International Journal of Nursing Studies 69 (2017) 78–90

Contents lists available at ScienceDirect

International Journal of Nursing Studies

journal homepage: www.elsevier.com/ijns

Review

The Internet of Things for basic nursing care—A scoping review

Riitta Mieronkoski[a,*], Iman Azimi[b], Amir M. Rahmani[c,d], Riku Aantaa[e,f], Virpi Terävä[a], Pasi Liljeberg[b], Sanna Salanterä[a,f]

[a] Department of Nursing Science, University of Turku, FI-20014 Turun Yliopisto, Finland
[b] Department of Information Technology, University of Turku, FI-20014 Turun Yliopisto, Finland
[c] Department of Computer Science, University of California Irvine, USA
[d] Institute of Computer Technology, TU, Wien, Austria
[e] Department of Anaesthesiology, Intensive Care, Emergency Care and Pain Medicine, 20014, University of Turku, Finland
[f] Turku University Hospital, 20521, Turku, Finland

ARTICLE INFO

Article history:
Received 7 July 2016
Received in revised form 29 December 2016
Accepted 23 January 2017

Keywords:
Basic nursing care
Hospitals
Internet of Things
Nursing informatics

ABSTRACT

Background: The novel technology of the Internet of Things (IoT) connects objects to the Internet and its most advanced applications refine obtained data for the user. We propose that Internet of Things technology can be used to promote basic nursing care in the hospital environment by improving the quality of care and patient safety.
Objectives: To introduce the concept of Internet of Things to nursing audience by exploring the state of the art of Internet of Things based technology for basic nursing care in the hospital environment.
Data sources and review methods: Scoping review methodology following Arksey & O'Malley's stages from one to five were used to explore the extent, range, and nature of current literature. We searched eight databases using predefined search terms. A total of 5030 retrievals were found which were screened for duplications and relevancy to the study topic. 265 papers were chosen for closer screening of the abstracts and 93 for full text evaluation. 62 papers were selected for the review. The constructs of the papers, the Internet of Things based innovations and the themes of basic nursing care in hospital environment were identified.
Results: Most of the papers included in the review were peer-reviewed proceedings of technological conferences or articles published in technological journals. The Internet of Things based innovations were presented in methodology papers or tested in case studies and usability assessments. Innovations were identified in several topics in four basic nursing care activities: comprehensive assessment, periodical clinical reassessment, activities of daily living and care management.
Conclusions: Internet of Things technology is providing innovations for the use of basic nursing care although the innovations are emerging and still in early stages. Internet of things is yet vaguely adopted in nursing. The possibilities of the Internet of Things are not yet exploited as well as they could. Nursing science might benefit from deeper involvement in engineering research in the area of health.

What is already known about the topic?

- The Internet of Things has emerged due to the recent technological revolution in developing low-cost, miniaturized, and energy-efficient wireless sensor devices, ubiquitous Internet connectivity and advances in cloud computing.
- Internet of Things is a novel paradigm where objects with unique identities can be integrated into an information network to provide intelligent services for remote monitoring of health and wellbeing.
- There are several opinion papers that highlight the possibilities of Internet of Things in the field of healthcare. However, the nursing care is rarely mentioned in these writings.

What this paper adds

- Numerous Internet of Things based solutions are proposed for basic nursing care in hospital environment but the innovations are still only emerging and tested in case studies and usability assessments.

* Corresponding author.
E-mail address: ritemi@utu.fi (R. Mieronkoski).

http://dx.doi.org/10.1016/j.ijnurstu.2017.01.009
0020-7489/

- The concept of Internet of Things is at present mainly used in technological field and is not yet adopted to nursing research.
- Nursing could benefit from deeper understanding of concepts developed and used by other disciplines.

1. Introduction

1.1. Background

Modern technology can be exploited to overcome some of the challenges of basic nursing care in hospitals. Basic nursing care is influenced by nursing staff shortness, work environment issues, impractical physical care environments and difficulties in identifying the patients' needs (Jangland et al., 2016; Lasater and Mchugh, 2016; West et al., 2005). On one hand, there is a need to reinforce nursing procedures concerning requirements for basic nursing care, and on the other hand, traditional standalone equipment in hospitals can be upgraded to collect, transfer and process the data efficiently and automatically. As a novel multidisciplinary concept, Internet of Things (IoT) can connect physical and virtual things and provides advanced solutions to combine and use information from heterogeneous sources (Atzori et al., 2010).

The most promising application of advanced technologies in nursing is their ability to support patient safety and quality of care. To ensure quality, safety and value in healthcare, clinical decisions need to be supported by accurate, timely, and up-to-date clinical information (Institute of Medicine, 2011). Nursing informatics, defined as "science and practice (that) integrates nursing, its information and knowledge, with management of information and communication technologies to promote the health of people, families, and communities worldwide." (IMIA Special Interest Group on Nursing Informatics, 2009) incorporates technologies such as tele-healthcare applications, electronic health records, automated data mining and big data technologies.

In addition to the informatics and software applications, sensors and embedded systems development can have a significant role in nursing care. Medical equipment, wearable sensors, and implantable devices are examples which are proposed to assist nursing in hospitals (Cao et al., 2012; Fraile et al., 2010). Proposed software and hardware entities can provide recognizable improvements in basic nursing care although there is a missing part to provide connectivity between different parts and to equip nursing with a comprehensive intelligent system. Internet of Things is able to fill this gap and have an important role in this domain although it may partially cover and overlap the aforementioned entities (i.e., health informatics and wearable devices).

1.2. Basic nursing care

Already the early nursing theorists Virginia Henderson and Florence Nightingale worked to define the role and actions of nurses. The common definition for nursing actions for the best patient outcomes has been a topic of debate. However, it is agreed that basic nursing care, also known as the "fundamentals of care" refers to the essential elements of care that are required by every patient regardless of their clinical condition (Kitson et al., 2010). All basic nursing care actions share three main points: the caring actions are needed by all patients; they are not related to a specific health problem; and they are not directed to a specific health goal (Englebright et al., 2014). In this review, we employ Englebright's et al. (2014) definition for the basic nursing care. The basic caring actions are divided into four activities. The first activity is **comprehensive assessment** including baseline assessment conducted after patient admission to the hospital. **Periodical clinical reassessment** is the second activity that includes regular assessments throughout the hospitalization. The third one as **activities of daily living** consists of personal hygiene, meals and activities. Finally, the last one is **care management** including coordination of care team activities.

1.3. Internet of Things

The Internet of things is an advanced network of objects (i.e. things) with unique identities, each of which interconnects or connects to a remote server to provide more efficient services (Atzori et al., 2010). The amalgamation of various fields such as data acquisition, communication and data analysis offers continues connectivity for the objects to collect, exchange and combine data. Consequently, it is possible to achieve inclusive knowledge about the entire system.

According to the specification and functionality of an Internet of Things based system to collect, transmit and process healthcare related data, the architecture of the system can be specified in three layers, the perception layer, the gateway layer and the cloud layer (Al-Fuqaha et al., 2015; Touati and Tabish, 2013). The perception layer (Fig. 1) is defined to capture comprehensive

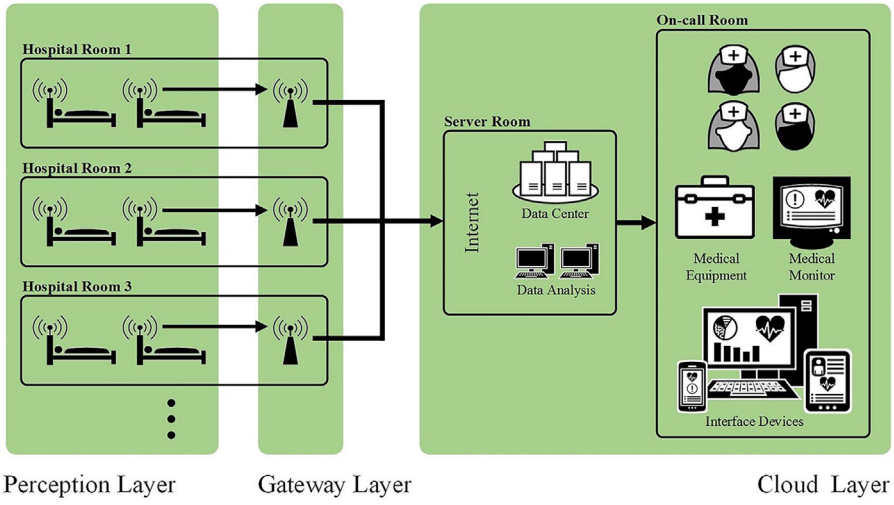

Fig. 1. The architecture of Internet of Things based healthcare systems in a hospital.

health and environmental data using heterogeneous sensors. This layer is the lowest layer and has the most contact with the studied or monitored entities including patients, nurses and objects. Medical devices (e.g. heart rate monitor, pulse oximeter and electrocardiography device), activity and localization devices (e.g. accelerometer and bed presence) and emergency buttons are items that stand in this layer to collect related data.

The gateway layer (Fig. 1) is allocated to connect the sensors to a remote server. The captured data are transmitted via wireless protocols such as Bluetooth and Wi-Fi to a local gateway. The gateway provides continuous connectivity for the sensors or other perception layer inputs and manages interruptions. Then, it transfers the gathered data to a remote or local server called a cloud for further analysis. Recently, the concept of bringing a processing paradigm entitled as fog computing to the vicinity of the sensors was proposed (Bonomi et al., 2014). This smart gateway is defined to improve the functionality of the system (e.g. decreasing latency and increasing consistency in case of the unavailability of an Internet connection) (Rahmani et al., 2015).

