

A Survey on Usability Aspects of Ubiquitous Computing

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Abstract

We live in a digital world which controls our physical environment. The increasing use of wireless network supports these digital devices to use mostly people. People prefer mobile devices such as smart phones and tablets to personal computers or laptops. This brings that accessing to information and services is available any time and everywhere. This can be called ubiquitous computing. There is a high demand of pervasive computing applications and they have grown in the last years. However, a large group of people do not engage with these developments. This attracted the researchers to think this problem and they link it with usability of systems. In this study, we reviewed the articles which published on usability of ubiquitous computing. Within the scope of this study, the first stage is defining ubiquitous and usability. In the second stage, this paper organizes and classifies the literature on the area in order to facilitate future research. The review covers 53 peer-reviewed journal articles from 18 journals published between 2000 and 2015. The resulting framework summarizes the progress in usability studies on pervasive computing environments research and provides future research directions.

Keywords: usability, ubiquitous computing, pervasive computing, mobile computing

1. Introduction

We are living in a digital world; digital devices become used to realize human activities and task. These digital devices improve interaction between human and physical environment. Digital devices control Physical world environment by sensing and accessing them. The increasing use of wireless network supports these digital devices to use mostly people. Technological developments remove barriers of using devices everywhere. There is a new term is appeared as ubiquitous which Poslad (2009) described it that “enables information and tasks to made available everywhere and support intuitive human usage, appearing invisible to user.”

Nowadays wireless communication is supported almost all electronic devices. With using Bluetooth and Wi-Fi technologies enable to share resources on hoc networks [2]. With these technologies everyday life are becoming ubiquitous. People prefer mobile devices such as smart phones and tablets to personal computers or laptops. This brings that accessing to information and services are available any time and everywhere [3].

There is a high demand of pervasive computing applications and they have grown in the last years. However, a large group of people do not engage with these developments. This attracted the researchers to think this problem and they link it with usability of systems. Usability is the critical success factor for these applications. As can be understood the definition of Poslad (2009), ubiquitous is related to human computer interaction. The term of human computer interaction has been widespread uses since in the mid-1980. It is possible to define human-computer interaction (HCI) as a discipline intended to design, implement and evaluate interfaces and interactive systems.

Usability is the one part of HCI and can be defined as “qualities attribute relating to how easy something is to use [6]. Also, the International Standard of Organizations (ISO) defines the usability in the standard of ISO 9421-11 as follows: “Usability is the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments”. As can be seen in the definition of ISO, the concept of usability has got three attributes; efficiency, effectiveness and

satisfaction. These attributes are defined by Liljegen (2006) as follows: “Effectiveness is the accuracy and completeness with which specified users can achieve specified goals in particular environments. Efficiency is the resources expended in relation to the accuracy and completeness of goals achieved. Satisfaction is the comfort and acceptability of the work system to its users and other people affected by its use [5].”

To Nielsen (1993), there are five attributes of usability, which should all be supported by the systems. These are as follows [5]:

- * Learnability: The system or an interface should be easy-to-learn so that end-users can rapidly overcome some work by using the system.
- * Efficiency: The system should be efficient-to-use so that when the system is learned by the users, it can also be used with a high proportion of productivity.
- * Memorability: The system should be easy-to-remember, so that the users should be able to remember everything with the system even they did not used the system for some period and they should not have to learn everything all over again.
- * Errors: The system should have a low error rate, so that users encounter with few errors during the use of the system and they should get rid of errors easily.
- * Satisfaction: The system should be pleasant to use, so users are subjectively satisfied when using it.

2. Research Methodology

Articles about usability of ubiquitous computing systems exist in various journals, and indexes. In order getting valuable articles, and preparing comprehensive study, we searched in Science Direct Database, ACM Digital Library database, Taylor & Francis Database and Google Scholar. Firstly, some keywords were determined for search, such as “usability”, “ubiquitous”, “pervasive”, “ubiquitous computing”, “pervasive computing” and “mobile computing”, and these keywords were looked for in abstract, title and keywords, and content of articles published in between 2000 and 2015.

