

Research Status and Trend Analysis on Context-Aware Application (2005-2014)

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Abstract

Recently, context-aware application has been one of the hottest researching fields in the domain of business intelligence. By reviewing the progress of context-aware application in these years, this paper proposes a four-layer classification framework and gives an analysis and comparison to the concept and theory, context-aware computing and typical application which are related to context-aware application. It also summarizes their characteristics and effects from the point of practical use. Lastly, some discussions and suggestions were given to emphasize the difficulty of current application conditions.

Keywords: Context-aware; Context modelling; User preference elicitation; Context-aware application; User interface

1. Introduction

With the development of mobile communication network, cloud computing and artificial intelligence and the appearance and popularization of wearable device as well as the price of sensor are falling, smart life is on the road in our daily life. To provide adequate service for the users, applications and services should be aware of their contexts and automatically adapt to their changing contexts, which is known as context-awareness [1, 2]. Schilit and Theimer first introduced the term “context”, describing it as location, identities of nearby people, objects and changes to those objects [3]. Hull *et al.* described context as the aspects of the current situation [4]. However, these definitions are too broad. Definition given by Dey and Abowd is widely recognized [5]. According to their definition, context refers to

“Any information that can be used to characterize the situation of entities (i.e., whether a person, place or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves.”

In the traditional recommendation system, people always pay attention to the relation between users and items, ignoring the context information between them. In order to improve the accuracy of recommendation and the satisfaction of users, some experts introduce context-aware computing theory into the recommended system. Numerous journals and conferences articles related to context-aware application have been published. Many researchers especially universities and institutes such as Free University of Bozen-Bolzano [6], Technical University of Munich [7], Seoul National University [8], Microsoft Research [9] are interested in context-aware application. ACM Conference on Recommender Systems (RecSys) has holding Workshops on Context-Aware Recommender Systems (CARS) from 2009, which mainly involved in the present hotspots and critical issues, such as context data acquisition and context modeling.

Hong *et al* proposed a five-level integrated framework for context-aware system: concept and research layer, network layer, middleware layer, application layer and user infrastructure layer, which is particularly instructive for the later research [10]. This architecture also can be applied to context-aware application. However, it has some defects the internal subdivisions of the application layer are unreasonable; the review only collects journals but ignores the academic value of the other literature; the review covers the period from 2000 to 2007, but in recent five years, research on context-aware application has been changing every day. Therefore, it is necessary for a review analysis again. In brief, the main objectives of this review are:

- (1) To classify and summarize research relevant for context-aware application.
- (2) Provide a conceptual framework for the integration and classification of articles.
- (3) Give suggestions for other researchers by the literature review.

The study is organized as follows: firstly, the research methods used in the data collection are described; secondly, the criteria used for classifying the literature on context-aware application is presented; thirdly, the context-aware application articles are analyzed and the classification results are reported; finally, conclusions are presented and the future research trend is discussed.

2. Research Methodology

2.1. Data Collection and Processing

Considering most of the contemporary research is published in conference proceedings, we included both academic journals from various disciplines and conference proceedings in our search. Despite a potentially lower quality of the conference proceedings, they are informative for charting the current research topics in this rapidly progressing area of research, and for identifying gaps to be covered by future research. We also expect that the best conference papers will evolve to journal articles and thus serve as leading indicators for the focus of future journal publications.

We set three selection criteria for extracting context-aware articles. If the papers did not meet the criteria, then they were excluded. The criteria are described as follows:

(1) We started the literature search with a wide systematic scan of online academic journals and conference databases based on the keywords “context-aware”. The following databases were searched: *ProQuest Direct*, *EBSCO Business Source Premier*, *Science Direct*, *Spring Link Online Libraries*, *IEEE Xplore* and *ACM Digital Library*.

(2) This paper mainly surveys the articles published from 2005 to 2014, perhaps involved a small amount of literatures before 2004. Meanwhile, some papers which were irrelevant to context-aware (except paper titles) or too pale in content to be useful were eliminated.