The cloud layer (Fig. 1) is the third and most remote section of the Internet of Things system. All the acquired data are transferred to the cloud via the gateway. The cloud can be obtained either via Internet connected remote servers provided by third parties or by local servers connected to local hospital information system (HIS) to provide more protective privacy and security. Using high processing power in the cloud platform, data analytics, data fusion and analysis are used to further process and develop the data (server room in the figure). The results of data processing can then be used in patient care. Real-time/offline data visualization of patients and their surroundings are available via monitors and interface devices (e.g. smartphones and tablets). The system could also enable healthcare personnel for instant responses, feedback and setting adjustments via an administration control panel. Moreover, providing more comprehensive services, such data processing could send feedback to devices used in nursing and patient care to update their configurations automatically.

The cloud layer (Fig. 1) is the third and most remote section of the Internet of Things system. All the acquired data are transferred to the cloud from the gateway. The cloud can be provided in two approaches. The first approach is obtained via Internet connected remote servers provided by third parties. The second one is achieved by local servers connected to local hospital information system (HIS) to provide more protective privacy and security. Using the high processing power in the cloud platform, data analytics, data fusion and reasoning are implemented to obtain new knowledge and results regarding incoming and stored data (server room in the figure). Afterward, the related obtained results along with collected data are provided for nurses. Real-time/offline data visualization of patients and their surroundings are available via monitors and interface devices (e.g. smartphones and tablets). The system could also enable healthcare personnel for instant responses, feedback and setting adjustments via an administration control panel. Moreover, providing more comprehensive services, it could send feedback to nursing equipment and update their configurations automatically according to the patients' and professionals' requirements.

Consequently, the Internet of Things enabled system is a paradigm that consists of embedded technologies of sensing, connecting and processing to bring advanced applications and services anyplace and anytime for different fields, especially in healthcare and nursing. Therefore, the usage of Internet of Things based systems as the state of the art in health sciences and basic nursing care, can influence improvements in the quality and safety of patient care.

1.4. Study objective

In this scoping review we introduce the concept of Internet of Things to nursing by exploring the current literature to identify the extent, range, and nature of the literature on the Internet of Things in basic nursing care in the hospital environment. In addition, we introduce recent innovations utilizing the Internet of Things concept in basic nursing care in the hospital environment.

2. Methods

We used a scoping review methodology, which can be used for mapping the size and scope of research on a topic, synthesizing findings, and identifying gaps in the literature (Grant and Booth, 2009). This is an appropriate approach given that we expect to find papers with diverse methodologies and evidence only emerging in

Table 1
The search terms and databases.

Database	Search terms	Number of papers found
Pubmed	"Internet of Things" OR "IoT"	429
	"Nursing informatics"	1096
Cinalh	"Internet of Things" OR "IoT"	29
	"Nursing informatics"	965
Scopus	"Internet of Things" OR "IoT"	251
	"Nursing informatics"	1148
Google Scholar	("Internet of Things" OR "IoT") AND ("Nursing" OR "Hospital")	32
ScienceDirect	("Internet of Things" OR "IoT") AND ("Nursing" OR "Hospital")	15
SpringerLink	("Internet of Things" OR "IoT") AND ("Nursing" OR "Hospital")	7
IEEE xplore	("Internet of Things" OR "IoT") AND ("Nursing" OR "Hospital")	77
	"Hygiene" AND ("Nursing" OR "Hospital")	26
	"Incontinence" AND ("Nursing" OR "Hospital")	27
	"Sleep" AND ("Nursing" OR "Hospital")	247
	"Respiration" AND ("Nursing" OR "Hospital")	194
	"Fall" AND ("Nursing" OR "Hospital")	437
ACM DL	("Internet of Things" OR "IoT") AND ("Nursing" OR "Hospital")	8
	"Hygiene" AND ("Nursing" OR "Hospital")	12
	"Incontinence" AND ("Nursing" OR "Hospital")	1
	"Sleep" AND ("Nursing" OR "Hospital")	6
	"Respiration" AND ("Nursing" OR "hospital")	0
	"Fall" AND ("Nursing" OR "hospital")	23

Table 2
Summary of the analysis.

Activity	Topics	Articles	IoT Layers			Data Collection			Target Group			Design				Paper Type		Year	Country
			Perception	Gateway	Cloud	Patient	Nurse	Environment	Children	Adults	Elderly	Discussion	Empirical/ Methodology	Case study	Usability	Journal	Proceedings		
Periodical clinical reassessment	Vital signs	Hart et al. (2010)	√	–	–	√	–	–	–	√	√	–	–	√	–	–	√	2010	CAN
		Hu et al. (2010)	√	√	–	√	–	–	–	√	√	–	√	–	–	–	√	2010	USA
		Andre et al. (2010)	√	√	–	√	–	–	–	√	√	–	–	√	–	–	√	2010	BEL
		Zito et al. (2011)	√	√	–	√	–	–	√	√	√	–	–	√	–	√	–	2011	IRL, ITA
		Donnelly et al. (2012)	√	–	–	√	–	–	–	√	√	–	–	–	√	–	√	2012	GBR
		Fang et al. (2012)	√	√	–	√	–	–	–	√	√	–	√	–	–	–	√	2012	CHN
		Huang et al. (2013)	√	√	–	√	–	–	–	–	√	–	–	–	√	–	√	2013	TWN
		Mamun et al. (2014)	√	√	√	√	–	–	–	√	√	–	–	–	√	–	√	2014	FIJ,BAN, IRL
		Liu and Hsu (2013)	√	–	√	√	–	–	–	–	√	–	–	–	√	–	√	2014	TWN
		Shi-Lin et al. (2015)	–	√	–	√	–	–	–	√	√	–	√	–	–	√	–	2015	CHN
		Liu et al. (2015)	√	–	√	√	–	–	–	–	√	–	–	–	√	√	–	2015	TWN
		Güder et al. (2016)	√	–	√	√	–	–	–	√	√	–	–	√	–	√	–	2016	USA
		Michard (2016)	√	√	√	√	–	–	–	√	–	–	–	–	–	√	–	2016	SUI
	Neonatal monitoring	Nachabe et al. (2015)	√	–	√	√	–	–	√	–	–	–	–	–	√	–	√	2015	FRA
		Huang et al. (2015)	√	–	–	√	–	–	√	–	–	–	–	√	–	–	√	2015	CHN, USA
	Pain	Martinez-Balleste et al. (2014)	√	–	√	√	–	–	√	–	–	–	√	–	–	–	√	2014	ESP
	Medication	Jara et al. (2010a)	√	–	√	√	–	√	–	√	√	–	√	–	–	–	√	2010	ESP, GBR
		Jara et al. (2010b)	√	–	√	√	–	√	–	√	√	–	√	–	–	–	√	2010	ESP
		Laranjo et al. (2012)	–	–	√	–	–	√	–	√	√	–	–	√	–	√	–	2012	PRT
		Jara et al. (2014)	√	√	√	√	–	√	–	√	√	–	√	–	–	√	–	2014	ESP
		Zhang et al. (2015)	√	–	√	–	–	√	–	√	√	–	√	–	–	–	√	2015	CHN
		Hua-li et al. (2015)	–	–	√	–	–	√	–	–	–	–	√	–	–	–	√	2015	CHN
Activities of daily living	Sleep detection	Biswas et al. (2010)	–	–	√	√	–	–	–	–	√	–	–	–	√	–	√	2010	SGP
		Rofouei et al. (2011)	√	–	√	√	–	–	–	√	–	–	–	√	–	–	√	2011	USA
		Liu and Hsu (2013)[a]	√	–	√	√	–	–	–	–	√	–	–	–	√	–	√	2013	TWN
		Rotariu et al. (2013)	√	√	–	√	–	–	–	√	√	–	–	√	–	–	√	2013	USA
		Zhu et al. (2015)	√	–	√	√	–	–	–	–	√	–	–	–	√	–	√	2014	JPN
		Liu et al. (2015)[a]	√	–	√	√	–	–	–	–	√	–	–	–	√	√	–	2015	TWN
	Secretion	Ang et al. (2008)	–	√	√	√	–	–	√	√	√	–	–	√	–	–	√	2008	MYS

Table 2 (*Continued*)

