Applied Nursing Research 47 (2019) 18–23

Contents lists available at ScienceDirect

Applied Nursing Research

journal homepage: www.elsevier.com/locate/apnr

Survey on the demand for adoption of Internet of Things (IoT)-based services in hospitals: Investigation of nurses' perception in a tertiary university hospital

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ARTICLE INFO

Keywords:
Internet of Things
Health care survey
Nursing services
Health services needs and demand

ABSTRACT

In hospitals, while the opportunities and challenges of Internet of Things (IoT) applications are continuously increasing, research on what IoT services are actually in demand in hospitals has not been conducted. In this study, a survey of working hospital nurses was conducted to confirm the demand for IoT services. A total of 1086 (90.2%) participants responded. Five out of seven points for all service questions were obtained, which indicates a high demand for all services. The highest demand was shown for a vital sign device interface system. A comparison between ward and non-ward nurses showed that individuals working in wards had a high demand for patient care related IoT services, and individuals working in non-ward departments demonstrated a high demand for IoT services to improve work efficiency. Overall, the results provide a framework for future directions of services that can improve the efficiency of medical staff and health outcomes of patients.

1. Introduction

Many objects around us are being integrated into networks within the Internet of Things (IoT) paradigm, which began with the development of information communication technology (ICT), such as sensor technology, Wi-Fi, Bluetooth, wide area network (WAN), wireless sensor network (WSN), and personal area network (PAN) communication (Atzori, Iera, & Morabito, 2010). Specifically, communication modules, such as radio frequency identification (RFID) and Bluetooth modules, have been miniaturized and embedded in various objects, such as cars, air conditioners, and lights, and they exchange information within a network (Gubbi et al., 2013; Kranz, Holleis, & Schmidt, 2010; Sundmaeker et al., 2010). As a result, large amounts of information, called “big data,” are generated from connected objects. Accordingly, needs for storage space, such as a “cloud”, where big data can be stored for data processing and data manipulation. Furthermore, big data application fields, such as artificial intelligence (AI) are coming to the forefront (Azimi et al., 2016).

Such ICT developments are influencing the healthcare structure of hospitals (Islam et al., 2015). Many IoT devices used in hospitals are connected to a single network. The IoT linked to the devices and equipment was allowed to wirelessly measure and transmit the biometric data, location information of medical staff and patients, and the location information of specimens and other items. In addition, IoT technology offers opportunities to collect a variety of personal lifelog data through wearable sensors and mobile applications (Xu et al., 2018; Yang et al., 2018). These data can be interfaced and integrated the hospital information system (HIS) with clinical data. Secondary effects of this wireless integration, including a higher quality of patient care management, reduced medical costs, increased work efficiency of nurses and other medical staff, and the overall improvement of the hospital medical environment are expected to occur as a result of the stored data.

Opportunities to apply IoT in medical fields are continuously expanding, and many studies are currently being conducted (Dimitrov, 2016; Liu et al., 2015; Perera et al., 2014; Ramirez et al., 2016; Risso et al., 2016; Sun et al., 2016). The key feature of IoT technology is to record and track the biometric information of patients, regardless of time and place, and to provide fast feedback through real-time data analysis (Xu, He, & Li, 2014). Improved patient safety and work

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https://doi.org/10.1016/j.apnr.2019.03.005
Received 11 May 2018; Received in revised form 19 March 2019; Accepted 24 March 2019

efficiency can be easily achieved, because a quick response is possible by raising an alarming for the medical staff or the guardian in real time if an emergency situation occurs in the hospital as well as at homes (Xu et al., 2014; Yang et al., 2014). Walking patterns in everyday life measured through a wearable device can be used to predict a fall (Ayers et al., 2014; Schwenk et al., 2014; van Schooten et al., 2015) and pressure ulcers can be monitored by sensors installed in a bed.(Peterson et al., 2013; Yousefi, Ostadabbas, & Faezipour, 2011) In addition, studies involving the use of IoT, such as those on managing assets using real time asset tracking technology, or providing customized services for rehabilitation patient who need long-term training and treatment (Fan et al., 2014; Yin, Fan, & Xu, 2012), are being actively conducted.

