Ubiquitous Computing

Applications and Research Opportunities

Jorge Luis Victória Barbosa
Apply Computing Graduate Program (Pipca)
University of Vale do Rio dos Sinos (Unisinos)
São Leopoldo, Brazil
jbarbosa@unisinos.br

***Abstract*—About 25 years ago, Mark Weiser introduced the concept of Ubiquitous Computing. Ten years later, Mahadev Satyanarayanan revisited and reinforced the concept by publishing studies focused on components and architectures to achieve the Pervasive Computing (synonym of ubiquitous computing). Since then, this computational paradigm has received increasing attention from researchers. Significantly, recent years have witnessed the proliferation of various technologies that enable the implementation of ubiquitous systems such as Location Systems and Location-based Services (LBSs). Furthermore, the application of ubiquitous computing in different knowledge areas has increasingly been studied, covering areas such as health (u-health), accessibility (u-accessibility), learning (u-learning), commerce (u-commerce) and games (u-games). This broad interest shows the relevance of this emergent technology and allows us to predict that the adoption of ubiquitous computing will generate a similar impact that the adoption of Internet has generated in various application areas (for example, e-commerce and e-learning). This article summarizes the evolution of ubiquitous computing and discusses emerging uses in some application areas. Additionally, the text discusses issues currently addressed by researchers that are considered challenges and consequently research opportunities. For example, studies related to Contexts Histories (also called Trails) and their use to support Profile Management and Context Prediction have been considered strategic. Finally, the article concludes by outlining trends in ubiquitous computing research.**

Keywords—ubiquitous computing; applications; profile management; contexts histories; context prediction.

I. INTRODUCTION

Approximately 25 years ago, Mark Weiser [1] introduced the concept of *Ubiquitous Computing* predicting a world where computing devices would be present in objects, environments and human beings themselves. These devices would interact naturally with the users without being noticed. Ten years after, Mahadev Satyanarayanan reinforced the concept through an article that would become a classic [2]. More recent articles have discussed general aspects and trends of Ubiquitous Computing [3], [4]. In addition, the improvement and integration of technologies, such as context-aware computing [5], adaptive systems [6], profile management [7] and recommender systems [8] have increasingly allowed the realization of the vision introduced by Weiser [1] and Satyanarayanan [2].

In this sense, ubiquitous computing has found application in a diverse range of knowledge areas, such as, health [9], commerce [10], competence management [11], learning [12]–[14], logistics [15], [16], accessibility [17] and games [18].

This article discusses the ubiquitous computing through three perspectives, namely, progress of involved technologies, emergent applications and research opportunities. The text is strongly guided by studies conducted in the Laboratory of Research on Mobile and Ubiquitous Computing (MobiLab[1]) at the University of Vale do Rio dos Sinos (Unisinos[2]) which is located in Southern Brazil.

During the last decade, the MobiLab has supported several projects dedicated to research and application of the ubiquitous computing concepts. This article can be considered as a guide containing current references, which can be used to deepen studies in this subject. In this sense, some research themes considered strategic were addressed in more detail, namely, Contexts Histories [11] (also called Trails [19]), Profile Management [7] and Context Prediction [20].

The remainder of this article is organized as follows. First, the progress of technologies related to ubiquitous computing is discussed in Section II. The third section covers six application areas which have been researched at MobiLab/Unisinos. Section IV approaches the research opportunities. Finally, the last section concludes the article discussing trends in ubiquitous computing.

II. PROGRESS OF RELATED TECHNOLOGIES

The proliferation of smartphones and tablet PCs has fostered an ample adoption of the *Mobile Computing* [21], [22]. In addition, the use of devices to location determination, such as the GPS[3], has been stimulated by an increase of precision combined with a decreasing of prices. *Location systems* [23], [24] have been embedded into mobile computers, allowing the development of *Location-based Services* (LBSs) [25]–[27]. Location is one of several types of information that can be used to support the concept of *Context* [28].

