal in the off-bed position could fluctuate within the range of +-1. To normalize the environmental effects, the range of fluctuation needs to be set at a threshold of 1-(-1)=2 as eq. (2) and eq. (3).

$$ratio_{offbed} = (PU_{offbed} - PL_{offbed})/2 \tag{2}$$

where $ratio_{offbed}$ is the dynamic ratio, PU_{offbed} is the maximum value of piezoelectric signal in off-bed position, and PL_{offbed} is the minimum value of piezoelectric signal in the off-bed position. The dynamic ratio is adopted to filter the different sensitivity of each panel sensor as in eq. (3). where P_i is current piezoelectric signal, and Pn is normalized piezoelectric signal.

$$P_n = P_i / ratio_{offbed} \tag{3}$$

where Pi is current piezoelectric signal, and Pn is normalize piezoelectric signal.

The notification events via LINE application include these three types - *i.e.* going out of bed, staying in same position, and too frequent movement. First, the going out of bed notification is an important status to help caregivers monitoring a fall from bed event. This status is detected when the position changes in the order of lying, sitting, and off-bed. In terms of bedsores or alleviate bedsore, the body needs repositioning every two hours. Therefore, the period where the patient is still in same position is required to set the notification. Moreover, the off-bed status is used to detect the accident as a result of leaving or losing from bed for a long time. Hence, a user can set the period of time for notification in the five positions; *i.e.* center, left, right, sitting, off-bed. If the patient stays still in the same position for longer than a certain threshold, the alert notification is pushed. The last type of notification, too frequent movement, will be alerted when the number of changing positions last longer than the set threshold. The different household and individual behaviours would affect the sensitivity of the model prediction. Therefore, the ECS provides the setting interface where 7 sensitivity levels and period of monitoring interest for each event can be altered as indicated in fig. 8.

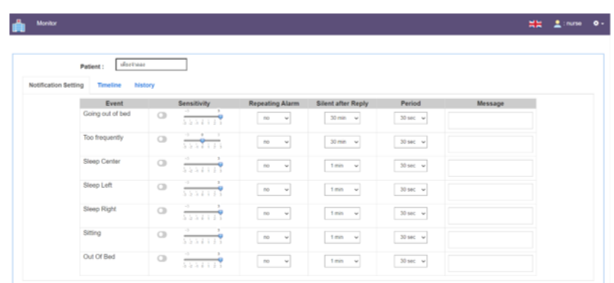


Fig. 8: UI for Notification Sensitivity Configure

Due to the misclassification of the model itself and the subjective behaviours of each individual, the sensitivity of errors is used to adjust the accuracy of notification. The levels of sensitivity are -3, -2, -1, 0, 1, 2 , 3, which is the error threshold as the consecutive time of misclassification status as 15, 12 ,10, 7, 5, 3, 0 seconds, respectively. If the period of misclassification status is no more than the threshold, the misclassification status is ignored. Otherwise, it is counted as a changing position.

TABLE I: Threshold of each Sensitivity in too Frequently Movements Notification

Threshold	Sensitivity						
	-3	-2	-1	0	1	2	3
Error (%)	15	12	10	7	5	3	0
Number of posture transition	0	3	5	7	10	12	15

For too frequent movement, two types of threshold are utilized for the notification rules as shown in table I. The too frequent movement notification is alerted when the number of changing positions are greater than the threshold.

V. Conclusion and Discussion

This paper proposed the ECS system which is equipped with the real-time signal and position monitoring system, in-bed posture prediction system and anomaly notification system. The system can seamlessly notify caregivers via LINE application whenever an in-bed patient is trying to move out of bed. Not only that, real-time signal and position are working perfectly. Nevertheless, we have encountered a slight problem when our system is deployed in household. The performance of in-bed posture prediction is affected by various factors, for instance, harmonic frequency of electrical devices, type of bed, and different activities at each household. Such that the posture of SITTING ON BED and OFF BED is not perfectly distinguishable. For future work, we aim to integrate in-bed posture prediction using image processing techniques since raw signals from piezoelectric sensors might be affected from environmental noise. Moreover, we aim to enhance our system by integrating with assistive robots. TeMi is one of the promising candidates since the add-on development is possible via the provided API.

Acknowledgment

The research is financially supported by the Thammasat University Research Fund under the National Research Council of Thailand (Contract No. 25/2561) for the project of "Digital platform for sustainable digital economy development," based on the RUN Digital Cluster collaboration scheme.

References

[1] D. E. Bloom, D. Canning and A. Lubet, "Global Population Aging Facts Challenges Solutions Perspectives,"Daedalus Volume 144 , Issue 2 , Spring 2015, p.80-92

[2] National Statistical Office, The 2017 Survey of the elder persons in Thailand, Bangkok, 2017

[3] Health systems research institute. "Fall down" Major cause of accident that effect in injury of elderly. Retrieved May 9, 2018, from

[4] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications, in IEEE Communications Surveys & Tutorials," vol. 17, no. 4, pp. 2347-2376, Fourthquarter 2015, doi: 10.1109/COMST.2015.2444095.

[5] Z. Pang, "Technologies and architectures of the Internet-of-Things (IoT) for health and well-being", Jan. 2013

[6] S. M. R. Islam, D. Kwak, M. H. Kabir, M. Hossain and K. Kwak, "The Internet of Things for Health Care: A Comprehensive Survey," in IEEE Access, vol. 3, pp. 678-708, 2015

[7] W. Viriyavit and V. Sornlertlamvanich, "Bed Position Classification by a Neural Network and Bayesian Network Using Noninvasive Sensors for Fall Prevention," Journal of Sensor, Volume 2020, Article ID 5689860, Hindawi, January 2020, pp. 1-14

[8] S. Sao and V.Sornlertlamvanich, "Long Short-Term Memory for Bed Position Classification," Proceeding of The 4th International Conference on Information Technology, October 2019, Bangkok