In hospitals, the opportunities and challenges of IoT application are continuously increasing. However, studies on what IoT services are actually in demand in hospitals have not been conducted. Accordingly, the focus of this study is to assist in the future development of IoT services and products that meet the needs of hospital users, by conducting a survey of nurses currently working in a hospital, on the demand for specific IoT services in hospitals.

2. Methods

2.1. Questionnaire design

A paper-based, self-reported questionnaire was used to survey the demand for IoT by nurses. We chose a paper-based survey rather than an electronic survey because the internet could not be accessed on the nurses' PCs at the study site. In addition, our nurses preferred to answer a paper-based survey as opposed to an electronic one. A multidisciplinary team, composed of a head nurse, a medical informatics professor, a research nurse in the department of medical information, and a researcher, was organized to develop the questionnaire items. The items were derived by referring to the previous IoT research literature. Fifteen items related to patient safety, work efficiency, and hospital environment were selected through internal reviews and discussions (listed in Table 1). As far as we know, most hospital IoT service items have not been fully implemented in hospitals in the real-world, or those services are under research and development. Thus, from the perspective of hospital needs, the 15 items were chosen by considering clinical and environmental relevance to most of hospitals. Among the selected items, real-time patient location tracking system and real-time asset tracking system were only available in a particular area and they were not fully-operational at the study site.

To verify the demand for each service item, participants were asked to choose and mark on their choice using a 7-point Likert scale, with answers between “very unnecessary” for one point to “very necessary” for seven points. A “do not know” answer was added to increase the discriminating power of scores due to the possibility of distorting the evaluation by the participants arbitrarily selecting a response when there is a service item that is difficult to understand in writing. Besides the 15 IoT service questionnaire items, participants were allowed to freely describe subjective opinions through questions asking for additional IoT service items or expected effects of IoT services.

2.2. Study subjects

In this study, a survey was conducted for all nurses working at a tertiary general university hospital, located in the Seoul metropolitan area with 1340 beds, opened as a fully digitized hospital in 2003 and is renowned as Stage 7 of the HIMSS Analytics Electronic Medical Record Adoption Model (EMRAM), from July 5 to August 9, 2016. The hospital features high information service levels with high levels of IT experience, and understanding and expectations among employees. From 1240 nurses, 36 of the nurses in six departments (nursing administration team, safe management team, psychiatric day-time ward, anticancer day-time ward, intravenous injection room, ostomy care education center) were excluded, as they worked in administration and/or in supportive care, and did not work in clinical nursing sites. All the nurses voluntarily participated, and informed consent was not required as per the Institute review board (IRB) because this survey study did not collect personally identifiable information and there is no risk to the identification of personal information. This study was approved (IRB No. B-1606-350-302) by the IRB of the affiliated institution. The survey was conducted by distributing the questionnaire to the nursing department and collecting them two weeks later. The survey took only a few minutes to complete, and no incentives were given to participants.

2.3. Data analysis

The collected data were processed by using R, version 3.3.1, and statistical analyses were carried out. The collected subjective opinions were reviewed manually and grouped into the categories of patient safety, work efficiency, and hospital environment.

2.3.1. Data pre-processing

Data pre-processing was performed to facilitate data analyses, as many missing and non-response data were included in the raw data set. First, individuals that marked the same answer throughout all IoT service items were classified as unreliable data (e.g., 1, 1, 1, …). To further facilitate analyses, non-response data (e.g., “do not know”; $n = 197$) were denoted as NA, which was the same representation as missing data, resulting non-response and missing data being processed in the same manner. A multiple imputation (MI) method was used to process and fill in the missing data (Sterne et al., 2009). This method creates n data sets by comparing to the adjacent data, and determines the output closest to the optimal data set among the created data sets. To minimize the effects between the service items and tenure of nursing, the missing data was separately processed by the 15 service items, the total nursing career, and tenure at current institution. The process flow of data pre-processing is shown in Fig. 1.