The increasing use of these technologies combined with the diffusion of sensors has enabled the availability of computational services in specific contexts (*Context-aware Computing* [5], [28], [29]. The idea consists in the perception of characteristics related to the users and their surroundings.

This study was financed by CNPq/Brazil (National Council for Scientific and Technological Development – http://www.cnpq.br – grant number 310443/2013-0).

[1] Mobile Computing Lab (MobiLab). http://www.unisinos.br/lab/mobilab.
[2] University of Vale do Rio dos Sinos. http://www.unisinos.br/global/en.
[3] Global Positioning System (GPS). http//www.gps.gov.

These characteristics are normally referred to as *Context* [28], namely any information that can be used to describe the circumstances concerning an entity. Based on perceived context, the application can modify its behavior. This process, in which software modifies itself according to sensed data, is named *Adaptation* [6]. Additionally, several other technologies can be highlighted as strategic for the development of modern computer systems, such as recommendation strategies [8], profile management [7], internet of things [30], mobile cloud computing [31], wireless sensor networks [32], among others.

The progress and integration of these technologies have fostered the implementation and adoption of ubiquitous systems [3], [4]. In this sense, the recent emergence of various application areas may be considered an indication that the ubiquitous computing is reaching a level of disruptive technology. The next section discusses applications and details of six of them.

III. APPLICATIONS

The significant impact generated by the adoption of Internet has shown how an emergent technology can transform the practices in different application areas. For example, the *Distance Education* (so called e-learning) [33] has revolutionized the educational strategies, changing the perspective from face-to-face approach to a remote learning. Another example is the commerce, where the e-commerce has created a new paradigm to negotiate and stimulated the emergence of several companies dedicated to explore this market opportunity.

The recent increase in the use of ubiquitous technologies enables the prediction that ubiquitous computing can repeat the phenomena generated by the widespread adoption of the Internet in recent decades. The consolidate communication systems (eg the Internet) will continue participating in the technology progress that will make real this forecast. However, the acceleration of the adoption of technologies discussed in Section II will increasingly contribute to the emergence of ubiquitous computing applications.

Considering this perspective, this section discusses emergent application areas. The approach is not exhaustive and prioritizes the areas that have been researched in the MobiLab/Unisinos, namely, health [9], accessibility [17], learning [12]–[14], logistics [15], [16], commerce [10] and games [18]. Table I summarizes the content of this section. The table columns were organized as follows:

- Applications areas: It indicates the name of application areas that were discussed in this section;
- Short name: It presents the short name used to indicate the application of ubiquitous computing in the area;
- Studies conducted: It is a summary of the research works conducted in MobiLab/Unisinos in each area;
- Models: It has the names of computational models proposed in MobiLab in each area.

Next subsections discuss each area in the same order they are listed in the table.

TABLE I. APPLICATION AREAS

Application areas	**Material for further studies**		
	Short name used to indicate the application of ubiquitous computing	***Studies conducted at MobiLab /Unisinos***	***Models***
Health	u-Health	It was proposed a model called *UDuctor* [9] for ubiquitous care of noncommunicable diseases.	UDuctor [9]
Accessibility	u-Acessibility	A model called *Hefestos* [17] was proposed to support u-accessibility for different types of people with disabilities.	Hefestos [17]
Learning	u-Learning	Four models were proposed to different types of learning environments: small-scale (*Local* [12]), large-scale (*GlobalEdu* [13]), decentralized (Global [14]) and competence management oriented (*MultCComp* [11]).	Local [12] GlobalEdu [13] Global [14] MultCComp [11]
Logistics	It does not exist	Two models were proposed. *SWTrack* [15] uses location systems to support geofencing and tracking, and *SafeTrack* [16] expands SWTrack [15] with automatic delivery management.	SWTrack [15] SafeTrack [16]
Commerce	u-Commerce	A model called *MUCS* [10] fosters trades based on user interests and context awareness.	MUCS [10]
Games	u-Games	A model called *Mobio Treat* [18] supports a multiplayer game based on mobile and wireless technologies.	Mobio Threat [18]

A. Health

As discussed by Vianna and Barbosa [9], the application of ubiquitous computing in health is called *u-Health* or pervasive health [34], [35]. The authors indicate that the applications are commonly centered in hospital routine management [36], [37], patients monitoring [37], [38], or well-being [34], [39].