(3) To ensure the quality of the conference papers, we focused our search on a few established conferences that are listed in Table 1. Besides, some other high-quality literatures from other conference also have been collected.

Table 1. Main Conferences Included in the Literature Search

Conferences by topics
Computing & Processing (Hardware/Software)
International Conference On Pervasive Computing And Applications(ICPCA)
Asia-Pacific Services Computing Conference(APSCC)
International Conference on Ubi-Media Computing (U-Media)
International Conference on Embedded and Ubiquitous Computing(EUC)
Communication, Networking & Broadcasting
International Conference On Advanced Communication Technology(ICACTION)
International Conference on Future Computer and Communication(ICFCC)
International Wireless Communications and Mobile Computing Conference
Signal Processing & Analysis
International Conference on Multimedia and Ubiquitous Engineering(ICMUE)
International Symposium on Information Science and Engineering(ISISE)
International Conference on Internet and Web Applications and Services(ICIW)
Others
Symposium on Usable privacy and security

The papers were selected according to the procedures shown in Figure 1. First of all, the articles were searched using six online databases. The total number of articles is 1492 and the detailed information is as follows: IEEE Xplore (537), Springer Link Online Libraries (303), Science Direct (217), ACM Digital Library (235), ProQuest Direct (141) and EBSCO Business Source Premier (59). Next, 894 articles were excluded because they did not have the keyword “context-aware” in the titles or abstracts. Finally, the articles were carefully reviewed to select those that considered context-aware as the core part. 306 articles remained because 292 articles did not meet the selection criteria. Based on these procedures, a total of 306 articles met all the selection criteria.