2.3.2. Validity and reliability

After pre-processing the data, the validity and reliability of IoT service items were examined, using a factor analysis. Factor loading values were examined to determine convergent validity, and the pattern matrix was obtained by using the promax rotation factor analysis to determine the discriminant validity. Cronbach's alpha values were obtained to determine if the service items used to construct the factors for three categories consistently represented the same concept.

Given that the loading values for all service items were from a minimum of 0.338 (> 0.3) to maximum of 0.958 (> 0.3), the convergent validity was confirmed to be statistically significant in the pattern matrix. Consistency of questionnaire items in three categories, such as patient safety (S1–S2, alpha: 0.77), work efficiency (W1–W9, alpha: 0.82), and medical environment (E1–E4, alpha: 0.85), was confirmed through factor analysis.

2.3.3. Demand analysis

The characteristics of survey participants, and the demand for each service item were examined using descriptive statistics. Given that the difference in the number of nurses among the departments was large, the demand level for each service item was compared by classifying departments into ward and non-ward, rather than into seven individual departments. Additionally, the total amount of nursing experience was also grouped into ≤ 5 and > 5 years. The level of demand for each service item according to experience and department were compared using a t-test.

Table 1
Hospital IoT service items.

Services	Description
Patient safety	
S1. Fall system	The system predicts a patient's fall risk, and alerts the attending nurse or caregivers.
S2. Pressure ulcer monitoring and management system	A prevention system that monitors the possibility of patient's pressure ulcer and alerts the attending nurse or caregivers.
Work efficiency	
W1. Smart Infusion pump system	An infusion pump management system with an EMR according to doctor's orders
W2. Continuous vital sign monitoring system	A system that continuously measures patient's vital signs using a bracelet or a non-restraining form of wireless mobile instrumentation device and transmits it to the EMR
W3. Smart patient transportation system	A support system for patient biosignal information collection and customized treatment preparation and transportation in an ambulance
W4. Hand disinfection system	A hand sanitization monitoring system with an RFID tag-enabled hand sanitizer installed at the door of patient room
W5. Rehabilitation management system	A system that checks rehabilitation patients' exercise and manages the schedule within the hospital by using various sensors
W6. Vital sign measuring device interwork system	A system that allows data collection and management at the same time by linking vital signs (such as blood pressure, biosignal, weight, height) measuring devices
W7. Medication monitoring services	A real-time monitoring and feedback system for inpatient medication status within the hospital
W8. Real-time patient location tracking system	A system that provides location-based services, such as guidance and call functioning, by determining location of inpatients and outpatients
W9. Medical staff location tracking system	A system that provides location-based services, such as emergency paging by determining the location of medical staff
Hospital environments	
E1. Staff environment monitoring system	A monitoring system that monitors the working environmental conditions, such as temperature, humidity, and hazardous substances, in the operating room, transplant ward, intensive care unit, and ward
E2. Ward instruments/equipment condition monitoring system	A system that monitors instruments/equipment condition, such as the temperature of refrigerators and freezers that store blood and other products
E3. Real-time asset tracking system	A system that provides asset location and inventory management services by attaching networkable sensors to hospital assets, such as medical equipment and wheel chairs
E4. Smart wireless lighting system	Energy-saving and patient fall prevention through wireless functions, automatic control functions, and motion detection functions, of patient room lighting