The article also addresses specifically how the treatment of noncommunicable diseases (NCDs) can benefit from u-Health technologies. The treatment of these diseases is continuous, so the patients must always be aware of their condition, following the treatment planned by the doctor. Furthermore, patients of NCDs should be engaged in the treatment, because some activities are performed daily by themselves and depend on their habits and lifestyle.

Considering the shortcomings identified in related works, Vianna and Barbosa [9] proposed UDuctor, a model for the ubiquitous care of NCDs. UDuctor supports the search of nearby resources and people that are able to help chronic patients in their activities. The model focuses on resources offering, but without losing self-management and communication supports, which are considered strategic features in systems of u-Health for NCDs.

B. Accessibility

The term *Ubiquitous Accessibility* was used by Gregg Vanderheiden [40] to indicate a new technology approach to support accessibility. He argues that since the computing is shifting from personal workstations to ubiquitous computing, accessibility should be thought accordingly with this new computational paradigm. In this sense, the *u-Accessibility* has emerged as a way to improve the quality of life of people with disabilities and the elderly. Several works can be cited as examples of efforts in this sense, such as AmbienNet [41], Awareness Marks [42], INHOME [43], UbiSmartWheel [44] and MIT Intelligent Wheelchair Project [45].

In this scope, the MobiLab proposed the Hefestos model [17]. Hefestos is an intelligent system applied to ubiquitous accessibility based on an architecture designed to support context awareness [28], profile management [7] and trails management [19]. In addition, the model proposes an ontology for accessibility. The proposal allowed the implementation of a smart wheelchair which was assessed by ten users with a range of disability degrees.

As discussed by the authors [17], the three contributions of Hefestos are: (1) a generic approach for different types of disabilities that returns personalized and contextualized resources for accessibility according to users' profiles [7]; (2) a software agent that supports the integration of the Hefestos with technologies dedicated to different kinds of disabilities; (3) the trails management of users [19].

C. Learning

The application of mobile and ubiquitous computing in the improvement of learning strategies has created two research fronts called *Mobile Learning* and *Ubiquitous Learning*. *Mobile learning* (m-learning) [46], [47] is fundamentally about increasing learners' capability to carry their own learning environment along with them. M-learning is the natural evolution of e-learning, and has the potential to make learning even more widely accessible. In m-learning model, mobile computers are still not embedded in the learners' surrounding environment, and as such they cannot seamlessly obtain information about learner context.

On the other hand, *Ubiquitous Learning* [12]–[14] refers to learning supported by the use of mobile and wireless communication technologies, sensors and location/tracking mechanisms, which work together to integrate learners with their environments. Ubiquitous learning systems connect virtual and real objects, people and events, in order to support a continuous, contextual and meaningful learning.

While the learner is moving with mobile device, the system dynamically supports learning process by communicating with embedded computers in the environment. The essence of Ubiquitous Learning is to realize which information can be presented throughout the learners' daily tasks, in different forms and places, and to link this data with the learners' educational process. Technologies that support Ubiquitous Learning should provide these aspects through mechanisms that allow knowing learners' profile, contexts involving them, and how learners relate to contexts.

