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Factor Analysis를 이용한 유비쿼터스 컴퓨팅 기반 정보시스템의 요구사항 분석
(Extracting Requirements for Ubiquitous Computing Technology-based IS Deploying Factor Analysis)

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Abstract

This paper discusses an empirical study on extracting requirements for ubiquitous computing technology-based information system (ubi-IS) using factor analysis. After preliminary review of related literature, features specific to ubiquitous computing technology have been retrieved, selected in terms of main elements of information system (IS) (network, device, user interface, and operating system), and further used as variables during conducting factor analysis. Quantitative data was collected through questionnaire approach. The results of factor analysis manifested 5 factors containing 15 variables, and eventually, based upon the extracted factors the requirements for ubi-IS were identified.

1. Introduction

Various projects and research have been undertaken in the area of ubiquitous computing technology-based service and environment since the early concept of ubiquitous computing was identified by Mark Weiser. The general concept of ubiquitous computing lies in the idea of "enhancing computer use by making many computers available throughout the physical environment, but making them efficiently invisible to the user." (Weiser, 1993b). Furthermore, ubiquitous computing is said to envisage "world of fully connected devices, with cheap wireless networks everywhere, and information accessible everywhere." (Weiser, 1993b).

In the field of IS based on ubiquitous computing technology, research is being carried out. The purpose of those studies is to overcome some drawbacks of conventional information system such as passiveness of information acquisition, difficulty in information share, etc (Hong *et al.*, 2004) by applying ubiquitous computing technology. Conventional computer-based IS can be leveraged by ubiquitous computing concept in several areas. Specifically, "as ISs increase their intelligence, it will become more important for these systems to acquire knowledge and expertise in agile ways in order to provide employees and decision makers with relevant information. Thus, ubiquitous computing technologies fit current intelligent ISs well." (Kwon *et al.*, 2005b).

To accomplish this, studies on applying ubiquitous computing technology concept to IS are being undertaken. In particular, Hong *et al.* (2004) proposed a ubiquitous computing technology-deployed IS " which identifies, manipulates, and extracts required information in an automated manner. " As well, Kwon *et al.* (2005a) suggested an intelligent expert system for proactive services deploying ubiquitous computing based on elaborate expert system paradigm, 'Context-Knowledge-Dialogue-Data-Model'. Further, they proposed a proactive intelligent decision support system as an expert system deploying ubiquitous computing technologies (ubiDSS) that is able " to improve the decision making framework in gathering and processing decision makers' contextual data in an automated way, which intelligently extracts proactive decisions." (Kwon *at al.*, 2005b).

However, current research on developing ubiquitous computing technology-based information system (ubi-IS) is being done without prior explicitly defined requirements for it. In the earlier mentioned work, Hong *et al.* (2004) put forward an improvement plan of existing ISs, where it was stated that ISs should provide personalized service, as well as different tasks, event and other relevant information should be stored in ISs to identify and manipulate easily connected processes. However, those requirements were not underpinned formally. Likewise, Kwon *et al.* (2005a, b) in both their studies described development of an expert system deploying ubiquitous computing technologies just mentioning its capabilities without realizing them within the concept of IS.

One way of formalizing the method of extracting the essential requirements to ubi-IS is through applying factor analysis. Particularly in this research, a methodology of extracting the requirements involving factor analysis was developed. The methodology comprised several stages. First, through related literature review, features specific to ubiquitous computing technology have been retrieved. These features were selected in terms of the main constructs of IS (network, device, user interface, and operating system), and further used as variables during the conducting factor analysis. Secondly, quantitative data was collected through a questionnaire approach. The results of factor analysis identified 5 factors containing 15 variables. Finally, the extracted factors served as a foundation for formulating the requirements for ubi-IS. In addition, the extracted requirements were classified in terms of priority which can be also considered in the technology adoption strategy for building a ubi-IS. Hereby, the purpose of this study is to extract and articulate requirements for ubi-IS and, therefore, fill in the gap mentioned earlier.

The remainder of this paper is organized as follows. Section 2 reviews features of ubiquitous computing paradigm, requirements for traditional ISs, and capabilities of ubi-IS.