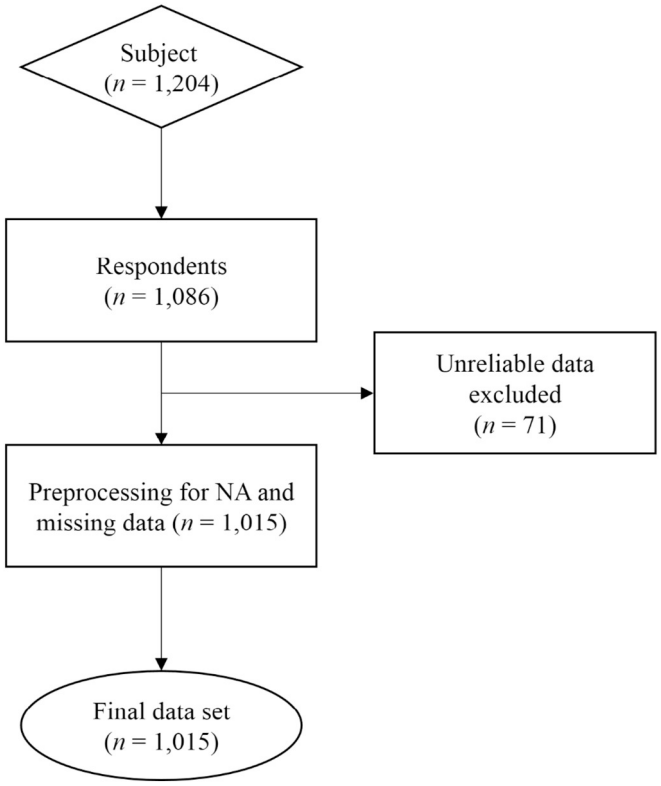

Fig. 1. Block diagram of data preprocessing flow.

3. Results

3.1. Respondent characteristics

A total of 1086 (90.2%) nurses responded. Of these respondents, the 71 respondents that marked the same answer throughout the entire IoT service items were removed as their data was unreliable data; thus, 1015 responses were retained. The demographic characteristics of the 1015 respondents are shown in Table 2. A total of three categorizations were possible. First, distribution by department was the highest for the ward (52.3%, 531), followed by the operating room (19.5%, 198), the intensive care unit (ICU; 17.0%, 173), the emergency room (6.2%, 63), the outpatient (3.1%, 31), the kidney dialysis (1.3%, 13), and the nursing home (0.6%, 6). In addition, distribution by nursing experience was divided into total nursing career and tenure at the current institution. The distribution according to tenure at the current institution were < 1 year (7.6%, 77), 1–5 years (62.8%, 637), 6–10 years (16.8%, 170), and > 11 years (12.9%, 131). Among these, nurses with 1–5 years of experience showed the highest distribution, with > 60%. Distribution by total nursing career were < 1 year (6.9%, 70), 1–5 years

Table 2
Demographic information of survey participants (n = 1086).

Characteristic	Respondents, n (%)	
Department		
Wards	*531*	(52.3)
Intensive care unit	*173*	(17.0)
Emergency room	*63*	(6.2)
Operating room	*198*	(19.5)
Outpatient	*31*	(3.1)
Nursing home	*6*	(0.6)
Kidney dialysis room	*13*	(1.3)
Tenure at current institution		
< 1 year	*77*	(7.6)
1–5 years	*637*	(62.8)
6–10 years	*170*	(16.8)
> 11 years	*131*	(12.9)
Total nursing career		
< 1 year	*70*	(6.9)
1–5 years	*477*	(47.0)
6–10 years	*318*	(31.3)
> 11 years	*150*	(14.8)

Table 3
Summary of descriptive statistics on IoT service demand of all nurses.

Service items	Mean	SD	Rank
Patient safety			
S1. Fall prediction and alarm system	5.69	1.29	6
S2. Pressure ulcer monitoring and management system	5.74	1.15	4
Work efficiency			
W1. Smart Infusion injector	5.62	1.44	9
W2. Continuous vital sign monitoring system	5.97	1.12	2
W3. Smart patient transportation system	5.50	1.15	11
W4. Hygienic hand disinfection system to prevent bacterial infection	5.36	1.23	13
W5. Rehabilitation management system	5.13	1.10	14
W6. Vital sign measuring device interface system	6.15	0.93	1
W7. Medication monitoring services	5.68	1.05	7
W8. Real-time patient location tracking system	5.50	1.27	12
W9. Medical staff location tracking system	5.03	1.52	15
Medical environment			
E1. Staff environment monitoring system	5.76	1.05	3
E2. Ward instruments/equipment condition monitoring system	5.73	1.06	5
E3. Real-time asset tracking system	5.63	1.12	9
E4. Smart wireless lighting system	5.60	1.13	10

(47.0%, 477), 6–10 years (31.3%, 318), and > 11 years (14.8%, 150). Again, the distribution was the highest for nurses in the 1–5 years range at 47%.