Activity	Topics	Articles	IoT Layers			Data Collection			Target Group			Design				Paper Type		Year	Country
			Perception	Gateway	Cloud	Patient	Nurse	Environment	Children	Adults	Elderly	Discussion	Empirical/ Methodology	Case study	Usability	Journal	Proceedings		
		Wai et al. (2010a)	√	√	√	√	–	–	√	√	√	–	–	–	√	–	√	2010	SGP, GBR, FRA
		Wai et al. (2010b)	√	√	√	√	–	–	√	√	√	–	–	–	√	–	√	2010	SGP, GBR, FRA
		Yamada et al. (2010)	√	–	–	√	–	–	√	√	√	–	–	√	–	–	√	2010	JPN
		Wai et al. (2011)	–	√	√	√	–	–	√	√	√	–	√	–	–	–	√	2011	SGP, GBR
		Nilsson et al. (2011)	√	–	–	√	–	–	√	√	√	–	–	√	–	–	√	2011	SWE
		Fuketa et al. (2014)	√	–	–	√	–	–	√	√	√	–	√	–	–	–	√	2014	JPN
	Fall detection	Huang et al. (2009)	–	√	–	√	–	–	–	–	√	–	√	–	–	–	√	2009	TWN
		Rawashdeh et al. (2012)	–	–	√	√	–	–	–	–	√	–	–	–	√	–	√	2012	USA
		Visvanathan et al. (2012)	–	√	√	√	–	–	–	–	√	–	–	√	–	–	√	2012	AUS
		Chou et al. (2013)	√	–	–	√	–	–	–	–	√	–	–	√	–	–	√	2013	TWN
		Enayati et al. (2014)	–	–	√	√	–	–	–	–	√	–	√	–	–	–	√	2014	USA
		Catarinucci et al. (2014)	–	√	√	√	√	–	–	–	√	–	–	√	–	–	√	2014	ITA
		Schwarzmeier et al. (2014)	√	–	–	√	–	–	–	–	√	–	√	–	–	–	√	2014	DEU
		Sriborrirux et al. (2014)	√	–	√	√	–	–	–	–	√	–	–	√	–	–	√	2014	THA
		Mamun et al. (2014)[a]	√	√	√	√	√	√	–	√	√	–	–	–	√	–	√	2014	FIJ, BGD, IRL
		Catarinucci et al. (2015)	–	√	√	√	√	√	–	–	√	–	–	√	–	√	–	2015	ITA
	Activity monitoring	Hu et al., (2010)[a]	√	√	–	√	–	–	–	√	√	–	√	–	–	–	√	2010	USA
		Schwarzmeier et al., (2014)[*]	√	–	–	√	–	–	–	–	√	–	√	–	–	–	√	2014	DEU
		Sriborrirux et al. (2014)[*]	√	–	√	√	–	–	–	–	√	–	–	√	–	–	√	2014	THA
Care management	Decision making support system	Bruballa et al. (2014)	–	–	√	√	√	√	–	–	–	–	–	√	–	–	√	2014	ESP
		Manate et al. (2014)	–	–	√	√	√	√	–	–	–	–	√	–	–	–	√	2014	ROU, GBR
		Boyi et al. (2014)	–	–	√	√	√	√	–	–	–	–	–	√	–	√	–	2014	CHN
		Abinaya and Swathika (2015)	–	–	√	√	√	–	–	–	–	–	√	–	–	√	–	2015	IND
		Aishwarya et al. (2015)	–	–	√	√	–	√	–	–	–	–	√	–	–	√	–	2015	IND
		Michard (2016)[a]	√	√	√	√	√	√	–	–	–	–	√	–	–	√	–	2016	SUI
	Tracking (personnel, patients, devices)	Alharbe et al. (2013)	–	√	√	√	√	√	–	–	–	–	√	–	–	–	√	2013	SAU, GBR
		Catarinucci et al. (2015)[a]	–	√	√	√	√	√	–	–	√	–	–	√	–	√	–	2015	ITA

		Carvalho et al. (2015)	√	–	–	√	√	√	–	–	–	–	–	√	–	–	√	2015	BRA
	Nurse calling system	Galinato et al. (2015)	–	–	–	√	√	–	–	√	√	–	–	–	√	√	–	2015	USA
		Kanan and Elhassan (2015)	√	√	√	√	√	– –	–	√	√	–	√	–	–	–	√	2015	ARE
		Sharma and Gautam (2015)	√	√	–	√	–	–	–	√	√	–	√	–	–	–	√	2015	IND
Comprehensive assessment	Hygiene	Herman et al. (2009)	–	√	–	–	√	√	–	–	–	–	–	√	–	–	√	2009	USA
		Johnson et al. (2012)	√	–	√	–	√	√	–	–	–	–	–	–	√	√	–	2012	USA
		Meydanci et al. (2013)	–	–	√	–	√	√	–	–	–	–	√	–	–	–	√	2013	TUR
		Asai et al. (2013)	√	–	–	–	–	√	–	–	–	–	–	–	√	–	√	2013	JPN
		Shhedi et al. (2015)	√	–	–	–	√	√	–	–	–	√	–	–	–	–	√	2015	ROU
		Shhedi et al. (2015)	√	–	–	–	√	√	–	–	–	–	√	–	–	–	√	2015	ROU
		Baslyman et al. (2015)	√	–	√	–	√	√	–	–	–	–	–	√	–	√	–	2015	CAN
		Misra et al. (2015)	√	–	–	–	√	√	–	–	–	–	√	–	–	–	√	2015	IND
		Galluzzi et al. (2015)	√	–	√	–	√	√	–	–	–	–	–	–	√	–	√	2015	USA
	Comfort	Vicini et al. (2012)	√	–	–	√	–	–	√	–	–	–	–	–	√	–	√	2012	ITA

[a] The article is also utilized in other sections.

the literature concerning Internet of Things based innovations in basic nursing care settings (Levac et al., 2010). We followed the scoping review guidelines of Arksey and O'Malley (2005) in five stages: 1) identifying the research question 2) identifying relevant studies 3) defining a relevant study selection 4) charting the data and 5) collating, summarizing and reporting the results.

We explored the following questions:

1. How is the Internet of Things used in basic nursing care?
2. What are the benefits of using the Internet of Things in basic nursing care?

2.1. Identifying relevant studies

The literature search was conducted in eight databases: Pubmed, Cinahl, Scopus, ScienceDirect, ACM DL (Association for Computing Machinery Digital Library), IEEE Xplore DL (Institute of Electrical and Electronics Engineers Digital Library), Google Scholar and SpringerLink. The databases were selected to cover the fields of the multidisciplinary research topic. The search was conducted in March and April 2016. Moreover, an additional search in the three nursing databases was conducted in September 2016 to include the wide range of nursing informatics literature to the review. At first all the nursing related databases were searched using a Boolean combination of the terms "Internet of Thing" OR "IoT" and the technological databases were searched for "Internet of Things" AND "Nursing" OR "Hospital". The second search was conducted only in technological databases replacing the term Internet of Things with the chosen basic nursing care terms to find detailed information. These terms were chosen to describe the aspects that are objective and detectable. Because of the novelty of the concept of Internet of Things, no time limit was used in first search. However, the search concerning nursing informatics was limited to the years 2006 to 2016. The review was limited to English language publications. The complete search strategy for each electronic database is listed in Table 1.

2.2. Study selection

The inclusion criteria were 1) a scientific peer-reviewed publication describing an Internet of Things based solution for basic nursing care 2) the Internet of Things solution is used or proposed for hospital environment 3) the term Internet of Things is used in the paper 4) the paper is a clinical study, a review, a commentary, an editorial or a conference proceeding. The exclusion criteria were 1) the paper describes only a technical design's development 2) the Internet of Things solution is used only for patient monitoring outside the hospital environment 3) the Internet of Things solution is only used for self-monitoring 4) the publication is a book, a book chapter, a magazine or a letter.

2.3. Charting the data

Information on authors, their country and publication year were collected. The type of the article and study design were analyzed. The Internet of Things innovations were identified and labelled to describe the basic nursing care topics. The technical development state of the three layers of the Internet of Things based system architecture was identified. Also the main target patient group was specified into children, adults and the elderly, although if no patient group was mentioned in an article, adult patients were chosen. The results of the analysis are collected in Table 2.

3. Results

3.1. Description of process and findings

Of the 5030 articles originally identified, 149 articles were removed as duplicates. The titles were screened and 4615 papers were excluded as non-relevant to the topic. 265 papers were chosen for closer assessment and identified as potentially relevant. 93 full-text articles were assessed for eligibility, and finally 62 were included in the qualitative synthesis (See Fig. 2 for the flow diagram). Despite the large number of articles of the search for the term "nursing informatics", only one article met the inclusion criteria.

The vast majority of the articles were peer-reviewed proceedings of technological conferences. These included descriptions of Internet of Things based innovation methodology or methodology tested in a case study or usability tests in the hospital environment. Only one article was published in a nursing journal, two in medical journals, and all other articles were published in technological journals. The journal articles did not differ from peer-reviewed proceeding papers in study designs. We found no clinical trials with comparisons or randomized designs. The articles were published between the years 2008–2016 and they were from 30 countries across four continents. Most of the Internet of Things solutions were targeted to adult and elderly patients with chronic diseases. Only a few were designed for a pediatric population. The data used in the Internet of Things solutions were collected in most cases from patients and the environment and more rarely from nurses. Most of the innovations proposed were related to vital signs detection and were set under **periodical clinical reassessment** activities of basic nursing care. The other topics in **periodical clinical reassessment** activities were neonatal monitoring, pain management and medication. **Comprehensive assessment activities** included topics of hygiene and comfort. Physical activity, fall detection, sleep, and secretion monitoring were set under **Activities of daily living**. Finally, **care management** activities included topics of decision making support, tracking personnel, patients and devises, and nurse calling system. Some of the topics could have been set under several activities, but only one was selected. The findings are described in Table 2.

3.2. Internet of Things based innovations for basic nursing care in the hospital environment

3.2.1. Periodical clinical reassessment

With Internet of Things-based solutions **vital signs** can be recorded using wireless devices connected to a gateway (Hart et al., 2010; Shi-Lin et al., 2015), body worn wireless sensors (Andre et al., 2010; Donnelly et al., 2012; Huang et al., 2013) or ambient sensors attached on walls or objects (Güder et al., 2016; Mamun et al., 2014; Huang et al., 2015; Zito et al., 2011). Wireless detection systems have the advantage of giving patients real-time dependable and continuous monitoring without causing any inconvenience to patients (Hu et al., 2010). A good example is a cuffless noninvasive measurement of blood pressure using pulse wave transit time as a part of a multifunctional device, containing continuous measurement of seven lead electrocardiography, respiration, temperature, blood pressure, peripheral capillary oxygen saturation, the motion state of a patient in real time (Fang et al., 2012). The heart rate of a patient can also be detected using a wireless ring probe (Huang et al., 2013) or a versatile system which detects electrocardiography, heart rate, respiration waveform and rate, skin temperature and motion with a single wearable sensor (Donnelly et al., 2012). The triggering algorithms are set to alarm for early recognition of patients requiring urgent attention. Some of the innovations have the advantage of detecting both physiological parameters and