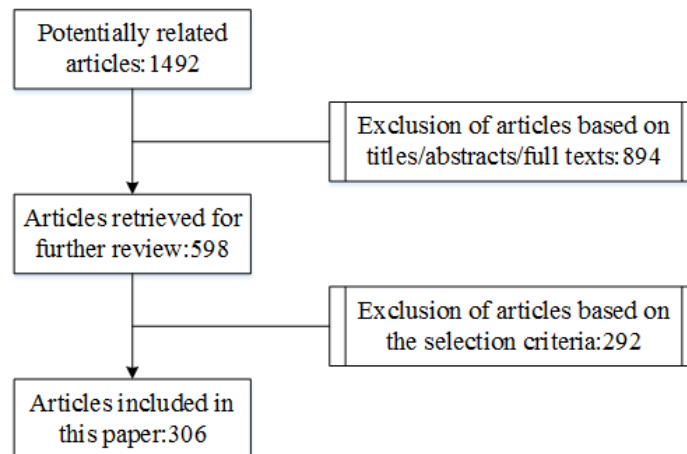


Figure 1. The Procedures to Select the Articles

2.2 Classification of Context-Aware Application Literature

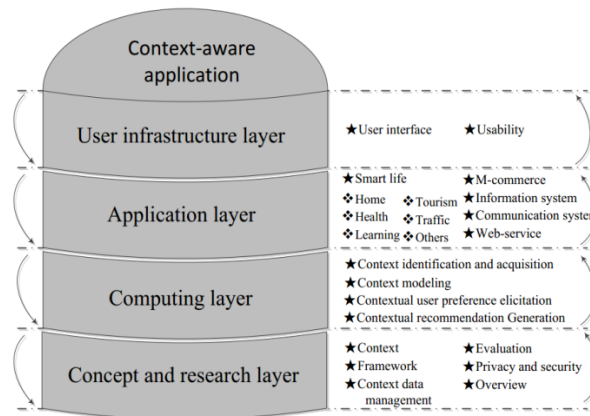


Figure 2. Classification Framework for Context-aware Application Papers

The classification framework is developed for classifying the literatures related with context-aware applications, which based on the literature that explores the context-aware prototype, systems, and application to offer classification criteria for dividing the literature appropriately. Hong *et al.* proposed a five-level integrated framework (concept and research layer, network layer, middleware layer, application layer and user infrastructure layer) for context-aware application [10]. In fact, the function of network layer and middleware layer can be combined for context-aware computing. In addition, the classification of context-aware application is defective: the application of smart space is too narrow that should be extended to tourism, traffic and others. Hence, the five-level framework proposed by Hong *et al.* can also be reduced to a four-level framework: concept and research layer, computing layer, application layer and user infrastructure layer. The classification framework for context-aware application is shown in Figure 2 the classification framework recognizes that context-aware application articles consist of four levels and each of them is discussed as follows:

2.2.1 Concept and Research Layer: It is the lowest level of the framework, which involves theories and foundation to construct context-aware systems. The articles included here describe the concept of context; the framework of context-aware system which illustrates acquiring, discovering, interpreting and accessing various contexts to build context-aware services; context data management; the evaluation that is focused on the evaluation method of the system and privacy and security when using context-aware application. Articles dealing with a general definition, foundational concepts of context-aware application and so forth were grouped under the heading “context-aware overview, content and characteristics”.

2.2.2 Computing Layer: Context-aware computing plays an important role in the context-aware application, which mainly involves with the following technologies:

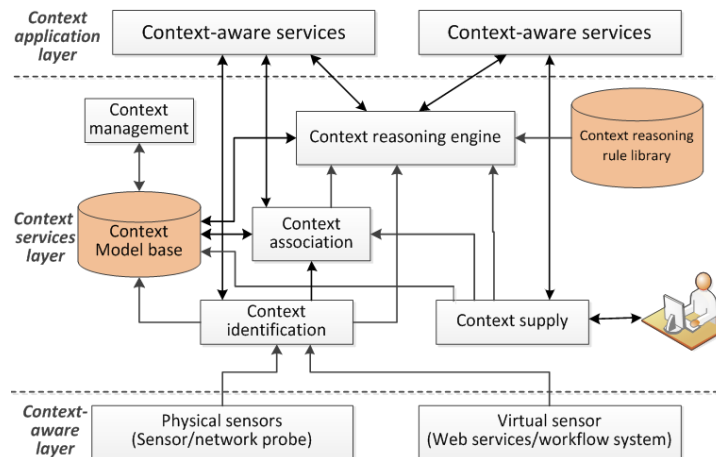


Figure 3. Technical Architecture of Context Identification and Acquisition

(1) Context identification and acquisition technology: The identification and acquisition of context not only provided by man-machine interaction, but it also recognized automatically by sensors [11]. In the man-machine interaction, the system will guide the users to express their current context accurately and input them into the system, to elicit the current context information of the users. While in the process of recognizing context automatically, direct context is commonly acquired by sensors or application software, whereas indirect context is obtained by inferring [12]. As Figure 3 depicts, context identification and acquisition technology architecture are built by different technologies to acquire the context effectively and interact with other applications.

(2) Context modeling technology: In context modeling, context information is integrated into the recommendation, and suitable algorithms and models are designed to manage multidimensional contextual user preference. Although it is complex to process high-dimensional data for context modeling, it is also highly efficient to dig the correlation among the users, contexts and items. Context modeling approaches can be divided into two categories: heuristic-based approaches and model-based approaches. The former such as the Nearest Neighbor algorithm [11], Cluster [13] are intuitive. However, papers on the similarity calculation formula of context related high-dimensional data are still rare. Scholars should strengthen the research in this respect. The later such as Bayesian network [12], Bayesian preference model [14], SVM [15] and tensor decomposition [16] used the method of machine learning to build the models. Compared with the former, model-based approaches are more time-consuming and great deals of parameters are needed for optimizing. Nevertheless, the later just requires a model, the data needed of which is much less than the original. So the data sparsity is reduced to some extent and the performance accuracy is raised as well [17].

(3) Contextual user preference elicitation technology: Preference is used to describe the ordering relation of two or more items for decision-makers. These technologies including two research ideas: quantitative analysis and qualitative analysis, and the main advantages and disadvantages between them are showed in Table 2.