3.2. Total demand survey results

The survey results (shown in Table 3) showed that five out of seven points for all items were obtained, which indicates high demand for all services. Specifically, "W6. Vital sign device interface system" showed the highest demand, with a score of 6.15 points on average. This was followed by "W2. Continuous vital sign monitoring system" (5.97) and "E1. Worker environmental monitoring system" (5.76), both of which showed high demand. Conversely, "W4. Hand disinfection system" (5.36), "W5. Rehabilitation management system" (5.13), and "W9. Medical staff location tracking system" (5.03), showed a relatively lower demand.

3.3. Difference between ward and non-ward departments

Analysis of differences in demand for each IoT service item between ward and non-ward departments revealed statistically significant differences in seven services (items W2, W3, W4, W6, W8, W9, E1; Table 4). As seen in the entire demand distribution, both ward and non-ward department groups showed the highest demand for items W2 (continuous vital sign monitoring) and W6 (vital sign device interface). However, there were slight differences for the other items. For individuals working in wards, the highest demand following items W2 and W6, were items S2, W7, and E2 (pressure ulcer monitoring and management system, medication monitoring system, and ward instrument/equipment condition monitoring, respectively). For individuals in the non-ward departments, the highest demand following W2 and W6 was seen for items E1, E2, and S2 (worker environmental monitoring system, ward instrument/equipment condition monitoring, and pressure ulcer monitoring and management system, respectively). When examining the items that showed statistically significant differences between ward and non-ward departments, wards showed a higher demand for W2, W6, and W8 (continuous vital sign monitoring, vital sign device interface, and patient location tracking), while non-ward departments showed higher demand for W3, W4, W9, E1 (smart patient transportation, hand disinfection, medical staff location tracking, and worker environmental monitoring). In other words, while a high demand was observed for items related to patient care in wards, given that there are many situations of long-term patient hospitalization, non-ward departments showed a high demand for items to improve work efficiency, such as improving work speed and simplifying unnecessary tasks. It was confirmed from item classification that wards considered these items from the perspective of patient safety, while non-ward departments considered them from the perspective of work efficiency.

3.4. Differences in nursing experience

Table 4 shows the difference in demand for each IoT service item for two groups, which were determined by dividing the total nursing career into ≤5 and > 5 years. As seen in the demand distribution of all nurses, both the ≤5 and the > 5 year groups showed high scores in "W2. Continuous vital sign monitoring system", "W6. Vital sign device interface system," and "E1. Worker environmental monitoring system." Additionally, examination of the differences between the two groups revealed that demand was significantly higher for nurses with more experience than for nurses with less experience in all items, except for "W1. Smart infusion pump." Specifically, high demand was seen for item "S1. Fall prediction system" along with items W2, W6, and E1 in the > 5 years group.

3.5. Subjective opinions

A total of 33 subjective opinions items were observed. Of these opinions, 24 items were excluded as being unrelated to IoT services, resulting in nine total IoT service items that were classified according to categories, and are shown in Table 5. In the patient safety category, suggestions such as an "alarm for fluid line disconnection risk," "remote on-off system for fluid line alarm," and "patient pressure ulcer monitoring and body repositioning system" were suggested.

In the medical environment category, there were opinions related to hospital asset management, such as "location tracking system for expensive instruments in the operating room," "management system for expensive medical supplies in the operating room," "management system for various sample tubes and medical supplies management system," and "a remote power control system for astral lamps, room lights, and CO_2 units."

In the work efficiency category, opinions that simplify the current nursing work process, such as "medicine vending machine," from which patients directly receive the medicine prescribed by the doctor, rather than nurses providing them, "automatic intake and excretion calculation system for bedridden patients," and "implantable biomedical instrumentation devices and linkage system" were proposed.

4. Discussion

A high overall demand for hospital IoT services was found in the present study. Even though many vendors are developing products using proprietary IoT technology, there are many cases in which these products cannot be used, as they are unrelated to the actual needs within the medical field. In addition, there has been almost no research conducted to determine the overall demand for IoT technology in hospitals. Accordingly, the present study aimed to ascertain the actual needs of hospitals, by conducting a survey of nurses currently working at a tertiary general university hospital, on the demand for specific IoT technology.