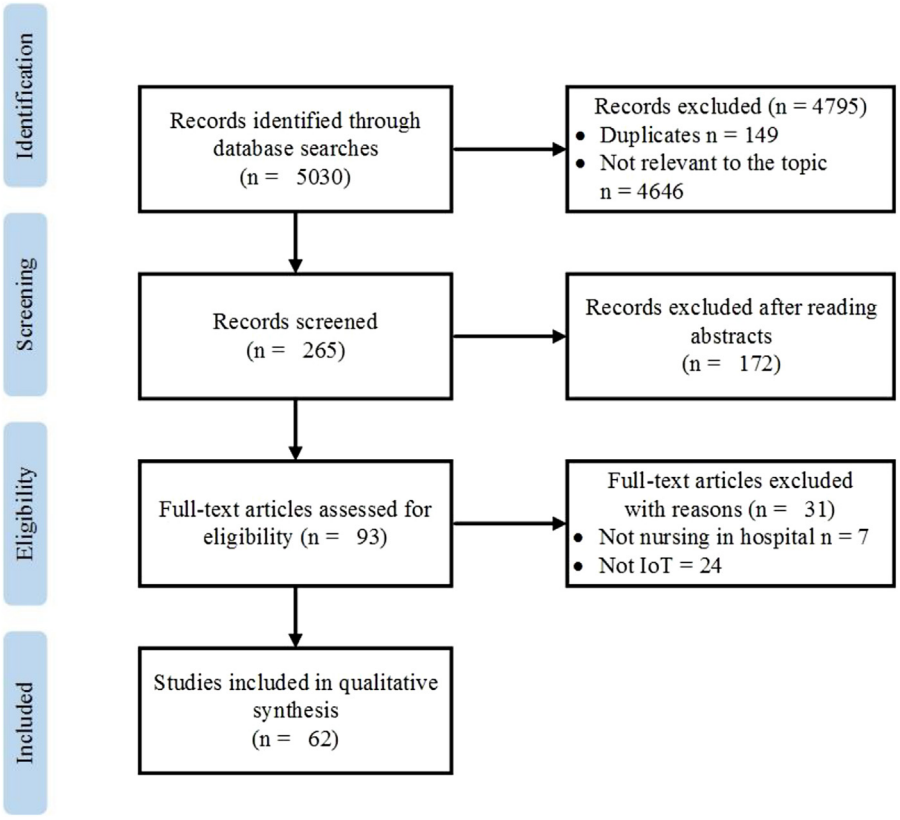

Fig. 2. Flow diagram of literature search modified from PRISMA (Moher et al., 2010).

tracking patients movements using the same hardware (Donnelly et al., 2012; Hu et al., 2010; Mamun et al., 2014).

Several systems for non-invasive and continuous respiration monitoring have been developed both for adults and children. Respiratory rate and pattern can be detected contactless from chest movements, using ultra-wideband technology (Huang et al., 2015; Zito et al., 2011). The sensor can also be connected into a patient's nasal prongs (Andre et al., 2010) or attached into a breathing mask (Güder et al., 2016) to detect respiration through airflow humidity changes. Humidity changes ionic conductivity which can be measured electrically and the data can be further transmitted to a smartphone or tablet computer for post-processing (Güder et al., 2016). An intelligent contact-free sensing pad under the patient on a hospital bed can also measure respiration by recording the changes in the capacitive coupling between the traces of the pad and correlating them to respiration (Hart et al., 2010).

For **neonatal monitoring**, detection of respiration and the possible apnea of an infant can be done by obtaining a breathing signal from an infant's chest vibration. An algorithm is applied to locate the chest of the infant due to possible movement and to set off an alarm in case of apnea (Huang et al., 2015). Also for the use of neonatal intensive care unit nurses, a newborn's physiological parameters, such as heart rate and temperature, and the environmental parameters, such as humidity of the incubator, can be detected via a wireless sensor network (Nachabe et al., 2015). The sensors are connected to a data hub device provided with a software agent for sensed data preprocessing and the server publishes the data into the hospital information system. In addition to physiological parameter detection, Martinez-Balleste et al. (2014) have proposed an automated pain detection system for infants using data acquisition with wearable sensors, video and audio processing. The system automatically analyses the pain or discomfort level of an infant and raises alarm upon predetermined conditions.

Considering **medication** in hospital surroundings, Jara et al. (2014, 2010a,b) introduce a pharmaceutical intelligent information system for drug delivery to mitigate adverse drug reactions. In the system, tags, e.g., Radio Frequency Identification, are provided for each medicine; then, utilizing tag readers, the medicine is detected, and related data is sent to the cloud layer. The related data and the patient profile are stored and the need to inform the healthcare personnel about possible consequences (e.g., allergies) and further actions is considered. In a similar manner, Laranjo et al. (2012) also offer a solution using Radio Frequency Identification tags for identifying hospital entities to implement medication control from the prescription to pharmaceutical drug control. Other systems including an intelligent medicine box (Zhang et al., 2015) and a pharmaceutical logistics and supply chain management system (Hua-li et al., 2015) are proposed to monitor and control patient medication and to implement tracing and supply chain management of medicines in hospitals from purchase to provision and distribution.

3.2.2. Activities of daily living

Sleep detection is in most cases based on vital signs monitoring throughout sleep. Rofouei et al. (2011) have proposed a non-invasive wearable neck-cuff sleep detection tool for the early diagnosis of sleep apnea which provides a summary of possible apnea events and a quantification of the severity of sleep apnea. Also a long term detection of patients' skin temperature using a wireless sensor system provides information of the circadian rhythm of patients (Rotariu et al., 2013). For versatile sleep/off sleep monitoring, basic accelerometer sensors and motion-sensing mattresses can be used to collect information about the sleep activity patterns of patients. Biswas et al. (2010) have successfully

done actigraphy based on body-worn accelerometer sensors to remotely monitor and study the sleep-wake cycle of patients at a nursing home. A soft motion sensing mattress or sensors located under a mattress can also collect data about physical activities in a bed (Liu et al., 2015; Zhu et al., 2015; Liu and Hsu, 2013). The corresponding digital signals collected by the mattress sensors are classified into different events such as on/off bed, sleep posture, pressure distribution, movement counts, respiration and heart rate (Liu and Hsu, 2013).

Considering Internet of Things related systems, Ang et al. (2008) have introduced a wireless intelligent incontinence management system to monitor **secretion** and to transmit wetness data to a central system and then further to alert the nurses via SMS. Similarly, Wai et al. (2010a,b) present a system comprising three Internet of Things layers. The first layer is defined to sense diaper wetness. The second layer is specified to provide a wireless connection for the sensors in the hospital. Finally, the third layer handles system operations, provides access to patients' incontinence profiles and sends notifications in case of detecting soiled diapers. To implement the notifications system more efficiently, a smartphone reminder is also integrated into the system (Wai et al., 2011). Various solutions including disposable wet sensors placed inside of diapers are also proposed. They are defined to detect diaper wetness and to transmit the data to the cloud for further actions (Fuketa et al., 2014; Nilsson et al., 2011; Yamada et al., 2010)

A patient alert system and a passive **fall monitoring** system are proposed by Huang et al. (2009) and Schwarzmeier et al. (2014) respectively to provide instant position information and emergency situation detection. A motion monitoring system, including five accelerometer sensors and a 3D avatar (an embodiment of a person) to illustrate the movements, is offered to reduce falls (Rawashdeh et al., 2012). Fall prevention systems are also introduced to notify the nurses about high risk fall activities (Visvanathan et al., 2012) and bed falling (Chou et al., 2013). Context-aware systems are specified to implement fall detection using visual sensors (Bian et al., 2015). In this approach, a camera is installed on a wall or a ceiling in a room instead of attaching devices to patients. The camera outputs are analyzed by online video processing methods instantaneously and related fall information are extracted and transferred to healthcare personnel's computers (Enayati et al., 2014). Also mobile systems can provide fall detection for hospitals such as a robotic system offered by Mamun et al. (2014). Along with patient condition monitoring, the system is enabled by a camera and a 3D laser sensor detects falls and provides emergency notifications. In addition to fall detection and prevention, there are systems to carry out in-general **activity monitoring** considering patient's activities continuously. Real-time monitoring using a necklace tag is proposed to exploit activity data. This data can be information regarding daily activity-level and level of functional ability (Sriborrirux et al., 2014). Providing wireless acute care, a non-contact Doppler sensor is also used to fulfill patient monitoring considering patient's vital signs and motions (Hu et al., 2010).

3.2.3. Care management

As Michard (2016) proposes, computers will be able to integrate the historical, clinical, physiologic and biological information necessary to predict adverse events, propose the best therapy and ensure the care is delivered properly. While the data gets bigger it becomes vital to find the relevant information quickly and easily for efficient and accurate **decision making**. Ontology based data modelling is used to classify the records stored in one database (Boyi et al., 2014) and the relationships between sensors and devices can be determined (Manate et al., 2014). With the help of algorithms, the systems can detect diseases and suggest treatments based on statistical calculations based on a big amount of raw data (Aishwarya et al., 2015). This may be particularly useful in emergency care (Abinaya and Swathika, 2015; Boyi et al., 2014).

A smart hospital system proposed by Catarinucci et al. (2015, 2014) offers localization for entities (e.g., patients, personnel and devices) along with emergency situation management; Carvalho et al. (2015) propose a model for individuals in nursing home framework for **tracking** purpose, and Alharbe et al. (2013) asserts a system to detect people and items in hospitals. Providing a connected network using the Internet of Things and intelligent services in the cloud, also the **nursing calling system** is reinforced in hospitals. An Internet of Things based call light system uses icons and phrases to allow patients to specify their needs when making a nurse call request. Thus, the nursing staffs are informed regarding the purpose of their call upon the initiation of the call light request (Galinato et al., 2015). Also the information of patients and nurses positioning can reinforce the nursing calling system and minimize the time between the patient assistance request and nurse arrival (Kanan and Elhassan, 2015; Sharma and Gautam, 2015).