When searching the keywords in abstract, title, content and keyword, 53 articles were found. The review covers 26 peer-reviewed journal articles from 18 journals published between 2000 and 2015 and 27 conference articles from different 17 conferences. The resulting framework summarizes the progress in usability research in ubiquitous area and provides future research directions. The list of Journals and Conferences is shown in Table 1.

Table 1. Journals with the number of articles

<i>Journal & Conferences</i>	<i># of the Articles</i>
Personal and Ubiquitous Computing	6
IEEE CS and IEEE ComSoc	2
TOCHI ACM Transactions on Computer-Human Interaction	2
Computers in Industry	2
Procedia computer Science	1
Computers and Electrical Engineering	1
International Journal oh Human Computer Studies	1
Future Generation Computer Systems	1
Computers in Human Behavior	1
Intel Research	1
SPROUTS: Working Papers on Information Systems	1
Interacting with Computers	1
Ubiquitous Computing and Communication Journal	1
International Journal of Computer Applications	1
National Institute of Standards and Technology	1
International Journal of Medical Informatics	1

Ergonomics	1
IBM Systems Journal	1

<i>Journal & Conferences</i>	<i># of the Articles</i>
Ubicomp, Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing	6
CHI, Proceedings of the Annual ACM Conference on Human Factors in Computing Systems	3
Mobile HCI, Proceedings of the International Conference on Human-Computer Interaction with Mobile Devices and Services	2
AHFE 2015, Procedia Manufacturing, 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences	1
Proceedings of the Multimedia, Interaction, Design and Innovation	1
PerDis'15 Proceedings of the 4th International Symposium on Pervasive Displays	1
CUU '00 Proceedings on the 2000 conference on Universal Usability	1
CITC4 '03 Proceedings of the 4th conference on Information technology curriculum	1
IHM'14, Villeneuve d'Ascq, France	1
AVI '08 Proceedings of the working conference on Advanced visual interfaces	1
ECCE '09 European Conference on Cognitive Ergonomics: Designing beyond the Product --- Understanding Activity and User Experience in Ubiquitous Environments	1
WH '14 Proceedings of the Wireless Health 2014 on National Institutes of Health	1
Third 2008 International Conference on Convergence and Hybrid Information Technology	1
Handbook of Research on Ubiquitous Computing Technology for Real Time Enterprises	1
HCI 2013	1
Experience Workshop on Pervasive Computing	1
Financial Cryptography and Data Security	1

These articles are, also, classified into the year category. Although the search included years between 2000 and 2015, 2 of the 53 articles were written in 2000, 3 of them was written in 2002, 4 of them were written in 2003, 1 of them were written in 2004, 5 of them were written in 2005, 5 of them were written in 2008, 4 of them were written in 2013, and 4 of them were written in 2014 and 15 of them were written in 2015. As can see in the figure, the numbers of articles published on usability about pervasive systems have changed each year. The result is shown in Figure 1.