Overall, the demand for IoT services of the entire hospital was high, and the highest IoT service demand was observed for "W6. Vital sign device interface system" and "W2. Continuous vital sign monitoring system." The above systems track patient vital signs or bio-signal data in real time, and remotely transmit the information, resulting in a rapid response in cases where patients experience abnormal health conditions. In other words, it can be considered that there is a high need for

Table 4
Difference in hospital IoT service demands by the department and career length.

	Ward	Non-Ward		≤5 years	> 5 years	
	Mean		*p*-Value	Mean		*p*-Value
Patient safety improvement						
S1. Fall system	5.68	5.70	0.7592	5.47	5.95	< 0.0001***
S2. Pressure ulcer monitoring and management system	5.74	5.74	0.9082	5.59	5.92	< 0.0001***
Work efficiency improvement						
W1. Smart Infusion pump	5.60	5.64	0.5987	5.59	5.65	0.5162
W2. Continuous vital sign monitoring system	6.04	5.89	0.0346*	5.87	6.08	0.0029**
W3. Smart patient transportation system	5.43	5.58	0.0292*	5.34	5.69	< 0.0001***
W4. hand disinfection system to prevent bacterial infection	5.23	5.50	0.0006***	5.16	5.59	< 0.0001***
W5. Rehabilitation management system	5.19	5.06	0.0604	4.98	5.30	< 0.0001***
W6. Vital sign measuring device interface system	6.25	6.04	0.0002***	6.07	6.25	0.0014**
W7. Medication monitoring services	5.72	5.64	0.2210	5.60	5.78	0.0053**
W8. Real-time patient location tracking system	5.62	5.37	0.0021**	5.33	5.70	< 0.0001***
W9. Medical staff location tracking system	4.94	5.13	0.0400*	4.81	5.29	< 0.0001***
Medical environment improvement						
E1. Staff environment monitoring system	5.66	5.87	0.0008***	5.59	5.96	< 0.0001***
E2. Ward instruments/equipment condition monitoring system	5.69	5.77	0.1802	5.56	5.93	< 0.0001***
E3. Real-time asset tracking system	5.63	5.64	0.8271	5.43	5.87	< 0.0001***
E4. Smart wireless lighting system	5.63	5.57	0.3326	5.42	5.81	< 0.0001***

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

reducing the workload of nurses, who are required to frequently check for patient stability so that they can quickly respond to changes in patient condition.

During a hospital stay, vital signs of patients are measured. This responsibility falls primarily on nurses, who are required check vital signs every hour or more, depending on the condition of the patient. The vital signs are currently recorded by hand at most medical facilities. In this process, occasional data losses or input errors occur. Integration of IoT technology into vital sign collection, which is one of the most fundamental tasks performed by nurses, can provide a stable service that reduces workload, and allows for rapid response to patient health changes. A previous study has shown the usefulness of this type of 24-hour remote health monitoring, with outcomes such as improved quality of care for patients, reduced number of nurses, and a decrease in the length of hospital stay (Li, Da Xu, & Wang, 2013; Metcalf et al., 2016).

In addition, services that address pressure ulcers (PU) and falls have a high demand from the patient perspective. Hence, they are important nursing management items that are directly related to patient safety (Bauer et al., 2016). Therefore, many studies are being conducted to examine these issues. PU management systems have been proposed in the form of a platform to map the amount of sustained pressure over the entire body of a patient. This technology ensures improvements in patient safety by automatically correcting the patient's posture using actuators when the PU risk is high, according to a specific algorithm. In addition, the iStoppFalls application, which is an ICT-based exercise recommendation application for fall prevention, has the advantage of managing patients even after they are discharged from the hospital. Previous research on this system has demonstrated a significant reduction in the rate of falls (Gschwind et al., 2015). As the above-mentioned items can lead to death in some cases, it is necessary to recognize and prevent them in advance, especially if they occur because of a combination of patient condition and carelessness. However, currently, such occurrences can only be reduced through prevention education for patients. There are no systems that can predict the occurrence of these issues, and alert the patients in advance. Therefore, a prediction system, built using IoT technology, will play a large role in preventing PUs and falls.