MobiLab proposed four ubiquitous learning models, each one oriented to specific environments or applications:

- Local [12]: This model aims to provide a location-and-context-aware ubiquitous architecture geared to create small-scale learning environments. Local is self-sufficient, and thus it does not require a middleware to support ubiquitous features. In addition, the model uses location information and learner profiles in a generic perspective, and so allowing the design of different kinds of learning application;
- GlobalEdu [13]: This model is oriented to large-scale environments. GlobalEdu uses profiles and location information to be aware of the learner's context and mobility. The model uses the ISAM middleware [48] to perform basic ubiquitous services and to support the large-scale proposal;
- Global [14]: Global is a decentralized infrastructure for ubiquitous learning environments. This infrastructure has an extensible architecture that can be specialized to create learning environments through the extension of agents or through the addition of new ones. Global is motivated by the vision that centralized structures are not adequate for the ubiquitous computing defined by Weiser [1] and Satyanarayanan [2];
- MultCComp [11]: This is a multi-temporal context-aware system for competences management [49]. MultCComp takes advantage of the joint use of workers' present and past contexts to help them to develop their competences. The system explores the research opportunity discussed in Section IV.a, mainly the Contexts histories [11], [50] (also called Trails [19], [33], [51]).

D. Logistics

As discussed by Oliveira et al. [15], [16] the transport is strategic in the supply chain integration, because it can be used to control flows of resources, goods and products [52]. In addition, transport is a significant part of the logistics costs, thus; its management is relevant to enhance efficiency and flexibility in fleet operation. In this sense, companies have used current technologies to obtain precise information to support this management [53] among which stands out the Global Position System (GPS) [54] and its use to implement location systems [23], [24] and monitoring/tracking systems [55].

Several research works have addressed the use of ubiquitous technologies to improve the transport logistics [56]–[60]. In this sense, the MobiLab/Unisinos proposed two models called SWTrack [15] and SafeTrack [16]. SWTrack [15] allows companies to track their vehicles and have control over the traveled routes. The model enables the users to identify whether a vehicle is following a planned route or deviating from the original path.

SWTrack uses off-the-shelf mobile technology and a Geofence technique named Route Adherence [61] to control the journey. On the other hand, SafeTrack [16] extends SWTrack to support the automatic delivery management of loads, without any user interaction. The control of the input/output cargo on the vehicle is based on radio-frequency identification (RFID), identifying in real-time, deliveries and pickups of loads made by mistake, or potential cargo theft.

E. Commerce

The use of mobile devices and ubiquitous technologies to support commerce is commonly classified as *context-aware commerce* [62]–[64] or *ubiquitous commerce* (so called *u-commerce*) [65]–[68]. Gershman [69] indicated three prerequisites for the success of u-commerce: (1) always be connected with the clients; (2) always be aware of clients' contexts (where they are, what they are doing and what is available around them); and (3) always be proactive, identifying real-time opportunities to meet client needs. Some proposals focus on commerce in goods [70]–[72] and others on the services market [73], [74].

The MobiLab proposed a model for ubiquitous commerce support, called MUCS [10]. MUCS uses the ubiquitous computing technologies to identify business opportunities for users as clients or suppliers. In addition, the model is a generic approach to support trade in goods and services without domain restrictions.

F. Games

The use of ubiquitous computing technologies in game development generated the *Ubiquitous Games* (*u-games* [75]). In this kind of game, players move to specific places in order to perform tasks. In addition, users interact with each other (multi-player) and with the environment around them (real objects). These interactions are based on wireless technologies that allow users to walk and also to send and receive information such as locations, users nearby and other kind of context-aware data.

Segatto et al. [18] indicated that a major issue for ubiquitous games is tracking, because it is difficult and expensive, to cover mixed areas such as cities, fields, and indoor locations and to track players and objects with accuracy up to a few meters. There are many tools that provide tracking capabilities, but they are not simple to set up and to configure.

The MobiLab developed *moBIO Threat* [18] a ubiquitous game based on communication technologies and integration of their capabilities. moBIO Threat provides an improved gaming experience in both interaction and tracking domains. In addition, the game is meant to be educational. In other words, its objective is to teach users about one or more subjects while they are playing. The game is also meant to be distributed, so users can set it up in their homes and schools. Furthermore, the project took into account that most players would probably not have all of the technologies utilized in this project available to them. Based on this, an adaptation layer was implemented to provide minimum loss of functionality in case of the absence or failure of one or more technologies.