In Section 3, the research methodology, including an overall procedure, as well as specific procedure, are described. Analysis and results are represented in Section 4. Section 5 discusses the requirements for conventional IS as opposed to the requirements for ubi-IS, demonstrates scenario of both ISs, as well as the priority among the extracted requirements. Finally, Section 6 concludes the paper.

2. Related research

2.1. Features of a ubiquitous computing paradigm

The concept of ubiquitous computing was first proposed by Mark Weiser in early 1990s. In his early works, he described the paradigm of ubiquitous computing as a technology "which is essentially invisible to the user." (Weiser, 1993a). Abowd (1999) named common features of ubiquitous computing applications: *transparent interaction, context-awareness,* and *automated capture*. Transparent interaction of a ubiquitous computing application, according to Abowd, can include gesture and handwriting recognition, freeform pen interaction, tangible user interfaces (using physical objects to manipulate electronic information) and manipulation interfaces (embedding sensors on computational devices to allow for additional modes of interaction). Context-awareness is an ability to sense the environment and to process speech and video and turn those signals into information that expresses some understanding of real-life situation. Automated capture stands for a feature of a ubiquitous computing environment that makes it possible to record everyday experiences of a user for later use.

Due to these advanced features of the ubiquitous computing paradigm its application seems to be promising and possesses a rich potential. However, so far no attempts have been done to realize them within the concept of an IS. Hence, this research defines the features of ubiquitous computing paradigm in terms of the concept of IS which is an intermediate step towards the extracting general requirements for a ubi-IS.

2.2. Requirements for IS

As the body of the IS concept is developed well enough, the requirements to it are also defined. One of the critical requirements is security. Mouratidis *et al* .(2004) stated that "security introduces not only quality characteristics but also constraints under which the system must operate." Accessibility, another significant requirement, characterizes the ease of access to information via Internet-based interfaces (Ziliaskopoulos and Waller, 2000; Arch-int and Batanov, 2003). Furthermore, Ziliaskopoulos and Waller (2000) mentioned several more requirements to an Internet-based geographic IS. Among them, an important issue is the ability to deal with real-time data, as well as simultaneous execution of multiple objects on many computers. Also, they recognized a need of an efficient administrative support system that allows users to manage their datasets and reports. Moreover, scalability of IS is a crucial requirement, as long as an IS should be able to evolve as more users and data get involved, and accommodate future growth and changes.

As far as the requirements are well established, consistency of an IS is guaranteed. However, in existing IS environments, an IS doesn't not provide users with information sufficiently and effectively, because users waste consume many hours searching for necessary information. Traditional ISs cannot be managed and processed automatically without a user's intervention, thus, the user's role is very important in the operational aspect of existing IS (Hong *et al.*, 2004).

Improvements can be made in the following areas. First, an IS should be able to recognize the task a user wants to accomplish. Second, tasks, events and relevant information should be saved in the IS to easily identify and manipulate connected processes. Next, the IS should be able to search and extract required events to process tasks automatically. What is more, the IS should process and manage the extracted events, and provide output of the extracted events to the user. Finally, all processes should be carried out automatically with minimum users' intervention (Hong *et al.*, 2004).

2.3. Capabilities of ubiquitous computing technology-deployed IS

To realize the enhancements stated above, a number of studies described the application of the key technologies of ubiquitous computing. Among scarce studies in this area, a remarkable one was by Kwon *et al.* (2005b). Their work described a decision support system enhanced with proactive and intelligent expert systems based on ubiquitous computing technologies (ubiDSS) that can utilize contextual data. To show the applicability of the proposed system, a prototype, Context-Aware Multi Agent System-My Optimization (CAMA-myOpt) was implemented. This next-generation DSS is able to support mobile decision making by providing "access to the smart space and/or service zone. In addition to ubiquity, the study described other capabilities of ubiDSS such as embeddedness, mobility, nomadicity, pro-activeness, invisibility, and portability." A key capability, according to Kwon *et al.*, is context awareness, which they define as an ability to automatically and transparently sense time, identity, location, and entity, so that the DSS is unobtrusive to the decision maker.