Because hospital IoT systems generate a seamlessly continuous stream sensor data, studying analytics algorithms that combine stream big data with the latest artificial intelligence technology to accurately predict the varying risk conditions of patients will become an important research topic in the future. In addition, because the hospital IoT solution and artificial intelligence technology can change the workflow to a preventive-focused nursing practice, studying the IoT service design will also be necessary to apply and develop these technologies within the nursing workflow by user search for nurses.

The differences in the demand for IoT services were observed considering the amount of total nursing experience. A significantly higher demand was observed in the > 5-year group for all items, except one,

Table 5
Other subjective opinions on hospital IoT services.

Classification	Other opinions	Department
Patient safety	Alarm for fluid line disconnection risk, remote alarm on-off system (remote controller)	ICU
	Patient pressure ulcer monitoring and body repositioning system	Ward
Work efficiency	Automatic intake and excretion calculation system	Ward
	Medicine vending machine	Ward
	Implantable biometric devices and linkage	Ward
Hospital environment	A system for expiration date management of various sample tubes and medical supplies, and automatic insurance fee input (registration) management	Ward
	Location tracking system for expensive instruments in the operating room	OR
	Management system for expensive medical supplies in the operating room	OR
	A remote power control system for astral lamps, room lights, and Co2 units in the operating room	OR

ICU – intensive care unit; OR – operation room.

when compared with the ≤5-year group. This disparity can be attributed to the following reason: even though the frequency of patient falls is low, the total number of falls increases for a longer career; thus, the demand for services addressing this issue would also increase. In addition, nurses with a longer career may believe that falls can be prevented more effectively if IoT technology is used, because of their experience in both pre- and post-digital hospital environments. We believe this will help introduce IoT services if future research can reveal the differences in perception according to the nursing experience by focus group overview research before introducing IoT services. After the introduction of IoT service, we will be able to investigate whether there are differences in the acceptance of technologies based on the nursing experience.

The primary limitation of this study is generalization. The findings cannot necessarily be considered to represent the opinions of nurses in hospitals worldwide, because the research was conducted at a single hospital in South Korea. In addition, the findings cannot be expressed as an insight for IoT applications for the entire hospital, because the survey was only conducted with nurses. Accordingly, a survey of IoT demand in multiple hospitals, which includes input from patients and all medical personnel, including doctors, should be conducted. Nevertheless, the results of the present study are significant in determining the demand for IoT services in the hospital, based on a high level of understanding and experience in ICT technology. This was established by a survey on nurses, who were acquainted with digital technology, and were working in a hospital environment.

Another limitation of the present study is that the discrimination was not sufficiently considered when establishing the IoT service items. Nurses working in a clinical setting answered positively with the expectation that it would be better if a specific IoT technology were applied, even if they considered it less important. In addition, this study did not measure which IoT services were already in operation or not in use in various settings; this could impact a nurse's perception of need. This should also be addressed in a future study.

5. Conclusion

This study examined the demand for various IoT-based services in a tertiary university hospital through a survey of nurses. Opportunities for IoT technologies were found in various areas that improve patient safety and the efficiency of medical staff and hospital environments. In the future, however, to successfully introduce IoT services in a hospital, challenges on big data management and analytics for continuous stream data from emerging devices should be investigated along with the latest artificial intelligence technology. A user research to properly integrate and optimize various predictive algorithms through big data analytics into nursing workflows will also have to be considered as a future research.

Conflict of interest

The authors declare that they have no conflict of interest.

Role of funding source

This work was supported by the Information Technology Research and Development (IT R&D) Program of Seoul National University Bundang Hospital, South Korea; SK Telecom.

Acknowledgements

SK and HB participated in the design of the study, drafted the manuscript, and contributed to the analysis and interpretation of data. HH and EJ substantially contributed to the conception and design, and also to data acquisition. SY critically revised the manuscript. All authors read and approved the final manuscript.

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