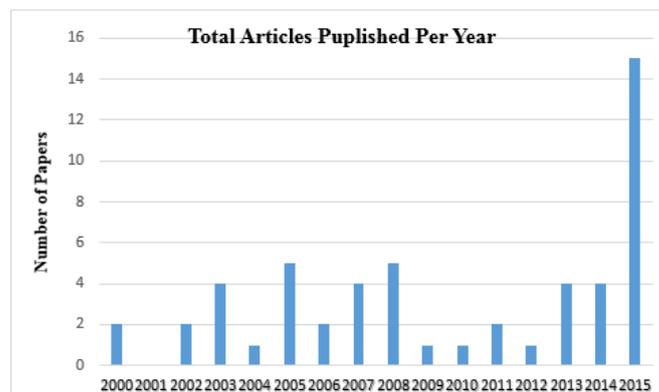


Figure 1. Total articles between 2000-2015

3. Result

Table 2. Evaluated articles

<i>Reference</i>	<i>Year</i>	<i>Publisher</i>	<i>Keywords</i>	<i>What it is about?</i>
[2]	2011	Pers Ubiquit Comput	Not available for this document.	It is about categorization factors which affect the usability of device association. They examined user actions with these devices. Not very related to our study.
[3]	2013	Computers in Human Behavior	Technology acceptance, Older adults Touchscreen tablet Usability	They examined the adoption of technology for older adults. They made a detailed survey among older users.
[4]	2005	International Journal of Human Computer Interaction	Not available for this document.	It is about the challenge usability issues of methodologies and they offered a new framework for usability testing.
[8]	2002	Proceedings of The International Conference on Computer Communication	Usability, appliance computing, new media, usability evaluation, interactive channels, pervasive computing, interactive TV	This paper is about the idea of new usability. They demonstrated the new approaches should be address to usability for developing technologies. They criticized the methodologies which were used in usability studies.
[9]	2011	International Journal of Computer Applications	HCI, SDLC, Pervasive Computing, Ubiquitous Computing, PC, Needs, Challenges.	They mentioned the usability problem of pervasive computing. They mentioned that there are limited usability studies about pervasive computing application.
[10]	2008	Third 2008 International Conference on Convergence and Hybrid Information Technology	Not available for this document.	It is about Usability Evaluation Factors for ubiquitous device. They scored each usability factor by web-based system. The systemization and simplification is done for usability test on ubiquitous device.
[11]	2000	Ergonomics	Not available for this document.	It is about usability testing and aspects of usability.
[12]	2003	IBM Systems Journal	Not available for this document.	It is about the usability challenges of mobile pervasive computing. They categorized the challenges. It does not cover aspects of usability.
[13]	2008	Mobile HCI 2008 Proceedings	Smart phone, Usability Evaluation, Design, User Interface	It is about the usability of smart phones on different platforms. They did not give any recommendations and techniques to implement usability.
[14]	2008	International Journal of human computer Studies	Enterprise mobility; Organizational usability; Mobile ICT; Foreign exchange trading; Middle East	It is about the organizational usability concept. They tried to empower the understanding of ICT using this concept.
[15]	2006	Pers Ubiquit Comput	Multimodal interaction, Gesture input Speech output ,GUI , Mobile ,Ubiquitous	It is about a gesture input system and its evaluation. This paper only covers ubiquitous perspective not related usability. They conducted an evaluation without considering usability aspects.

[16]	2005	Pers Ubiquit Comput	Login, User authentication, Ubiquitous computing ,CCSW, Activity-based computing, Electronic patient record, Healthcare , Hospitals	It is about new concepts for user authentication in ubiquitous computing. They only described some usability problems associated with login ERP system.
Reference	Year	Publisher	Keywords	What it is about?
[17]	2007	Pers Ubiquit Comput	Not available for this document.	It is about ubiquitous technologies on health-care domain. They conducted two studies and present a context aware mobile computer terminal. In the literature part they mentioned usability and ubiquitous computing shortly.
[18]	2009	European Conference on Cognitive Ergonomics: Designing beyond the Product	Usability evaluation methods, user testing, usability test	It is about usability testing. Two usability evaluation methods represented and according to these methods some examples given. And they mentioned about how these methods can be used to ubiquitous systems testing.
[19]	2013	Pers Ubiquit Comput	Usability, Personalized services , Context awareness, Privacy, Ubiquitous computing	It is about a usability study on Mobile Electronic Personality Context-aware mobile application. They identified user needs, based on user interviews, surveys, prototypes and field evaluations. Firstly, they mentioned the related works, and then they applied usability criteria to their study.
[20]	2012	Pers Ubiquit Comput	Wearable interfaces, Input techniques, Augmented paper, Contextualization, Mobility	In this study, they gave two solutions to enable ubiquitous interactions. These solutions were based on human computer interaction techniques and environments.
[21]	2003	Pervasive Computing, IEEE	Not available for this document.	It is about wearable computing technologies and designing these systems.
[22]	2005	Working Papers on Information Systems	Standards, Pervasive Computing, User Interface, Hypertext	It is about designing ubiquitous computing systems. They investigated design standards on aspects of pervasive computing such as usability and device independence
[23]	2008	Handbook of Research on Ubiquitous Computing Technology for Real Time Enterprises	usability engineering, user interface, interaction design, intelligent user interfaces	It is about user interface design for ubiquitous computing. He gave two approaches for designing user interfaces. He focused two ubiquitous scenarios and according to these scenarios he built an intelligent user interface.
[24]	2014	In Proceedings of the Wireless Health 2014 on National Institutes of Health	Usability Testing, Guideline Reviews, Mobile Health, Mobile Applications	They tested the Health Information Management System Society using usability guidelines. Then, they gave a detailed analysis and a real world case study.
[25]	2004	Intel Research	Not available for this document.	They tried to make easier to share the evaluating results of ubicomps applications between researchers. For this purpose, they proposed a framework and provided a structure with the key areas of evaluation.
[26]	2013	In HCI International 2013-Posters' Extended Abstracts	Technology Acceptance Model, Ubiquitous computing Evaluation Areas, Usability, User Acceptance, University Web Portal Interfaces.	The main purpose of this study was selecting a suitable usability and user acceptance criteria to evaluate the South African web portal interfaces. They applied this study on ubiquitous environments. They provided a guideline for usability and user acceptable standards.
[27]	2014	NISTIR	Not available for this document.	They developed a framework to provide a structure. With this structure cloud user