Table 2. Comparison of Different Contextual user Preference Elicitation Approaches

	The main advantages and disadvantages	Technology
Quantitative analysis	(1) Easy to quantize and calculate, and convenient for the generation of recommendation and Top-n recommendation; (2) Makes the preferences of each specific context user form a total order, weak order expression between preferences is not allowed, which is not good for describing the relation between the preferences of any two specific context users and logical reasoning.	Collaborative filtering; Similarity computation; Cluster; Decision tree;
Qualitative analysis	(1) It is good for describing the context users' preferences which don't always satisfy the total order, and convenient for handling the weak order of preferences (visualized, natural), and can express the relation of the specific examples of preferences of any two context users and carry out logistical reasoning;(2) Not easy to quantize and calculate.	E-R diagram; Strict partial order model; Greedy algorithm

(4) Contextual recommendation generation technology: This technology is used to generate recommendation according to the existing preferences of context users and by combining with the current contexts. In the traditional recommendation system, similar users have the similar preferences, and Bora thinks that the preference of other like-minded users in similar context which towards an item in the current context should also be considered [18]. However, contextual recommendation generation technology is still facing many problems, such as which model to choose and how to optimize parameters, how to detect and resolve the confliction of generation results based on multi-sources data fusion and so on.

2.2.3 Application Layer: With their serious computational power, the context-aware applications have an expansive prospect, which provide personalized services under the intelligent conditions (home, hospital, tourism, *etc.*) for the users. Baek *et al* designed a smart home care system based on the context-awareness technology. When a user wants to go to unfamiliar places to travel, it plays an important role as a tour guide [19]. Bellotti *et al* put forward implementing tour guides that present tourists with high-quality multimedia information and services [20]. More importantly, they could assist the users in the real-time event and during the in-car trip as well. Based on a two-layer clustering analysis on the characteristics of music, Su *et al* designed an uMender system that divide users into different groups and generate recommendation according to the similarities of contexts [12]. Context-aware application can also be used in some other fields, such as M-commerce, information system and Communication system. Applications and services not only handle current task, situation and action but also, anticipate future behavior, moving point and problem of user which may be found in in our smart life.

2.2.4 User Infrastructure Layer: Mobility is the core of the context-awareness. It is characteristic for handheld devices and their users that they are continuously moving in several simultaneous fuzzy contexts [21]. Handheld device is limited by such factors as the inconveniences of keyboard input and smaller screens weaken, increase the load of human-computer interaction [22]. Therefore, research of user interface (UI) and usability of handheld device are of extremely important and urgent.

In UI research, it is generally acknowledged that the contents are confusing when a screen changed due to a location change. To overcome inherent weaknesses of small interface such as phones and pads, research on user modeling and human-computer interaction for considering the emergence of ubiquitous and mobile computing environments should be strengthened. Usability involves investigating the user needs based on user interviews, field evaluations with users, and expert evaluations of context-aware services. When it comes to usability evaluation for context-aware application, some researchers suggested a hybrid evaluation method comprised of cognitive walkthrough and heuristic evaluation for UI supporting mobility of context-aware systems.

3. Results of the Analysis

According to the data collection selection criteria aforementioned, a total of 306 papers were reviewed ultimately, namely 197 journal papers, 91 conference papers, 14 master's and doctoral dissertations and 4 books. These papers are classified according to different criteria, and the basic characteristics are as follows :

3.1 Distribution of Literatures by Online Database

The article by online database is categorized in Table 3. There are a total of 306 articles from online databases. In Table 3, IEEE Xplore is the highest proportion (101 articles, 33.01%), because it offers articles of many journals (IEEE Pervasive Computing, IEEE Internet Computing and IEEE Wireless Communications) which have subject relevant to context-aware systems. Spring Link Online Libraries (61 articles, 19.93%) have roughly the same proportion as Science Direct (58 articles, 18.95). Other online databases are ACM Digital Library (42 papers, 13.73%), ProQuest Direct (21 papers, 6.86%), Wiley InterScience (13 papers, 4.25%) and EBSCO Business Source Premier (10 papers, 3.27%).