3.2.4. Comprehensive assessment

Hand **hygiene** as a significant method to mitigate infection transmission in hospitals and has been reinforced by Internet of Things related systems. Baslyman et al. (2015) present a real-time hand hygiene monitoring to monitor healthcare professionals in hospital rooms and provide a reminder whether hand hygiene is missed. Asai et al. (2013) also offer a system using sensors and interface devices to encourage individuals to practice hand antisepsis. Moreover, different systems are proposed for hand hygiene monitoring using installed sensors in hospital rooms and user-tags for personnel (Misra et al., 2015; Meydanci et al., 2013; Johnson et al., 2012; Herman et al., 2009). Shhedi et al. (Shhedi et al., 2015) also introduce a system to monitor individuals in hospital rooms. Their system recognizes whether a person enters the room, complies with hand hygiene or leaves the room. Using positioning sensors, their system is enabled to monitor hand movements during hand hygiene. Similarly, a system is proposed by Galluzzi et al. (2015) to monitor hand washing duration in hospitals and to classify hand hygiene movements using wrist worn sensors.

Different from the other proposed solutions used mainly for patient detection and management, Vicini et al. (2012) introduces a novel Internet of Things based device for the **comfort** of hospitalized children. The interactive device enables socialization not only with the hospital personnel but with other people regardless of the illness or hospital environment. By playing active learning games the children are given the opportunity of learning and growing during their experience in hospital and gaining a state of wellbeing (Vicini et al., 2012).

The main Internet of Things solutions identified in this review are summarized in Fig. 3.

4. Discussion

The fact that most of the included articles were from technology field can be interpreted at least in two ways. Firstly, the topic of Internet of Things in nursing is at infancy as more research and implementation is required. The technological field has a tradition of testing and publishing new methodologies in early stages in case studies and usability tests. Secondly, the articles in nursing field may have insufficient technical description of used devises or use different terminology for similar technology. Because of the terminological issues, an additional literature search was conducted in September 2016 in nursing informatics. However, it was not very relevant to the topic and only one more article met the inclusion criteria and could be included in the review (Galinato et al., 2015). Our study revealed that nursing informatics research

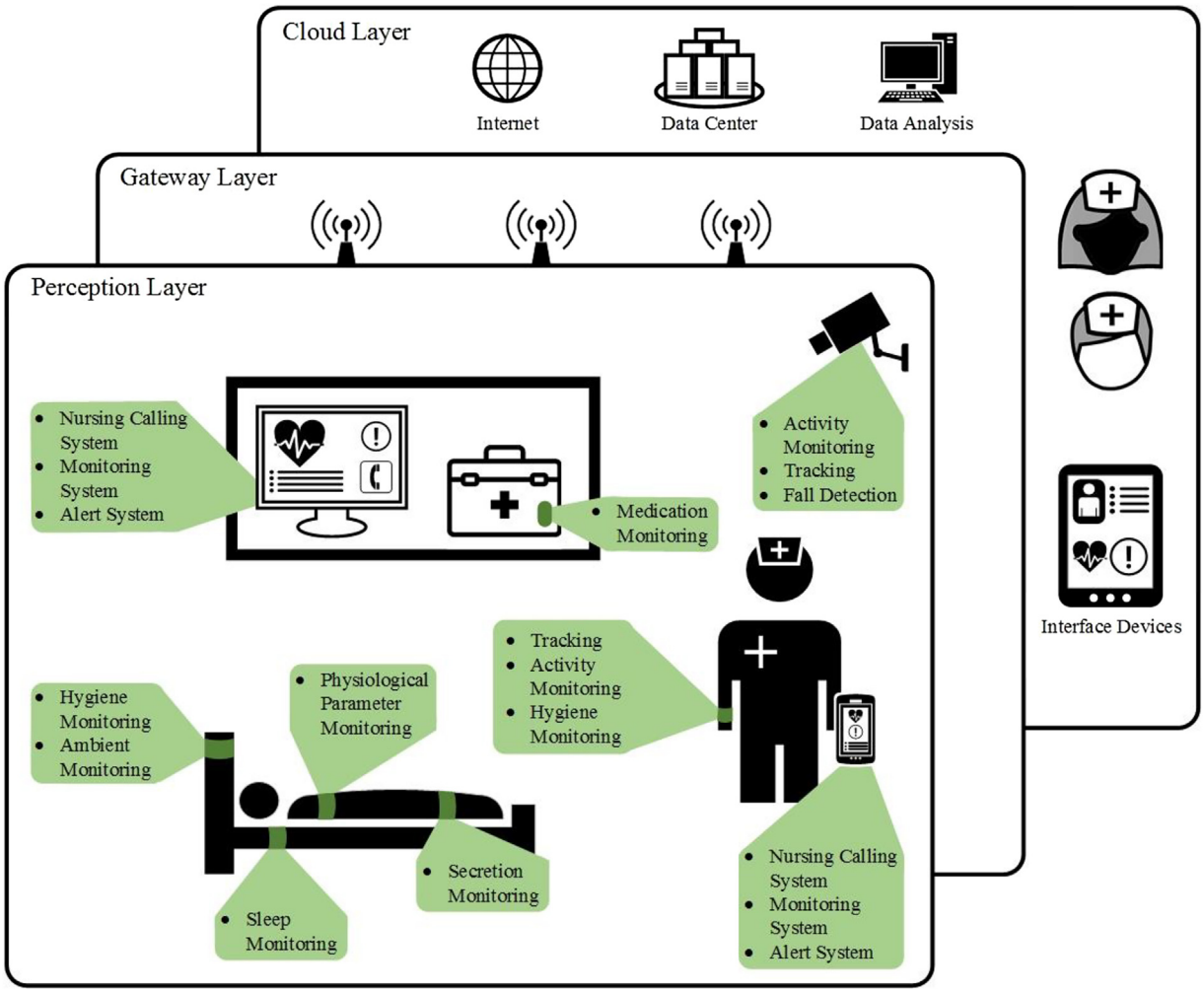

Fig. 3. Internet of Things solutions for nursing in hospital environment.

has not yet focused on Internet of Things and its possibilities in basic nursing care. Nursing informatics mostly concerns integration of the nursing information and knowledge with the information management technologies. However, Internet of Things could offer a new approach to provide real-time wireless health monitoring and cloud computing also in basic nursing care to enable intelligent decision-making support for nurses.

The reviewed papers target at patient centered issues to improve the quality of nursing care with personated health and functioning profiles, and to improve patient safety with automated alert systems and continuous real time monitoring. Innovations in care management provide information about the location and amount of available resources, the means of management and use of big data. Most innovations were based on the monitoring of patients' state giving the nurses vital information and supporting the assessment and decision making processes. While nurses devote a great deal of their time to documentation, medication administration, and care coordination and somewhat less time to actual patient care activities (Hendrich et al., 2008), one of the main advantages of using new Internet of Things solutions in hospitals is the automation of patient data collection and processing utilizing low cost sensors, devices and technologies. Moreover, it enables the hospital system to formalize the incoming raw data into standard electronic health record. This allows nurses to use more time for patient care instead of routine detection of patients' vital signs and transferring patient data to the electronic patient records. Also totally new innovations for problems were offered; automated tracking of patients and personnel along with fall detection and nurse calling systems give the organization new means of promoting patient safety. The Internet of Things also brings new opportunities to the still unsolved and continuous struggle against the health care associated infections by providing automated hand hygiene detection and reminders.

A valuable property of these innovations is that they are mostly inconspicuous and allow the patient to move more freely which leads to the improvement of the traditionally passivating hospital environment. Wireless solutions promote a feeling comfort for all patients particularly in cases of children and disoriented patients, and also promotes patient safety. Another value is the opportunity to include family in the care by offering real time data remotely, if the family is not able to be present in the hospital (Nachabe et al., 2015; Martinez-Balleste et al., 2014).

Personalized smart services could also be provided for patients in hospitals using Internet of Things based platforms. Acquiring and storing various information (e.g., medical parameters, activities, etc.) from a patient during their hospital stay along with the patient's medical history, provides a comprehensive understanding about the patient's state. Considering this knowledge, it is possible to use data analysis algorithms including machine learning (Murphy, 2012) and pattern recognition (Bishop, 2006) methods to offer personalized services for each patient. For instance, patients would achieve an advantage in diagnosis and treatment procedures by enabling personalized decision making approaches and subsequently minimizing mistakes.

In nursing, the ethical issues related to Internet of Things technologies must be highlighted. In addition to the smart applications that Internet of Things based systems could provide for nursing and hospital environment, the systems should provide security. System security as an important subject in Internet of Things based systems is defined to preserve privacy and improve trust between patients and professionals (Moosavi et al., 2016, 2015; Sicari et al., 2015). It becomes more significant particularly for hospitals in which patients' medical information is available. As discussed in Yang et al. (2012), the potential confidentiality issues can be considered in three parts regarding the three Internet of Things tiers. The perception layer which includes various sensors collecting data from patients and nurses might encounter a data breach. The gateway as an intermediate tier to provide connection between sensors and the cloud might be targeted by many challenges. Finally, the cloud layer containing data centers stores all the patients' and nurses' related information. Addressing security requirements are essentials in Internet of Things based hospital systems and should be satisfied using robust security schemes.

In addition to security and privacy issues, the transparency of the new technology for all stakeholders should be ensured. In health care, informed consent by Internet of Things users or indirect stakeholders can be difficult to obtain if technical knowledge is required (van den Hoven 2013). The nurses need not only the skills to use the new technological solutions, they also need understanding of the wider picture of risks and benefits. These requirements are part of the competence nurses need in technology and informatics in their work in the future (Gassert, 2008).

5. Limitations

Since the area of investigation is still in an early stage, the literature is diverse in quality. We included many types of studies to achieve a picture of the field. This has obviously affected the scientific level of the study. However we found it important to include all chosen studies in the analysis to get a good picture of the state of the art. The search terms were not a complete list of all the relevant areas in basic nursing care and this is a limitation. In addition, the concept of the Internet of Things has a broad definition, therefore only papers with sufficient technical description were chosen in the review.