3. Research methodology

3.1. Overall procedure

The research methodology comprised four major stages (Figure 1). In the first stage, through exhaustive review of related literature (journal papers and proceedings) features, are derived characterizing the ubiquitous computing paradigm. In the second stage, a survey is conducted using a questionnaire to acquire quantitative data for factor analysis. The questionnaire included a scenario demonstrating an example of a ubi-IS as well as statements defining each feature. In the third stage, having obtained the quantitative data, factor analysis is executed using the Statistical Package for Social Science (SPSS) v.13. This stage obtains representative factors consisting of the presented variables (features of ubi-IS). Finally, during the last stage, the extracted factors are interpreted, creating a basis upon which the requirements for the ubi-IS were formulated.

3.2. Specific procedure

In the first stage, an exhaustive literature review is carried out. Specifically, the literature includes journal papers and proceedings related to the ubiquitous computing paradigm. Altogether in our review, 30 papers and proceedings dating from 1990 to the present were examined and at least 50 retrieved features of ubiquitous computing service, applications and environment were derived. Out of the 50 retrieved features 17 related to ubi-ISs were sorted by experts in terms of the four major elements of IS: network, device, user interface, and operating system.

In the second stage of the research methodology, a survey is conducted to collect quantitative data essential for executing a factor analysis. Particularly, a data collection questionnaire approach is utilized. The questionnaire consists of a scenario of a ubi-IS specific workflow example and statements characterizing each feature. A respondent, having read the scenario and clearly envisioned what ubi-IS is, can approve or disapprove the statements drawn in the questionnaire. All features in the questionnaire are supposed to be evaluated on a 7-point scale, where the extreme points of "1" and "7" indicated whether the respondent completely disagrees or completely agrees with each statement respectively. An example of such a statement is displayed below. The questionnaires were distributed among 100 graduate students having at least five years the experience in computer and industrial engineering which implies that they have a sufficient notion of the concept of IS.

Example: "The service through ubiIS should be provided calmly, namely without users' recognition."

Completely *1 2 3 4 5 6 7*
Completely *agree*
don't agree

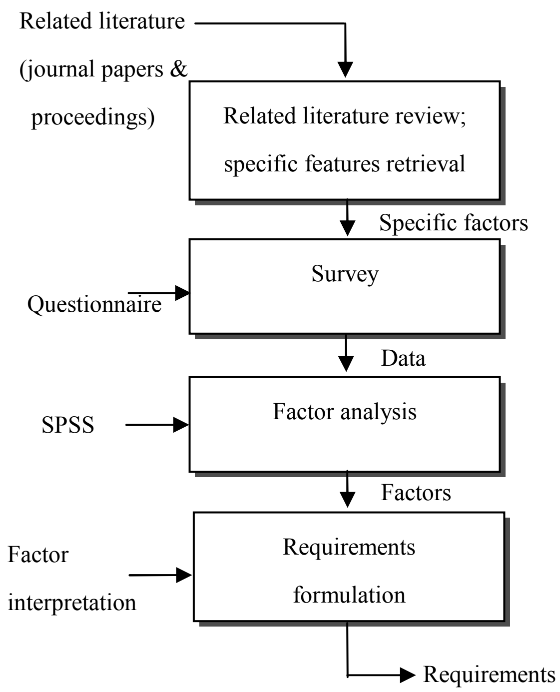

Figure 1. Research methodology procedure

In the third stage, prior to executing the factor analysis itself some preliminary analyses is conducted. In particular, to ensure the suitability of the variables, the KMO (Kaiser-Mayer-Olkin) test and Bartlett's test of sphericity were carried out. The KMO test measures the adequacy of a sample in terms of the distribution of values for the execution of factor analysis (Geourge and Mallery, 1999). The acceptable values should be greater than 0.5 (Geourge and Mallery, 1999; Field, 2000). Bartlett's test of sphericity determines whether the correlation matrix is an identity matrix, i.e. the matrix, all components of which are '0', except the diagonal components which are '1', because the factor analysis becomes meaningless if an identity matrix is exhibited (Geourge and Mallery, 1999; Field, 2000).