Table3. Distribution of Literatures by Online Database

Online database	Articles	Proportion (%)
<i>IEEE Xplore</i>	101	33.01%
<i>Spring Link Online Libraries</i>	61	19.93%
<i>Science Direct</i>	58	18.95%
<i>ACM Digital Library</i>	42	13.73%
<i>ProQuest Direct</i>	21	6.86%
<i>Wiley InterScience</i>	13	4.25%
<i>EBSCO Business Source Premier</i>	10	3.27%
Total	306	100%

3.2 Distribution of Literatures by Year

The number of articles by publication year is depicted in Figure 4. Numerous context-aware articles have grown considerably since 2005. From the figure, we can see that the number of articles in 2013 has becomes 7 times more than the number of articles in 2005. It is absolute that the concern about context-aware systems was increased and will be continued. Seen from the literatures, the number of journal and conference articles tends to be increasing as a whole, whereas the number of master's and doctoral dissertations and books is relatively small, and the details are as follows.

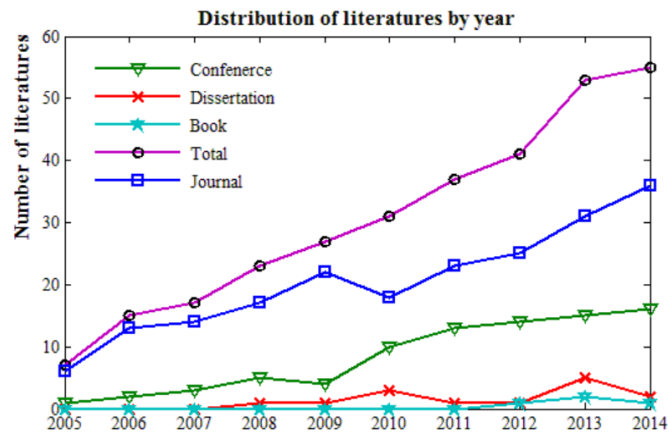


Figure 4. Distribution of Literatures by Year

3.3 Distribution of Literatures by Literature Type

The articles by journal literature type are categorized in Table 3. Journal papers is the highest proportion (197 articles, 64.38%), other literatures are conference papers (91 articles, 29.74%), Dissertations (14 thesis, 4.57%) and books (4 books, 1.31%).

Table 4. Distribution of Literatures by Literature Type

Literature type	Articles	Proportion (%)
Journal papers	205	66.99%
Conference papers	83	27.12%
Dissertations	14	4.58%
Books	4	1.31%
Total	306	100%

3.3.1 Journal Papers: Table 5 lists the journals that had published three or more context-aware articles Expert Systems with Applications had by far the most articles (15 articles, 7.61%). IEEE Pervasive Computing published 10 articles (7.11%). Int. J. of Mobile Communications had the third largest percentages (7articles, 3.55%). Expert systems with applications is a refereed international journal whose focus is on exchanging information relating to expert and intelligent systems applied in industry, government, and universities worldwide. IEEE Pervasive Computing explores the many facets of pervasive and ubiquitous computing with research papers, departments covering wearable and mobile technologies, and more.

Table 5. Journals with Three or more Papers on Context-Aware Application

Journal	Articles	Proportion of TJP*
<i>Expert Systems with Applications</i>	15	7.61%
<i>IEEE Pervasive Computing</i>	14	7.11%
<i>Int. J. of Mobile Communications</i>	7	3.55%
<i>Personal and Ubiquitous Computing</i>	6	3.19%
<i>Pervasive and Mobile Computing</i>	6	3.19%
<i>Wireless Personal Communications</i>	6	3.19%
<i>IEEE Intelligent Systems</i>	4	2.13%
<i>IEEE Communications Magazine</i>	3	1.60%

*TJP represents Total of Journal Paper.