6. Conclusions

In conclusion, modern Internet of Things based technology offers various innovations for basic nursing care but most the innovations are still emerging. Internet of things is yet vaguely adopted in nursing. The possibilities of the Internet of Things are not yet exploited as well as they could. The automation of the patient and hospital environment monitoring and collection and management of data might promote the quality of care and patient safety in basic nursing care but there is still no evidence of effectiveness or efficacy in the literature. In the studied research the proposed technologies are in the testing phase and need to be studied further to ensure their feasibility and security for hospital use. Nursing science might benefit from deeper involvement in engineering research in the area of health and nursing care.

Authors contributions

Review design: RM, IA, AR, RA, PL, SS; data collection: IA, RM, VT; data analysis: RM, IA; and manuscript preparation: IA, RM, VT, AR, RA, PL, SS.

Acknowledgments

This study was funded by the Academy of Finland, decision number 287075.

References

Abinaya, Kumar, Swathika, V., 2015. Ontology based public healthcare system in Internet of Things (IoT). Procedia Comput. Sci. 50, 99–102. doi:http://dx.doi.org/10.1016/j.procs.2015.04.067.

Aishwarya, K., Harshitha, S., Chandrasekaran, K., 2015. A Reinforcement Learning Approach to E-Health 2, 411–415.

Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., Ayyash, M., 2015. Internet of Things: a survey on enabling technologies protocol and applications. IEEE Commun. Surv. Tutor. 17, 2347–2376. doi:http://dx.doi.org/10.1109/COMST.2015.2444095.

Alharbe, N., Atkins, A.S., Akbari, A.S., 2013. Application of ZigBee and RFID technologies in healthcare in conjunction with the Internet of Things. Proceedings of International Conference on Advances in Mobile Computing & Multimedia – MoMM'13, ACM Press New York, New York, USA, pp. 191–195. doi:http://dx.doi.org/10.1145/2536853.2536904.

Andre, N., Druart, S., Gerard, P., Pampin, R., Moreno-Hagelsieb, L., Kezai, T., Francis, L. A., Flandre, D., Raskin, J.-P., 2010. Miniaturized wireless sensing system for real-time Breath activity recording. IEEE Sens. J. 10, 178–184. doi:http://dx.doi.org/10.1109/JSEN.2009.2035666.

Ang, L.M., Ow, S.H., Seng, K.P., Tee, Z.H., Lee, B.W., Thong, M.K., Poi, P.J.H., Kunanayagam, S., 2008. Wireless intelligent incontinence management system using smart diapers. 5th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, ECTI-CON 2008, IEEE, pp. 69–72. doi:http://dx.doi.org/10.1109/ECTICON.2008.4600374.

Arksey, H., O'Malley, L., 2005. Scoping studies: towards a methodological framework. Int. J. Soc. Res. Methodol. 8, 19–32. doi:http://dx.doi.org/10.1080/1364557032000119616.

Asai, T., Kanazawa, A., Hayashi, H., Minazuki, A., 2013. Development of a system to raise awareness of hand hygiene in various environments. 2013 International Conference on Signal-Image Technology and Internet-Based Systems, SITIS 2013, IEEE, pp. 924–931. doi:http://dx.doi.org/10.1109/SITIS.2013.150.

Atzori, L., Iera, A., Morabito, G., 2010. The Internet of Things: a survey. Comput. Netw. 54, 2787–2805. doi:http://dx.doi.org/10.1016/j.comnet.2010.05.010.

Baslyman, M., Rezaee, R., Amyot, D., Moutthan, A., Chreyh, R., Geiger, G., Stewart, A., Sader, S., 2015. Real-time and location-based hand hygiene monitoring and notification: proof-of-concept system and experimentation. Pers. Ubiquitous Comput. 19, 667–688. doi:http://dx.doi.org/10.1007/s00779-015-0855-y.

Bian, Z.-P., Hou, J., Chau, L.-P., Magnenat-Thalmann, N., 2015. Fall detection based on body part tracking using a depth camera. IEEE J. Biomed. Health Inform. 19, 430–439. doi:http://dx.doi.org/10.1109/JBHI.2014.2319372.

Bishop, C.M., 2006. Pattern Recognition and Machine Learning. Springer.

Biswas, J., Maniyeri, J., Gopalakrishnan, K., Shue, L., Eugene, P.J., Palit, H.N., Siang, Foo Yong, Seng, Lau Lik, Li, Xiaorong, 2010. Processing of wearable sensor data on the cloud – a step towards scaling of continuous monitoring of health and well-being. 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology, IEEE, pp. 3860–3863. doi:http://dx.doi.org/10.1109/IEMBS.2010.5627906.

Bonomi, F., Milito, R., Natarajan, P., Zhu, J., 2014. Fog Computing: A Platform for Internet of Things and Analytics. Springer International Publishing, pp. 169–186. doi:http://dx.doi.org/10.1007/978-3-319-05029-4_7.

Boyi, Xu, Da, Xu Li, Hongming, Cai, Cheng, Xie, Jingyuan, Hu, Fenglin, Bu, 2014. Ubiquitous data accessing method in ioT-based information system for emergency medical services. IEEE Trans. Ind. Inform. 10, 1578–1586. doi:http://dx.doi.org/10.1109/TII.2014.2306382.

Bruballa, E., Taboada, M., Cabrera, E., Rexachs, D., Luque, E., 2014. Simulation and big aata: a way to discover unusual knowledge in emergency departments: work-in-progress paper. 2014 International Conference on Future Internet of Things and Cloud. IEEE, pp. 367–372. doi:http://dx.doi.org/10.1109/FiCloud.2014.65.

Cao, H., Landge, V., Tata, U., Seo, Y.-S., Rao, S., Tang, S.-J., Tibbals, H.F., Spechler, S., Chiao, J.-C., 2012. An implantable, batteryless, and wireless capsule with integrated impedance and pH sensors for gastroesophageal reflux monitoring. IEEE Trans. Biomed. Eng. 59, 3131–3139. doi:http://dx.doi.org/10.1109/TBME.2012.2214773.

Carvalho, C.M.A., Rodrigues, C.A.P., Aguilar, P.A.C., de Castro, M.F., Andrade, R.M.C., Boudy, J., Istrate, D., 2015. Adaptive tracking model in the framework of medical nursing home using infrared sensors. 2015 IEEE Globecom Workshops (GC Wkshps), IEEE, pp. 1–6. doi:http://dx.doi.org/10.1109/GLOCOMW.2015.7414030.

Catarinucci, L., De Donno, D., Mainetti, L., Palano, L., Patrono, L., Stefanizzi, M.L., Tarricone, L., 2014. Integration of UHF RFID and WSN technologies in healthcare systems. 2014 IEEE RFID Technology and Applications Conference (RFID-TA), IEEE, pp. 289–294. doi:http://dx.doi.org/10.1109/RFID-TA.2014.6934245.

Catarinucci, L., de Donno, D., Mainetti, L., Palano, L., Patrono, L., Stefanizzi, M.L., Tarricone, L., 2015. An ioT-aware architecture for smart healthcare systems. IEEE Internet Things J. 2, 515–526. doi:http://dx.doi.org/10.1109/JIOT.2015.2417684.

Chou, W.-C., Lin, W.-Y., Lee, M.-Y., Lei, K.F., 2013. Design and assessment of a real-Time accelerometer-Based lying-to-Sit sensing system for bed fall prevention.