The factor analysis itself comprises several major steps, where the first is the decision on the number of factors for inclusion. Factor loadings are the correlations between variables and the factor. If factor loading is high (more then 0.4) it implies that the factors and variables are critical (Lattin *et al.*, 2003). In order to determine the number of factors for inclusion, the Kaiser criterion (or eigenvalues approach) and the percentage of variance approach are used. Following the Kaiser criterion, factors number for inclusion should be equal to the number of eigenvalues of the correlation matrix that are greater than 1 (Kim and Mueller, 1978). In the percentage of variance approach, all extracted factors should account for at least 60% of total variance (Malhotra, 1996). Initially, factors in classical factor analysis are described in terms of *common factors* and *unique factors*, where the common factors account for the correlations among the variables, whereas the unique factors account for the remaining variance, including error associated with each variable (Harman, 1976). Thus, the lower the variance of unique factors that includes error, the more reliable the measure is (Lattin *et al.*, 2003). Furthermore, the results are difficult to interpret right after the extraction unless the factor solution is rotated. In other words, non-rotated factor solution has arbitrary orientation, which is referred to as *rotational indeterminacy*

(Lattin *et al.*, 2003). For this reason, rotation is used to simplify factor solution. Finally, to examine the internal consistency of the survey, the value of Chronbach's alpha is calculated. A minimum level of 0.7 is recommended for the extracted factors to be considered reliable (Nunnally, 1978).

During the final stage of the methodology, the factors extracted through factor analysis are analyzed in terms of the features they were constructed of. Specifically, it was inferred how the features cooperated with one another so that they could logically construct a certain requirement.

4. Analysis and results

4.1. Test overall

As the methodology implies, in the first stage 50 most frequently mentioned features specific to ubiquitous computing paradigm were retrieved, out of which 17 were extracted with the viewpoints of IS. These features were classified into 4 major constructs of IS, such as network, device, user interface, and operating system as represented in Table 1.

In the second stage, in order to collect quantitative data for conducting factor analysis, a questionnaire was administered. The data collection was completed within 2 weeks. Out of 100 distributed, 80 feasible questionnaires were returned and considered in the factor analysis.

No		Features	Description
1	NETWORK	Mobility	Ability to be operated in mobile environment
2		Security	Ability to protect users' personal information
3		Accessibility	Ability to be easily accessed
4		Scalability	Ability to provide stable and scalable work even if the system is overloaded
5		Interoperability	Connects various kinds of devices
6	DEVICE	Invisibility	Ability to provide service calmly, namely without users' recognition
7		Durability	Ability to maintain 'Power-on' status all the time
8		Embeddedness	Ability to be embedded into physical environment and be unseen
9		Portability	Ability of being used hands-free or with one hand
10	USER INTERFACE	Customizability	Ability to provide information to users according to their profile and preferences
11		Nomadicity	Ability to be used while a user moves from place to place
12		Usability	Ability to underpin input and output with by various

			user interfaces
13		Versatility	Ability to be operated as a user moves from place to place and be manipulated using different physical objects
14	OPERATING SYSTEM	Context inference	Ability to provide users with service fairly correlated with their current context
15		Agility	Ability to complete operations on real-time basis
16		Personalization	Ability to remember users' common patterns and use them later
17		Pro-activeness	Ability to provide users with the service they are likely to require in the nearest future depending on their current situation

Table 1. Features of ubiquitous computing in terms of IS concept.

4.2. Results

On the third stage of the research methodology, factor analysis was performed on the collected data. However, prior to factor analysis itself, to ensure the suitability of the variables, KMO test and Bartlett's test of sphericity were conducted. The result of the KMO test was 0.639 and the probability associated with Bartlett's test of sphericity was 0.000 which was less than then level of significance. Consequently, the variables were concluded to be statistically suitable for the factor analysis.

After executing the factor analysis itself, the factors extracted in this study accounted for 68.827% of the total variance explained, which is considered to be acceptable. To interpret the results a widely used orthogonal rotation (Varimax) was applied to find the orientation of factor axes so that each variable has relatively high loadings (positive or negative) on only a few factors, preferably on 1, with most of the other loadings being close to 0 (Lattin *et al.*, 2003). Therefore, the variables left out of the extracted factors were *personalization*, and *usability*. Specifically, these 2 variables with factor loading more than 0.4 were still loaded on more than 1 factor after the rotation. To examine the internal consistency of the survey, the value of Chronbach's alpha was calculated. The resultant value of Cronbach's alpha of this study was 0.835, which indicated the internal consistency of the survey.