3.3.2 Conference Papers: Table 6 lists the conferences that had published three or more context-aware articles. ICACT had by far the most articles (9 articles, 9.89%). ACM conference on Recommender systems had the second largest percentages of context-aware articles among the international conferences. International Conference on Advanced Communication Technology (ICACT) is an open forum for scholars, researchers, and engineers to the extensive exchange of information on newly emerging technologies, standards, services, and applications in the area of the advanced communications technology. ACM conference on Recommender systems is the premier international forum for the presentation of new research results, systems and techniques in the broad field of recommender systems.

Table 6. Conference with Three or more Papers on Context-Aware Application

Conference	Articles	Proportion of TCP*
<i>International Conference on Advanced Communication Technology, ICACT</i>	9	9.89%
<i>ACM conference on Recommender systems</i>	4	4.40%
<i>International ACM SIGIR conference on Research and development in information retrieval</i>	3	3.30%
<i>International conference on intelligent user interfaces</i>	3	3.30%
<i>International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies</i>	3	3.30%
<i>International Conference on Mobile Data Management,</i>	3	3.30%
<i>Workshop on Context-Aware Movie Recommendation</i>	3	3.30%

*TCP represents Total of Conference Paper.

3.3.3 Dissertations, and Books: According to the dissertations and books related to context-aware application, which many cover aspects such as the context-aware theory, framework[23], data management [24], computing [25-29], privacy and security[30,31], application[32,33]. Not only are the content of these dissertations and books high systematization and intricate, but also found out many unique theoretical viewpoints in the field of context-aware application, which must be an important driving force for the context-aware application development.

3.4 Distribution of Literatures by Subject

Table 7 shows the distribution of articles by subject. Most papers (96articles, 31.37%) were related to the concept and research layer. The application layer (95articles, 31.05%) and the computing layer (93articles, 31.6%) had the second and third largest percentages of context-aware application papers. User infrastructure layer had the lowest percentages, which is merely 7.19% of the total.

Overall, four major topics made up a large proportion within all reviewed papers. They were “Smart life”(53 papers), “Context modeling”(29 papers), “Contextual user preference elicitation”(27 papers) and “Context”(26 papers). All of these indicate that research on context-aware application is shifting from the basic research such as the concept of context-aware into the technologies as context modeling and user preference elicitation, which are the key to the applications implementation.

Table 7. Distribution of Literatures by Subject

Classification criteria	Articles	Percentage of subject	Percentage of all subjects
1 Concept and research layer	96	100%	31.37%
1.1 Context	26	27.08%	8.49%
1.2 Framework	20	20.83%	6.54%
1.3 Context data management	16	16.67%	5.23%
1.4 Evaluation	10	10.42%	3.27%
1.5 Privacy and security	15	15.63%	4.90%
1.6 Overview	9	9.37%	2.94%
2 Computing layer	93	100%	30.39%
2.1 Context identification and acquisition	15	16.13%	4.90%
2.2 Context modeling	29	31.18%	9.48%
2.3 Contextual user preference elicitation	27	29.03%	8.82%
2.4 Contextual recommendation generation	22	23.66%	7.19%
3 Application layer	95	100%	31.05%
3.1 Smart life	53	55.79%	17.32%
3.1.1 Home	12	12.63%	3.92%
3.1.2 Health	13	13.68%	4.25%
3.1.3 Learning	13	13.68%	4.25%
3.1.4 Tourism	3	3.16%	0.98%
3.1.5 Traffic	3	3.16%	0.98%
3.1.6 Others	9	9.48%	2.94%
3.2 M-commerce	10	10.53%	3.27%
3.3 Information system	12	12.63%	3.93%
3.4 Communication system	9	9.47%	2.94%
3.5 Web-service	11	11.58%	3.59%
4 User infrastructure layer	22	100%	7.19%
4.1 User interface	17	77.27%	5.56%
4.2 Usability	5	22.73%	1.63%
Total	306		100%

4. Discussion, Implication, and Conclusion

Context-aware application has attracted the attention of both business and academics. This paper identifies 306 articles on context-aware application published between 2005 and 2014. Although this review does not claim to be exhaustive, it does provide a reasonable amount of insight into the state of the art in context-aware application research. We are confident that as context-aware application become increasingly pervasive, research in context-aware application will be more important internationally. The results presented in this paper have several important implications.