				experience can be evaluated. The framework identifies the attributes and measures the critical usability areas.
[28]	2010	IEEE Pervasive Computing	Not available for this document.	It is about the usability of public transit system. Author tried to improve enhance the usability of the systems. He mentioned the design issues for this purpose.
Reference	Year	Publisher	Keywords	What it is about?
[29]	2005	Interacting with Computers	Model-based approaches, Tools, Usability, Task Models, Multi-device Interfaces.	It is about the providing a model based approaches and related tools. They mentioned the important issues for usable interactive software. They tried to bring solutions to this area challenges.
[30]	2005	Experience Workshop on Pervasive Computing.	Not available for this document.	They mentioned about the security requirements, challenges and experiences with ubiquitous computing.
[31]	2000	Proceedings on the 2000 conference on Universal Usability	Context-aware computing, mobile computing, social navigation	It is about the design and deployment context aware tools in networked environments. They focused the user while designing the system.
[32]	2002	ACM Transactions on Computer-Human Interaction (TOCHI)	Cooperative design, ubiquitous and mobile technology, usability practice, user interface methodology	They mentioned “design collaboratorium” and defined this term.
[33]	2003	Proceedings of the 4th conference on Information technology curriculum	Human-computer Interaction, usability, usability engineering, design methods, ubiquitous computing.	They mentioned key HCI concepts, and discussed the challenge issues .Then; they deduced that these challenges will drive Information Technology curriculum development.
[34]	2014	Proceedings of the 26th Conference on l' Interaction Homme-Machine	Usability Testing, Ubiquitous Systems, Quality.	They tried to identify challenges for usability testing in ubiquitous Systems. This paper is similar review article but it is too short to conclude any result.
[35]	2008	Proceedings of the working conference on Advanced visual interfaces	Mobile Interaction Design, Prototyping, Usability, Evaluation.	It is about a software framework. Not related our study.
[36]	2013	CHI 2013	Human Factors; Performance; Security	In this paper, they represented their Android Application which uses a novel authentication method. They tested their application and concluded that this application is more secure than the other approaches. Usability is not very related with this paper subject.
[37]	2007	Financial Cryptography and Data Security	Not available for this document.	They presented a usable security idea to design a system. With this idea they tried to take advantage of pervasive computing technology.
[38]	2007	Ubiquitous Comp. and Communication Journal	Pervasive computing, Mobile computing, MARKS, Mobile devices, Middleware for mobile computing, Middleware for pervasive computing	They mentioned the Knowledge Usability, Resource Discovery and Self- Healing Problems. To solve these problems they implemented a middleware which called MARKS. Then, they stated positive affect of MARKS.
[39]	2003	UbiComp 2003	Not available for this document.	It is about computer security in pervasive computing for a usability-wise UbiComp Systems.