2013 IEEE International Conference on Systems, Man, and Cybernetics, IEEE, pp. 1471–1475. doi:http://dx.doi.org/10.1109/SMC.2013.254.
Donnelly, N., Harper, R., McCAnderson, J., Branagh, D., Kennedy, A., Caulfield, M., McLaughlin, J., 2012. Development of a ubiquitous clinical monitoring solution to improve patient safety and outcomes. 2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, IEEE, pp. 6068–6073. doi:http://dx.doi.org/10.1109/EMBC.2012.6347378.
Enayati, M., Banerjee, T., Popescu, M., Skubic, M., Rantz, M., 2014. A novel web-based depth video rewind approach toward fall preventive interventions in hospitals. 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, IEEE, pp. 4511–4514. doi:http://dx.doi.org/10.1109/EMBC.2014.6944626.
Englebright, J., Aldrich, K., Taylor, C.R., 2014. Defining and incorporating basic nursing care actions into the electronic health record. J. Nurs. Scholarsh. 46, 50–57. doi:http://dx.doi.org/10.1111/jnu.12057.
Fang, Zhen, Zhao, Zhan, Sun, Fangmin, Chen, Xianxiang, Du, Lidong, Li, Huaiyong, Tian, Lili, 2012. The 3AHcare node: health monitoring continuously. 2012 IEEE 14th International Conference on E-Health Networking, Applications and Services (Healthcom), IEEE, pp. 365–366. doi:http://dx.doi.org/10.1109/HealthCom.2012.6379438.
Fraile, J.A., Bajo, J., Corchado, J.M., Abraham, A., 2010. Applying wearable solutions in dependent environments. IEEE Trans. Inf. Technol. Biomed. 14, 1459–1467. doi:http://dx.doi.org/10.1109/TITB.2010.2053849.
Fuketa, H., Yoshioka, K., Yokota, T., Yukita, W., Koizumi, M., Sekino, M., Sekitani, T., Takamiya, M., Someya, T., Sakurai, T., 2014. 30.3 Organic-transistor-based 2 kV ESD-tolerant flexible wet sensor sheet for biomedical applications with wireless power and data transmission using 13.56 MHz magnetic resonance. 2014 IEEE International Solid-State Circuits Conference Digest of Technical Papers (ISSCC), IEEE, pp. 490–491. doi:http://dx.doi.org/10.1109/ISSCC.2014.6757525.
Güder, F., Ainla, A., Redston, J., Mosadegh, B., Glavan, A., Martin, T.J., Whitesides, G. M., 2016. Paper-based electrical respiration sensor. Angew. Chem. Int. Ed. 55, 5727–5732. doi:http://dx.doi.org/10.1002/anie.201511805.
Galinato, J., Montie, M., Patak, L., Titler, M., 2015. Perspectives of nurses and patients on call light technology. Comput. Inform. Nurs. 33, 359–367. doi:http://dx.doi.org/10.1097/CIN.0000000000000177.
Galluzzi, V., Herman, T., Polgreen, P., 2015. Hand hygiene duration and technique recognition using wrist-worn sensors. Proceedings of the 14th International Conference on Information Processing in Sensor Networks – IPSN'15, ACM Press New York, New York, USA, pp. 106–117. doi:http://dx.doi.org/10.1145/2737095.2737106.
Gassert, C.A., 2008. Technology and informatics competencies. Nurs. Clin. N. Am. 43, 507–521. doi:http://dx.doi.org/10.1016/j.cnur.2008.06.005.
Grant, M.J., Booth, A., 2009. A typology of reviews: an analysis of 14 review types and associated methodologies. Health Inf. Libr. J. 26, 91–108. doi:http://dx.doi.org/10.1111/j.1471-1842.2009.00848.x.
Hart, A., Tallevi, K., Wickland, D., Kearney, R.E., Cafazzo, J.A., 2010. A contact-free respiration monitor for smart bed and ambulatory monitoring applications. 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology, IEEE, pp. 927–930. doi:http://dx.doi.org/10.1109/IEMBS.2010.5627525.
Hendrich, A., Chow, M.P., Skierczynski, B.A., Lu, Z., 2008. A 36-hospital time and motion study: how do medical-surgical nurses spend their time? Perm. J. 12, 25–34.
Herman, T., Pemmaraju, S.V., Segre, A.M., Polgreen, P.M., Curtis, D.E., Fries, J., Hlady, C., Severson, M., 2009. Wireless applications, for hospital epidemiology. 1st Acm International Workshop on Medical-grade Wireless Networks, ACM Press, New York, New York, USA, pp. 45–50. doi:http://dx.doi.org/10.1145/1540373.1540384.
Hu, W., Lie, D.Y.C., Kakade, M.U., Ichapurapu, R., Mane, S., Lopez, J., Li, Y., Li, C., Banister, R.E., Dentino, A., Nguyen, T., Zupancic, S., Griswold, J., 2010. An intelligent non-contact wireless monitoring system for vital signs and motion detection. 2010 International Conference on System Science and Engineering, IEEE, pp. 190–194. doi:http://dx.doi.org/10.1109/ICSSE.2010.5551795.
Hua-li, K., Duan-hao, F., Wei-wei, F., Qian, L., 2015. Design and Implementation of Pharmaceutical Logistics and Supply Chain Management System for Hospital. , pp. 1149–1152.
Huang, C.-N., Chiang, C.-Y., Chang, J.-S., Chou, Y.-C., Hong, Y.-X., Hsu, S.J., Chu, W.-C., Chan, C.-T., 2009. Location-Aware fall detection system for medical care quality improvement. 2009 Third International Conference on Multimedia and Ubiquitous Engineering, IEEE, pp. 477–480. doi:http://dx.doi.org/10.1109/mue.2009.84.
Huang, J.-H., Wang, T.-T., Su, T.-Y., Lan, K.-C., 2013. Design and deployment of a heart rate monitoring system in a senior center. 2013 IEEE International Conference on Sensing, Communications and Networking (SECON), IEEE, pp. 71–75. doi:http://dx.doi.org/10.1109/SAHCN.2013.6644963.
Huang, Xinming, Sun, Ling, Tian, T., Huang, Zeyan, Clancy, E., 2015. Real-time non-contact infant respiratory monitoring using UWB radar. 2015 IEEE 16th International Conference on Communication Technology (ICCT), IEEE, pp. 493–496. doi:http://dx.doi.org/10.1109/ICCT.2015.7399885.
IMIA-NI, 2009. Definition of Nursing Informatics. Helsinki, Finland: IMIA Nursing Informatics Special Interest Group. https://imianews.wordpress.com/2009/08/24/imia-ni-definition-of-nursing-informatics-updated/ (accessed 10.10.16).
Institute of Medicine, 2011. The Learning Health System and Its Innovation Collaboratives. . http://docplayer.net/2723483-The-learning-health-system-and-its-innovation-collaboratives.html.
Jangland, E., Kitson, A., Muntlin Athlin, Å., 2016. Patients with acute abdominal pain describe their experiences of fundamental care across the acute care episode: a multi-stage qualitative case study. J. Adv. Nurs. 72, 791–801. doi:http://dx.doi.org/10.1111/jan.12880.
Jara, A.J., Alcolea, A.F., Zamora, M.A., Skarmeta, A.F.G., Alsaedy, M., 2010a. Drugs interaction checker based on IoT. 2010 Internet of Things (IOT), IEEE, pp. 1–8. doi:http://dx.doi.org/10.1109/IOT.2010.5678458.
Jara, A.J., Belchi, F.J., Alcolea, A.F., Santa, J., Zamora-Izquierdo, M.A., Gómez-Skarmeta, A.F., 2010b. A pharmaceutical intelligent information system to detect allergies and adverse drugs reactions based on internet of things. 2010 8th IEEE International Conference on Pervasive Computing and Communications Workshops, PERCOM Workshops 2010, IEEE, pp. 809–812. doi:http://dx.doi.org/10.1109/PERCOMW.2010.5470547.
Jara, A.J., Zamora, M.A., Skarmeta, A.F., 2014. Drug identification and interaction checker based on IoT to minimize adverse drug reactions and improve drug compliance. Pers. Ubiquitous Comput. 18, 5–17. doi:http://dx.doi.org/10.1007/s00779-012-0622-2.
Johnson, R., Tsouri, G.R., Walsh, E., 2012. Continuous and automated measuring of compliance of hand-hygiene procedures using finite state machines and RFID. IEEE Instrum. Meas. Mag. 15, 8–12. doi:http://dx.doi.org/10.1109/MIM.2012.6174572.
Kanan, R., Elhassan, O., 2015. A combined batteryless radio and WiFi indoor Positioning System. 2015 23rd International Conference on Software, Telecommunications and Computer Networks (SoftCOM), IEEE, pp. 101–107. doi:http://dx.doi.org/10.1109/SOFTCOM.2015.7314058.
Kitson, A., Conroy, T., Wengstrom, Y., Profetto-McGrath, J., Robertson-Malt, S., 2010. SCHOLARLY PAPER: Defining the fundamentals of care. Int. J. Nurs. Pract. 16, 423–434. doi:http://dx.doi.org/10.1111/j.1440-172X.2010.01861.x.
Laranjo, I., Macedo, J., Santos, A., 2012. Internet of Things for medication control: service implementation and testing. Procedia Technol. 5, 777–786. doi:http://dx.doi.org/10.1016/j.protcy.2012.09.086.
Lasater, K.B., Mchugh, M.D., 2016. Nurse staffing and the work environment linked to readmissions among older adults following elective total hip and knee replacement. Int. J. Qual. Heal. Care 28, 253–258. doi:http://dx.doi.org/10.1093/intqhc/mzw007.
Levac, D., Colquhoun, H., O'Brien, K.K., 2010. Scoping studies: advancing the methodology. Implement. Sci. 5, 1–9. doi:http://dx.doi.org/10.1186/1748-5908-5-69.
Liu, Y.-W., Hsu, Y.-L., 2013. Development of a bed-Centered telehealth system based on a motion-Sensing mattress. 2013 IEEE International Conference on Systems, Man, and Cybernetics, IEEE, pp. 1466–1470. doi:http://dx.doi.org/10.1109/SMC.2013.253.
Liu, Y.-W., Hsu, Y.-L., Chang, W.-Y., 2015. Development of a bed-centered telehealth system based on a motion-sensing mattress. J. Clin. Gerontol. Geriatr. 6, 1–8. doi:http://dx.doi.org/10.1016/j.jcgg.2014.06.001.
Mamun, K.A., Sharma, A., Hoque, A.S.M., Szecsi, T., 2014. Remote patient physical condition monitoring service module for iWARD hospital robots. Asia-Pacific World Congress on Computer Science and Engineering, IEEE, pp. 1–8. doi:http://dx.doi.org/10.1109/apwccse.2014.7053854.
Manate, B., Munteanu, V.I., Fortis, T.F., Moore, P.T., 2014. An intelligent context-Aware decision-Support system oriented towards healthcare support. 2014 Eighth International Conference on Complex, Intelligent and Software Intensive Systems, IEEE, pp. 386–391. doi:http://dx.doi.org/10.1109/CISIS.2014.54.
Martinez-Balleste, A., Casanovas-Marsal, J.-O., Solanas, A., Casino, F., Garcia-Martinez, M., 2014. An autonomous system to assess, display and communicate the pain level in newborns. 2014 IEEE International Symposium on Medical Measurements and Applications (MeMeA), IEEE, pp. 1–5. doi:http://dx.doi.org/10.1109/MeMeA.2014.6860144.
Meydanci, M.A., Adali, C., Ertas, M., Dizbay, M., Akan, A., 2013. RFID based hand hygiene compliance monitoring station. 2013 IEEE International Conference on Control System, Computing and Engineering, IEEE, pp. 573–576. doi:http://dx.doi.org/10.1109/ICCSCE.2013.6720030.
Michard, F., 2016. Hemodynamic monitoring in the era of digital health. Ann. Intensive Care 6, 15. doi:http://dx.doi.org/10.1186/s13613-016-0119-7.
Misra, P., Rajaraman, V., Aishwarya, S.N., Dwivedi, B., Warrior, J., 2015. CleanHands: an integrated monitoring system for control of hospital acquired infections. Proceedings of the 14th International Conference on Information Processing in Sensor Networks – IPSN '15, ACM Press New York, New York, USA, pp. 348–349. doi:http://dx.doi.org/10.1145/2737095.2742928.
Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., 2010. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Int. J. Surg. 8, 336–341. doi:http://dx.doi.org/10.1016/j.ijsu.2010.02.007.
Moosavi, S.R., Gia, T.N., Rahmani, A.-M., Nigussie, E., Virtanen, S., Isoaho, J., Tenhunen, H., 2015. SEA: a secure and efficient authentication and authorization architecture for IoT-based healthcare using smart gateways. Procedia Comput. Sci. 52, 452–459. doi:http://dx.doi.org/10.1016/j.procs.2015.05.013.
Moosavi, S.R., Gia, T.N., Nigussie, E., Rahmani, A.M., Virtanen, S., Tenhunen, H., Isoaho, J., 2016. End-to-end security scheme for mobility enabled healthcare Internet of Things. Future Gener. Comput. Syst. 64, 108–124. doi:http://dx.doi.org/10.1016/j.future.2016.02.020.
Murphy, K., 2012. Machine Learning: A Probabilistic Perspective. The MIT Press.
Nachabe, L., Girod-Genet, M., ElHassan, B., Jammas, J., 2015. M-health application for neonatal incubator signals monitoring through a CoAP-based multi-agent system. 2015 International Conference on Advances in Biomedical Engineering (ICABME), IEEE, pp. 170–173. doi:http://dx.doi.org/10.1109/ICABME.2015.7323279.
Nilsson, H.-E., Siden, J., Gulliksson, M., 2011. An incontinence alarm solution utilizing RFID based sensor technology. 2011 IEEE International Conference on