IV. Research Opportunities

Since the publication of the classical articles of Weiser [1] and Satyanarayanan [2], the ubiquitous computing has evolved in a significant way, as can be seen in texts dedicated to discuss the area [3], [4]. In this evolution, several research topics have been consolidated, such as locations systems [23], [24] and location-based services [25]–[27]. On the other hand, the insight of Weiser was broad and still carries several challenges. Based on them, several trends have emerged bringing research opportunities. This section is dedicated to some of them, specifically, opportunities that have been explored in the MobiLab. Three of them were considered strategic and detailed in this article, namely, Contexts Histories [11] (also called Trails [19], [33]), Profile Management [7] and Context Prediction [20]. Table II summarizes the discussion that will be conducted in the next subsections.

A. Contexts histories

Rosa et al. [11] discussed basic aspects of context awareness and strategies used to best use it. The authors argue that context-aware architectures which use not only present contexts, but also measurements of the past, need to store visited contexts for further use. This information from past contexts related to an entity is called its context history [50], [76]. Some works refer to this history as trail [19], [33], [51].

Some works focus on life logging [77]–[79]. Their main purpose is to enhance human memory by using the capabilities of computers. Other works approach the use of contexts histories in the decision making process [50], [76], [80]. Dey et al. [28] also briefly described the importance of using history in decision.

The MobiLab has studied the value of considering users' past actions performed in the contexts visited during a period, such as, the activities done, the applications used, the contents accessed, and any other possible data [11], [19], [33]. This information helped to improve the distribution of content and services in context-aware environments, because applications were using an additional and more complete information source. In other words, applications started using contexts histories in conjunction with the current context information and users' profiles to take decisions [7], [19].

TABLE II. RESEARCH OPPORTUNITIES

Research opportunities	**Material for further studies**		
	Names of the research opportunities	***Studies conducted at MobiLab /Unisinos***	***Models***
The support to record and recover historical information about contexts visited by entities for future use.	Contexts Histories [11] (also called Trails [19], [33])	It was proposed a model called *UbiTrail* [19] for trail management.	UbiTrail [19]
The support to create, recover and automatically update profile information of entities.	Profile Management [7]	A model called *e-Profile* [7] was proposed to support dynamic profiles for different kinds of applications.	eProfile [7]
The support to predict contexts, typically using contexts histories.	Context Prediction [20]	A model called *Oracon* [20] was proposed to automatic adaptation of context prediction based on contexts histories.	Oracon [20]

B. *Profile Management*

Wagner et al. [7] argued that for an application to adapt itself effectively to users, it is not only important to know the history of contexts visited by them, but to understand who the users are – that is, what are their relevant characteristics. This kind of application organizes its knowledge about a user in User Profiles [7]. The profiles are stored in a format called User Model [81].

Furthermore, the ubiquitous computing indicates that systems should become increasingly invisible to their users [1]. However, a system can only become invisible if it is proactive, and can only be proactive by knowing the user [2]. Wagner et al. [7] affirmed that for a system to know its users, it must know the users histories [19], understand the contexts in which they are inserted [28], and be able to process this set of information into user profiles [7], [81].

In this sense, MobiLab proposed eProfile [7], a ubiquitous profile manager of generic domain oriented towards distributed environments, with inter-system interoperability. eProfile infers profiles data through analysis of contexts histories of entities, following rules defined by the own entities, and provides data inferred to be used by different applications. These applications can register entities' actions in contexts histories and infer profile information from these histories, using semantic interoperability; thus allowing different applications to share information and infer a unified profile.

C. *Context Prediction*

Rosa et al. [20] affirmed that with the use of the users' current contexts (present) and their contexts histories (past), applications already have a reasonable information source to base their decisions. Nonetheless, in order to become proactive and act before the context has actually changed, future contexts have to be predicted [82]. This has motivated researchers to study the use of another temporal aspect; the future [83]. The obtainment of the users' future contexts is made through predictions techniques. Based on users' histories and current contexts, algorithms predict the contexts that probably will describe the users' future situations [84].