[40]	2007	Springer Berlin Heidelberg	Pervasive health care, Wellness Monitor, mote, TinyOS, MARKS, Cancer, chemotherapy, Tmote Sky.	They presented software called Wellness Monitor to utilize the portability and ubiquity of smart devices to help Cancer patients.
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<i>Reference</i>	<i>Year</i>	<i>Publisher</i>	<i>Keywords</i>	<i>What it is about?</i>
[41]	2006	UbiComp 2006 Workshop	Usability, usable ubiquitous computing, smart conference rooms, mobile devices, meeting support, rich media, context-aware computing, collaboration, etc.	They mentioned the challenge between usability and functionality for a smart conference room. They tried to design a usable conference room.
[45]	2015	Future Generation Computer Systems	Communication asymmetry, Cloud-based application, Social networking service, Social networking service, Older adults, Family Community	Before they design and implement a cloud-based application Social Connector, they carried out a formative study to understand the asymmetry between adults and their relatives. They evaluated Social Connector in terms of usability. According to result, they redesigned the application and the last version of application reduced the challenges and helped older adults to communicate their relatives.
[46]	2015	Computers and Electrical Engineering	Health information technology (HIT), Mobile web service, Collaborative recommender, Wireless sensor network, Cloud-computing	They proposed a framework which combines different technology to develop a Mobile Health Recommendation system. Their purpose is to decrease difficulties of the system and help to users efficiently. For this reason they applied a usability study. According to usability evaluation results, users have positive attitude and they believe that the systems will help their personal health management. At the end of the paper, the authors identify that the usability responses will help to understand the user feeling.
[47]	2015	Computers in Industry	Enterprise information system, Manufacturing, ICT, Data value chain, Context Awareness, Usability, Human learning	They discussed the problems in the Enterprise Information Systems (EIS) such as context awareness and usability. They believe that logical context can improve the usability of (EIS) without adding new information.
[48]	2015	Computers in Industry	User experience of smart home, Augmented reality, Virtual reality, Hybrid reality, Visualization and interaction	They mentioned that there is little study to evaluate user experience. They evaluated context-aware smart home in terms of usability. They proposed an approach to developers to understand users. The results show that their approach helped developers and end users to more efficiently experience the smart home.
[49]	2015	Procedia Computer Science	Usability Evaluation; Internet Protocol TV; Monitoring Devices; Home Care	They presented the usability evaluation of a health care application based IPTV which brings technical solutions to support home care. The results show that elderly users are satisfied while interacting with TV set, but some control functions need to be developed.

[50]	2015	International Journal of Medical Informatics	Medical informatics, Anesthesiology, Medical records systems computerized, Hospital information systems	This study evaluates the use and usability of QR codes systems in the anesthesia information management system. They used questionnaires to measure usability. The results show that using QR codes have high acceptance and satisfaction.
Reference	Year	Publisher	Keywords	What it is about?
[51]	2015	International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences,	Augmented tabletop game; Context-aware technology; RFID; User-centered design	Using context-aware technology RFID, they developed a new generation game. They applied user-centered design during the development. In the usability evaluation, they used heuristic approach to find the problems of the prototype.
[52]	2015	Proceedings of the Multimedia, Interaction, Design and Innovation	User interface; graphical user interface; usability evaluation; user experience; wearable computing, Google Glass; education; HCI workshops; ubiquitous computing	They evaluated Google Glass device interface with unfamiliar students. They tried to find the challenges about wearable technology. They mentioned that desktop/mobile design principles not suitable for wearables. According to results, users had difficulties to touch Google Glass screen.
[53]	2015	PerDis '15, Proceedings of the 4th International Symposium on Pervasive Displays	tools; space; behavior; ubicomp; software	They evaluated People Watcher Application in terms of usability to analyze <i>interaction in space</i> . They performed a case study and applied System Usability Scale. They argued that HCI's approach to space is less and tried to understand the effect of space.
[54]	2014	UbiComp' 2014	CSCW, Ubiquitous Computing, Affinity-Diagram, Collaboration, Brainstorming	They proposed a system which supports user's collaboration using different devices. They identified that usability is the key element of collaboration while doing brainstorming.
[55]	2015	UbiComp' 2015	Animal-computer interaction; user-centered design; assistive technologies; canine design; assistance dogs	They explored the process of designing an alarm system which enables dogs to call for help. They tested this emergency alarm system for different situations and tried to find dog's behavior. To identify the requirements, they also conducted a usability testing with human participants.
[56]	2015	CHI 2015	Classifiers; accuracy; accuracy acceptability; inference;	Not very related our subject. They introduced a new measure which enables to optimize classifier evaluation for HCI and ubiquitous system.
[57]	2015	Mobile HCI'15	mobile interaction; multi-modal; elastic input; mobile input device; wearable; string-based interaction; casual interaction	They explored the potential of elastic controllers. They tested elastic interaction using <i>Elasticcon</i> which is a wearable device. They prototyped this device and made small three case studies. They believe that their device will be applicable for the selection, manipulation and navigation tasks.