RFID-Technologies and Applications, IEEE, pp. 359–363. doi:http://dx.doi.org/10.1109/RFID-TA.2011.6068662.

Rahmani, A.-M., Thanigaivelan, N.K., Tuan Nguyen, Gia, Granados, J., Negash, B., Liljeberg, P., Tenhunen, H., 2015. Smart e-Health Gateway: bringing intelligence to Internet-of-Things based ubiquitous healthcare systems. 2015 12th Annual IEEE Consumer Communications and Networking Conference (CCNC), IEEE, pp. 826–834. doi:http://dx.doi.org/10.1109/CCNC.2015.7158084.

Rawashdeh, O., Sa'deh, W., Rawashdeh, M., Qu, G., Ferrari, M., Harrison, B., Hammond, R., Maddens, M., 2012. Development of a low-cost fall intervention system for hospitalized dementia patients. 2012 IEEE International Conference on Electro/Information Technology, IEEE, pp. 1–7. doi:http://dx.doi.org/10.1109/EIT.2012.6220763.

Rofouei, M., Sinclair, M., Bittner, R., Blank, T., Saw, N., DeJean, G., Heffron, J., 2011. A non-invasive wearable neck-cuff system for real-time sleep monitoring. 2011 International Conference on Body Sensor Networks, IEEE, pp. 156–161. doi:http://dx.doi.org/10.1109/BSN.2011.38.

Rotariu, C., Costin, H., Pasarica, A., Cristea, C., Dionisie, B., 2013. Wireless skin temperature measurement system for circadian rhythm monitoring. 2013 E-Health and Bioengineering Conference (EHB), IEEE, pp. 1–4. doi:http://dx.doi.org/10.1109/EHB.2013.6707345.

Schwarzmeier, A., Weigel, R., Fischer, G., Kissinger, D., 2014. A low power fall detection and activity monitoring system for nursing facilities and hospitals. 2014 IEEE Topical Conference on Biomedical Wireless Technologies, Networks, and Sensing Systems (BioWireleSS), IEEE, pp. 28–30. doi:http://dx.doi.org/10.1109/BioWireleSS.2014.6827736.

Sharma, C., Gautam, D.K., 2015. Design development and implementation of wired Nurse calling system. 2015 International Conference on Green Computing and Internet of Things (ICGCIoT), IEEE, pp. 1258–1262. doi:http://dx.doi.org/10.1109/ICGCIoT.2015.7380657.

Shhedi, Z.A., Moldoveanu, A., Moldoveanu, F., Taslitchi, C., 2015. Real-time hand hygiene monitoring system for HAI prevention. 2015 E-Health and Bioengineering Conference (EHB), IEEE, pp. 1–4. doi:http://dx.doi.org/10.1109/EHB.2015.7391474.

Shi-Lin, H., Bei, L., Jun, Y., Guang-Fei, C., Shu-Chao, L., Dan, Z., 2015. Development of physiological parameters gateway for medical IOT ward. Open Autom. Control Syst. J. 7, 1667–1673. doi:http://dx.doi.org/10.2174/1874444301507011667.

Sicari, S., Rizzardi, A., Grieco, L.A., Coen-Porisini, A., 2015. Security, privacy and trust in Internet of Things: the road ahead. Comput. Netw. 76, 146–164. doi:http://dx.doi.org/10.1016/j.comnet.2014.11.008.

Sriborrirux, W., Leamsumran, P., Dan-klang, P., 2014. Real-time system for monitoring activity among the elderly using an RF SoC device with triaxial accelerometer data over a wireless sensor network. 2014 IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-Bio2014), IEEE, pp. 1–4. doi:http://dx.doi.org/10.1109/IMWS-BIO.2014.7032430.

Touati, F., Tabish, R., 2013. u-Healthcare system: state-of-the-art review and challenges. J. Med. Syst. 37, 9949. doi:http://dx.doi.org/10.1007/s10916-013-9949-0.

Vicini, S., Bellini, S., Rosi, A., Sanna, A., 2012. An internet of things enabled interactive totem for children in a living lab setting. 2012 18th International ICE Conference on Engineering, Technology and Innovation, IEEE, pp. 1–10. doi:http://dx.doi.org/10.1109/ICE.2012.6297713.

Visvanathan, R., Ranasinghe, D.C., Shinmoto Torres, R.L., Hill, K., 2012. Framework for preventing falls in acute hospitals using passive sensor enabled radio frequency identification technology. 2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, IEEE, pp. 5858–5862. doi:http://dx.doi.org/10.1109/EMBC.2012.6347326.

Wai, A.A.P., Foo, S.F., Jayachandran, M., Biswas, J., Nugent, C., Mulvenna, M., Zhang, D., Craig, D., Passmore, P., Lee, J.E., Yap, P., 2010a. Towards developing effective Continence Management through wetness alert diaper: experiences, lessons learned, challenges and future directions. 2010 4th International Conference on Pervasive Computing Technologies for Healthcare, IEEE, pp. 1–8. doi:http://dx.doi.org/10.4108/ICST.PERVASIVEHEALTH2010.8832.

Wai, A.A.P., Victor, F.S.F., Jayachandran, M., Biswas, J., Nugent, C., Mulvenna, M., Daqing, Z., Craig, D., Passmore, P., Jer-Ens, L., Yaps, P., 2010b. Technical development and clinical evaluation of intelligent continence management system at nursing home. 12th IEEE International Conference on E-Health Networking, Application and Services, Healthcom 2010, IEEE, pp. 345–352. doi:http://dx.doi.org/10.1109/HEALTH.2010.5556544.

Wai, A.A.P., Foo, S.F., Biswas, J., Donnelly, M., Parente, G., Nugent, C., Yap, P., 2011. Smart phone reminder system for managing incontinence at nursing home. Proceedings of the International Symposium on Consumer Electronics, ISCE, IEEE, pp. 254–259. doi:http://dx.doi.org/10.1109/ISCE.2011.5973827.

West, E., Barron, D.N., Reeves, R., 2005. Overcoming the barriers to patient-centred care: time, tools and training. J. Clin. Nurs. 14, 435–443. doi:http://dx.doi.org/10.1111/j.1365-2702.2004.01091.x.

Yamada, K., Toshiaki, N., Ishihara, K., Ohno, Y., Ishii, A., Shimizu, S., Araki, T., Takahashi, R., Takahashi, H., Shimizu, E., 2010. Development of new type incontinence sensor using RFID tag. 2010 IEEE International Conference on Systems, Man and Cybernetics, IEEE, pp. 2695–2700. doi:http://dx.doi.org/10.1109/ICSMC.2010.5641889.

Yang, X., Li, Z., Geng, Z., Zhang, H., 2012. A multi-layer security model for internet of things. Internet of Things 388–393. doi:http://dx.doi.org/10.1007/978-3-642-32427-7_54.

Zhang, T., Liu, Z., Cao, X., Xia, W., 2015. Intelligent medicine box monitoring and management system. 2015 International Conference on Computer Science and Mechanical Automation (CSMA), IEEE, pp. 153–156. doi:http://dx.doi.org/10.1109/CSMA.2015.37.

Zhu, X., Zhou, X., Chen, W., Kitamura, K.I., Nemoto, T., 2015. Estimation of sleep quality of residents in nursing homes using an internet-Based automatic monitoring system. 2014 IEEE International Conference on Ubiquitous Intelligence and Computing, 2014 IEEE International Conference on Autonomic and Trusted Computing, 2014 IEEE International Conference on Scalable Computing and Communications and Associated Sy, IEEE, pp. 659–665. doi:http://dx.doi.org/10.1109/UIC-ATC-ScalCom.2014.138.

Zito, D., Pepe, D., Mincica, M., Zito, F., Tognetti, A., Lanata, A., De Rossi, D., 2011. SoC CMOS UWB pulse radar sensor for contactless respiratory rate monitoring. IEEE Trans. Biomed. Circuits Syst. 5, 503–510. doi:http://dx.doi.org/10.1109/TBCAS.2011.2176937.