4.3.Extracted factors

In the final stage, based upon the retrieved factors,
the requirements for ubi-IS were articulated. On the whole, 5 factors including 15 variables were extracted through factor analysis as Table 2 shows.

Factor	Variables constructing the factor	Factor loading	% of variance explained	Cumulative % of variance
F1	Durability	0.737	27.587	27.587
	Scalability	0.728		
	Agility	0.667		
	Versatility	0.610		
	Accessibility	0.575		
F2	Portability	0.805	13.227	40.811
	Interoperability	0.791		
	Mobility	0.753		
	Nomadicity	0.704		
F3	Context inference	0.810	11.863	52.674
	Customizability	0.755		
	Pro-activeness	0.719		
F4	Embeddedness	0.871	8.759	61.433
	Invisibility	0.645		
F5	Security	0.897	7.934	68.827

Table 2. Extracted factors

4.4. Interpretation of the extracted factors

Factor	Factor interpretation	Variables constructing the factor
F1	Negotiability	Durability
		Scalability
		Agility
		Versatility
		Accessibility
F2	Seamlessness	Portability
		Interoperability
		Mobility
		Nomadicity
F3	Autonomy	Context inference
		Customizability

		Pro-activeness
F4	Transparency	Embeddedness
		Invisibility
F5	Security	Security

Table 3. Interpretation of the extracted factors.

Factor 1 "Negotiability"

The first factor was constructed by the combination of *durability*, *scalability, agility, versatility,* and *accessibility.* To guarantee the negotiation between users' needs and IS' services, the IS should agilely respond to versatile users' commands while holding the status of power-on as well as maintaining maximum accessibility all the time.

Factor 2 "Seamlessness"

Four variables represented in the second factor were *portability, interoperability, mobility,* and *nomadicity.* In order to provide service pervasively and seamlessly, IS should be operated in a mobile environment. As a nomad user of the ubi-IS moves from place to place with a portable device accessing the IS, the interface, which is underpinned by interoperable network should follow the user.

Factor 3 "Autonomy"

The third factor was composed of three variables: *context inference, customizability,* and *pro-activeness*. To provide service to users without their interference ubi-IS should be able to recognize a user's current status and, based upon the current context and the user's personal profile and preferences, the IS should provide service the user is likely to request in the future.

Factor 4 "Transparency"

"*Transparency*" was build up of *embeddedness* and *invisibility*. To guarantee that the service is unobtrusive it should be delivered to users through unseen devices, embedded into physical environment, calmly, without users' recognition.

Factor 5 "Security"

This factor included the stand alone variable *security*. Whatsoever, it is quite a significant factor for ubi-IS in particular, and ISs in general, in contrast to the previous factors. Hence, it might be the reason why *security* was not included within other factors but stayed self-inclusive.

7. Conclusion and future work

In this paper a study on extracting the requirements for a ubi-IS using factor analysis approach was demonstrated. The results of factor analysis revealed 5 requirements for ubi-IS represented by autonomy, transparency, seamlessness, security, and negotiability. In addition to being identified by factor analysis, it would be useful to rank them in terms of their importance as well as to derive a priority among the features that constructed the requirements. The results of these analyses would manifest the most important requirement among the others alongside with the most important feature. The sequence of the features importance could be further considered in further technology adoption for building a ubi-IS.

An important implication of this research can be the fact that it is reasonable to define the objectives an IS is expected to reach, in order to avoid trial-and-error cases during its development and implementation. Particularly in this study, an attempt was made to determine what kind of requirements a ubi-IS should meet from the standpoint of its potential users. Thus, the 5 requirements articulated earlier can be regarded as critical for designing a substantial IS based on ubiquitous computing technology since those requirements blend the essential characteristics of ubiquitous computing technology in terms of an IS concept.

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