Recent research has explored prediction in various kinds of applications, such as trends of stocks [85] and failure in software [86]. A more general research trend focuses on context prediction. Burbey and Martin [87] organized and discussed works dedicated to predict personal mobility for location prediction. In addition, Lee and Lee [88] use the location prediction to support ubiquitous decision support.

Rosa et al. [20] highlighted recent studies that discuss and classify works in research topics related to context prediction, such as anticipatory mobile computing [89] and prediction in pervasive computing [90]. These surveys present and compare context prediction techniques and propose solutions, particularly highlighting challenges and opportunities associated with this research field.

Pejovic and Musolesi [89] indicate the treatment of privacy and anonymity as a challenge in research related to anticipatory mobile computing. Ameyed et al. [90] state that another research challenge is the lack of general approaches for dealing with context prediction and, specifically, to allow automatic adaptation using context prediction. Recently, MobiLab proposed Oracon [20] to meet these challenges.

Oracon [20] is a generic model that adapts itself in order to apply the best prediction algorithm in a particular case and situation. This adaptive approach is the main contribution of this work and differentiates the proposed model of other related works. In addition, the model supports important features of ubiquitous computing, such as context formal representation and privacy, which are not well explored by other works.

The main strengths of the proposed model are the flexibility allowed by the automatic selection of the prediction method and also the generic context information made possible by the formal representation. These features make the Oracon a generic model that can be used by any kind of context-aware application. On the other hand, its main weakness is related to performance constraints. Oracon selects the best prediction algorithm using a ranking obtained by testing all algorithms in a piece of contexts history provided by the application. This strategy may result in a high load processing and limit the feasibility of the proposal in real environments.

V. Conclusion

Weiser [1] and Satyanarayanan [2] established the fundamentals of ubiquitous computing and today various technologies are ready to be used in the implementation of ubiquitous systems, as Locations systems [23], [24] and Location based services [25]–[27]. Other technologies have been studied in recent years and have reached a level that allows their initial application, as Context-aware computing [5], [28], [29] and Adaptation [6].

However, the Section IV showed that there are technological challenges that still need to be overcome, such as profile management [7] and context prediction [20]. They are considered trends in ubiquitous computing research. In turn, the Section III showed how large are the possibilities of ubiquitous computing application. Studies are in the early stages and there is still plenty of room for research.

Finally, it is important to note that the applications described in Section III (Table I) and the research opportunities discussed in Section IV (Table II) continuously have been explored at MobiLab/Unisinos, being considered current research issues, as can be seen by recent references cited throughout the text. So, all material discussed in this article has been evolving on a daily basis through academic works.

Acknowledgment

The projects developed at MobiLab have been financed by CAPES/Brazil (Coordination for the Improvement of Higher Education Personnel), CNPq/Brazil (National Council for Scientific and Technological Development) and FAPERGS (Research Foundation of Rio Grande do Sul). I would like to acknowledge these institutions for their support. I also thank Unisinos for embracing the research discussed in this article and for supporting MobiLab.

References

[1] M. Weiser. (1991). The Computer for the 21st Century. *Scientific American*. [Online]. *265(3)*, pp. 94–104. Available: http://dx.doi.org/10.1145/329124.329126

[2] M. Satyanarayanan. (2001). Pervasive computing: vision and challenges. *IEEE Personal Communications*. [Online]. *8(4)*, pp. 10–17. Available: http://dx.doi.org/10.1109/98.943998

[3] R. Caceres and A. Friday. (2013). Ubicomp Systems at 20: Progress, Opportunities, and Challenges. *IEEE Pervasive Computing*. [Online]. *11(1)*, pp. 14–21. Available: http://dx.doi.org/10.1109/MPRV.2011.85