The concept and research layer has the highest percentage of context-aware articles (96 articles, 31.37%). This layer can be divided into 6 subjects. They are context (26 articles, 8.49%), framework (20 articles, 6.54%), context data management (16 articles, 5.23%), evaluation (10 articles, 3.27%), privacy and security (15 articles, 4.90%) and overview (9 articles, 2.94%). The concept of context is always one of the most debatable and controversial arguments that academia has not reach a consensus yet, especially the concept of organization context. Context data management has become one of the obstacles of the context-aware application. Erik *et al* introduced the concept of Contextualized Attention Metadata (CAM) to describe context [34]. However, CAM is

restricted to small-scale data. For the forthcoming big data, existing technology seem incapable of action. Evaluation has been one of the hotspot of the study in context-aware application fields and plenty of typical models were generated such as Balanced Score Card (BSC), IS Success Model and so on. The issues of privacy and security have been plaguing the development of personalized service system and context-aware application [35]. Besides, it will result in violations of privacy and serious social problems, even directly affects the stability of society.

Computing layer (93 articles, 30.39%) is the most critical layer of system implementation and operation. Scholars/researchers spent much more time in studying context modeling (29 articles, 9.48%), contextual user preference elicitation (27 articles, 8.82%) and contextual recommendation generation (22 articles, 7.19%) rather than context identification and acquisition (15 articles, 4.90%) in this layer. Direct context are easily accessible but it proved difficult to extract meaningful context in the process of context identification and acquisition. Therefore, the ways of reasoning and implicit acquisition are generally adopted to obtain context information. Yap *et al.* presented the SVM method to dynamically identify the optimum context and further proposed iteration and filtering techniques based on Bayesian Network to remove the context parameters which have no influence on users' preferences [12]. Context modeling is regarded as the most important part to mining the relationship among the user, context and item. Nevertheless, existing technologies about context modeling are complex, and each one has its advantages and disadvantages. It is absolutely vital to choose the appropriate modeling technique. Adomavicius *et al* suggested that a combined context recommendation technology (like multistage combination and linear combination of prediction model, the combined methods based on the machine learning technologies of boosting, bagging and stacking) should be designed to improve the accuracy, novelty, instantaneity, diversity and robustness of recommendation [14]. The contextual preference elicitation technologies are also too numerous to mention. Table 2 has shown the comparison of different preference elicitation technologies. Once the users' context changes, the users' preference are also changes, namely preference evolution. However, these technologies cannot solve this issue effectively.

There are 95 articles in the application layer, which account for 31.05% of the reviewed articles. This layer mainly includes 6 subjects: smart life (52 papers, 17.32%), M-commerce (10 papers, 3.27%), information system (12 papers, 3.93%), communication system (9 papers, 2.94%) and web service (11 papers, 3.95%). Smart life can be also divided into 6 specific topics: home (12 papers, 3.92%), health (13 papers, 4.25%), learning (13 papers, 4.25%), tourism (3 papers, 0.98%), traffic (3 papers, 0.98%) and others (9 papers, 2.94%). All of these indicate that the context-aware applications have penetrated into every corner of our lives. We think that context-aware applications will have tremendous potential in the future. However, the scope of applications or services in most articles is limited to small regions: home, school, hospital and so on. In addition, context-aware applications have a long way to go before it comes in market cosmically as these applications are lack of strategic alternatives and business models for gaining the revenue.