[58]	2015	UbiComp' 2015	Life Science; Hands-free Documentation; Google Glass;	In this study, they used Google Glass combining it with a wrist-worn gesture sensor. They tested wearables in the Wet Lab to capture and guide the experiments. They conducted a usability study with 22 participants. According to results, wearable systems minimize the required interaction efforts, and provide the means to interact with a computing system.
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<i>Reference</i>	<i>Year</i>	<i>Publisher</i>	<i>Keywords</i>	<i>What it is about?</i>
[59]	2015	UBICOMP/ISWC '15	Mobile ambulatory assessment; mood sensing; mood recognition; smartphone-based wearable sensing	In this study, they present a context-aware application which assess the user' mood. They evaluated this app in terms of usability and unobtrusiveness. Firstly, they identified the features which are best for the recognition. Then, they conducted the usability study with 9 participants. They applied System Usability Scale (SUS) and find the average SUS score is 90. Moreover, they asked the participants for general feedback. According to results, application has very high usability and minor obtrusiveness.
[60]	2015	CHI 2015,	ubiquitous networks; framework; web; cross-device	In this study, they presented a framework for creating web application across multiple devices and called it Connichiwa. They had four key goals. One of them was usability of Connichiwa's API. They tested technical feasibility of Connichiwa in seven example applications. According to results Connichiwa supports modern consumer devices and these devices are not limited by location, number, size or technical capabilities. No external hardware is required.

Personal and Ubiquitous Computing is the first journal that is exclusively dedicated to the field of usability of ubiquitous computing. Besides this journal many high quality journals such as IEEE CS and IEEE ComSoc, International Journal oh Human Computer Studies, Interacting with Computers and TOCHI ACM Transactions on Computer-Human Interaction have published articles focusing on usability aspects of pervasive computing.

4. Limitations of the Study

In this review study, the keywords “usability”, “ubiquitous”, “pervasive”, “ubiquitous computing”, “pervasive computing” and “mobile computing”, was used and these keywords were looked for in abstract, title and keywords, and content. However, all articles about usability aspects of ubiquitous computing were not reached. We just only searched in Science Direct Database, ACM Digital Library database, Taylor & Francis Database and Google Scholar. Moreover, there can be some articles in these databases are not presented in this study. Here we just presented the articles which contain at least two keywords together such as “usability” and “ubiquitous”. Furthermore, some articles did not choose best keywords related to their study and not investigated the subject of the study in the abstract part of article very well. The other limitation in the study is that we could not reach the full text format of the articles. Most articles in the Taylor & Francis Database need to payments to see full text. Because of this reason these articles did not added to study.

5. Discussion & Conclusion

We live in a digital world which controls our physical environment. The increasing use of wireless network supports these digital devices to use mostly people. People prefer mobile devices such as smart phones and tablets to personal computers or laptops. This brings that accessing to information and services is available any time and everywhere. This can be called ubiquitous computing. There is a high demand of pervasive computing applications and they have grown in the last years. However, a large group of people do not engage with these developments. This attracted the researchers to think this problem and they link it with usability of systems. In this study, we reviewed 53 the articles which published on usability of ubiquitous computing. Within the scope of this study, the first stage is defining ubiquitous and usability. In the second stage, this paper organizes and classifies the literature on the area in order to facilitate future research. The review covers 53 peer-reviewed journal articles from 26 journals published between 2000 and 2015.

Articles about usability of ubiquitous computing systems exist in various journals, and indexes. In order getting valuable articles, and preparing comprehensive study, we searched in Science Direct Database, ACM Digital Library database, Taylor & Francis Database and Google Scholar. Firstly, some keywords were determined for search, such as “usability”, “ubiquitous”, “pervasive”, “ubiquitous computing”, “pervasive computing” and “mobile computing”, and these keywords were looked for in abstract, title and keywords, and content between 2000 and 2015.

In the Results Part, we looked all paper and examined them what are they about. As seen as the Table 2 some articles were not related our main subject. Some of them was only related the usability part, and some of them with the pervasive computing part. Moreover, design issues with the pervasive computing systems mostly mentioned in these studies. Because of the keywords, a few articles found which are not related with our purpose. They just use the keyword usable with the technologies such as wearable and security applications. They were about new concepts for user authentication in ubiquitous computing. They only describe some usability problems associated with login ERP system [16].

We can divide our study into two parts: between 2000 and 2014 and in 2015. Before 2015, as the mentioned article [9] that there is limited usability studies about pervasive computing application and none of the articles mentioned the business perspectives of the usability studies in the ubiquitous computing. They did not state the cost of these techniques. The other remarkable point that most articles only considered the smart phones not all mobile devices. Articles are more related with the usability of smart phones on different platforms than ubiquitous computing [13]. Especially, the most usability studies exist in the mobile health field [17, 24, 40]. Just a few articles were about public transit system and smart places such as smart conference room [28, 40]. The other field was context-aware usable systems. Similar as the other fields they just spell the name of usability. They don't make any usability tests on the application. In this study, I recognized that only six articles [3, 17-19, 40, 41] conducted usability test and applied usability criteria to their application until 2015. As the mention above to understand the system usability we need to apply available usability test.

In 2015, there are more study related to usability and ubiquitous computing. I found 77 articles published in different databases. I examined them in detail and showed 15 of them which are more related than the others in this study. 5 of them were related to social life [45, 49, 53, 55, 59]. Two of them [46, 50] were related to mobile health field. Three of them were about on wearable technology [52, 57, 58]. Just one of them is related to smart home technology. Moreover, context-aware systems were handled by the researchers. Researchers gave more attention to usable ubiquitous systems in the last year.. The big difference between 2015 and 2000-2014 is that researchers conducted usability tests with the application or systems. Articles [48, 49, 57, 59] are very good examples to usability studies.

According to this review study, we can see that the other important issue is about the attributes or methodologies of usability. The first paper [8] which examined in detail was about the idea of new usability. They demonstrated the new approaches should be address to usability for developing technologies in 2002. They criticized the methodologies which were used in usability studies. They warned us to if we don't understand and implement new usability, we will face bad-designed systems, services and products. I see that researchers did not consider this warn so now we have the ubiquitous usability problems. As the mentioned at Article [9] usability characteristics need to update to implement pervasive systems. We still use Nielsen's basis proposed model. Articles [8, 9] agree with the enhancing the proposed model.

Based on challenges identified, user is one major component of pervasive computing and the future works should apply a usability test to pervasive computing environments. When they design a new

system they need to consider user interaction, interface of environment and should develop it easy to use. In the last year, Mobile HCI, CHI and Ubicomp conferences gave more attention to usability aspects of ubiquitous computing. This is good news for the researchers and developers. Moreover, a specific conference or journal can be arranged for this subject. It will help developers and researchers to know current methodologies and technologies about aspects of usability in pervasive computing.

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