The user infrastructure layer (22 articles, 7.19%) is the nearest layer to the user, which mainly includes two subjects: user interface (17 articles, 5.56%) and usability (5 articles, 1.63%). As main terminals of the context-aware applications, mobile devices have its inherent defaults, such as difficulty in input and display and poor data processing ability [36]. How to provide personalized information and services in such devices have plagued researchers and experts. However, the papers about this aspect are still rare. Scholars should strengthen the research in this respect. In conclusion for the above implications, we would like to offer the following suggestions for further research in context-aware application.

(1)Future research should pay more attention to strategic alternatives and business models for gaining the revenue by using context-aware systems. As previously mentioned, many researches have focused on the context-aware theory, technology and application. Studies on strategic alternatives and business models for gaining the revenue by using context-aware systems are very few. Bessai *et al* proposed a context-aware business process approach to evaluate and enhance business process models for a context using work-flow patterns [37]. Existing literature mainly focused on the factors that explain failing business models rather than providing practical design issues to improve business model viability [38] Context-aware application would not be widely adopted without driving by the commercial interests under the market economy condition. In addition, it is urgent to provide better service to users and develop technologies integration, which is based on a good business model. We believe that context-aware application will be commercialized massively in the future.

(2)Future research should pay more attention to high quality system solutions and industry ecosystem on smart home. Current research mainly relate to involve single application, how to join these applications into an ecosystem at the same intelligence environment is still to be a difficult technical problem. For example, it plagued by fragmented and lack of high quality system in the field of smart home, besides we have a lot of brands of smart home device, but they hardly compatible as its technical standards disunion. Above all, Due to the lack of support of the ecosystem, the smart home is difficult to form a non-boundary system solutions at present.

(3)Future research should pay more attention to the context data processing technology. Data in our world has been exploding, multimedia and individuals with smartphones and on social network sites will continue to fuel exponential growth [39] However, it is difficult to find valuable data as the data density is too low. In other words, the data processing has become unusually onerous, and context data processing is certainly no exception. In a situation like this, it becomes very troublesome to analysis and excavate user's preference and to explore the relation among the user, item and its context. It is urgent to make a study of context data processing technology emphatically and we believe that there is going to be a flood of technologies in this area.

(4)Future research should pay more attention to evolution of contextual user preference. Contextual user preference is not fixed. On the contrary, it would be changed by internal and external factors such as age, experience, circumstances and people around them [40].For instance, when we are at the clothing store, choice preference of people on clothing will change along with age, size, status and so on. We need to collect existing context so as to extract new preference while the original preference changed. Otherwise, the accuracy rate of the recommended may drop significantly and inaccuracy recommendations may frustrate users. Therefore, it is extraordinary important to intensify the analysis and study of the evolution of contextual user preference.

(5)Future research should pay more attention to the context-aware application evaluation and intelligent information processing among mobile devices. The recommending efficiency of context-aware application is not only related to context-aware technologies but also to the setting of evaluation indexes. Existing research only pay attention to the accuracy, but ignore the real-time, novelty and robustness of recommendation [14].In addition, massive mobile devices with computing and storage capacity emerge in an endless stream. Since a large number of restrictions of these mobile devices in screen size, computing power, storage capacity and connection speed, therefore, a profound reform is definitely necessary for the ways of information storage, organization, retrieval and dissemination in mobile interfaces [41]. We look forward to seeing contributions and breakthroughs in this field in the near future.

(6)Future research should pay more attention to privacy and security of context-aware applications. Problems on privacy and security have plagued personalized recommender system for a long time. Especially smart home, it will cause irreparable damage once the

information leakage while it records our daily lives [42]. The privacy and security of context-aware applications are quite complicated and difficult to solve. But solutions about this are rare. Scholars should strengthen the research in this respect. Certainly, there are still some deficiencies in this paper. Regardless of all the efforts we have made to search context-aware relevant papers from multiple sources, the limitations of descriptors we have chosen may still lead to a lack of some correlative articles in this review.

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