[4] G. D. Abowd. (2012). What Next, Ubicomp? Celebrating an Intellectual Disappearing Act, in *Proceedings of the ACM Conference on Ubiquitous Computing*. New York, USA, pp. 31–40. [Online]. Available: http://dx.doi.org/10.1145/2370216.2370222

[5] M. Knappmeyer, S. L. Kiani, E. S. Reetz, N. Baker, and R. Tonjes. (2013). Survey of Context Provisioning Middleware. *IEEE Communications Surveys & Tutorials*. [Online]. *15(3)*, pp. 1492–1519. Available: http://dx.doi.org/10.1109/SURV.2013.010413.00207

[6] J. L. Oliveira, R. Souza, C. F. R. Geyer, C. A. Costa, J. L. V. Barbosa, A. Pernas, and A. C. Yamin. (2014). A Middleware Architecture for Dynamic Adaptation in Ubiquitous Computing. *Journal of Universal Computer Science*. [Online]. *20(9)*, pp. 1327–1351. Available: http://dx.doi.org/10.3217/jucs-020-09-1327

[7] A. Wagner, J. L. V. Barbosa, and D. N. F. Barbosa. (2014). A Model for Profile Management Applied to Ubiquitous Learning Environments. *Expert Systems with Applications*. [Online]. *41(4)*, pp. 2023–2034. Available: http://dx.doi.org/10.1016/j.eswa.2013.08.098

[8] J. Bobadilla, F. Ortega, A. Hernando, and A. Gutiérrez. (2013). Recommender systems survey. *Knowledge-Based Systems*. [Online]. *46*, pp. 109–132. Available: http://dx.doi.org/10.1016/j.knosys.2013.03.012

[9] H. D. Vianna and J. L. V. Barbosa. (2014). A Model for Ubiquitous Care of Noncommunicable Diseases. *IEEE Journal of Biomedical and Health Informatics*. [Online]. *18(5)*, pp. 1597–1606. Available: http://dx.doi.org/10.1109/JBHI.2013.2292860

[10] L. K. Franco, J. H. Rosa, J. L. V. Barbosa, C. A. Costa, and A. C Yamin. (2011). MUCS: A Model for Ubiquitous Commerce Support. *Electronic Commerce Research and Applications*. [Online]. *10(2)*, pp. 237–246. Available: http://dx.doi.org/10.1016/j.elerap.2010.08.006

[11] J. H. Rosa, J. L. V. Barbosa, M. R. Kich, and L. K. Brito. (2015). A Multi-Temporal Context-aware System for Competences Management.. *International Journal of Artificial Intelligence in Education*. [Online]. *25(4)*, pp. 455–492. Available: http://dx.doi.org/10.1007/s40593-015-0047-y

[12] J. L. V. Barbosa, R. Hahn, D. N. F. Barbosa, and A. I. C. Z. Saccol. (2011). A Ubiquitous Learning Model Focused on Learner Integration. *International Journal of Learning Technology*. [Online]. *6(1)*, pp. 62–83. Available: http://dx.doi.org/10.1504/IJLT.2011.040150

[13] D. N. F. Barbosa, J. L. V. Barbosa, P. B. S. Bassani, J. H. Rosa, M. Lewis, and C. P. Nino. (2013). Content management in a ubiquitous learning environment. *International Journal of Computer Applications in Technology*; [Online]. *46(1)*, pp. 24–35. Available: http://dx.doi.org/10.1504/IJCAT.2013.051385

[14] J. L. V. Barbosa, D. N. F. Barbosa, J. M. Oliveira, and S. A. J. Rabello. (2014). A Decentralized Infrastructure for Ubiquitous Learning Environments. *Journal of Universal Computer Science*. [Online]. *20(2)*, pp. 1649–1669. Available: http://dx.doi.org/10.3217/jucs-020-12-1649

[15] R. R. Oliveira, F. C. Noguez, C. A. Costa, J. L. V. Barbosa, and M. P. Prado. (2013). SWTRACK: An Intelligent Model for Cargo Tracking Based on Off-the-Shelf Mobile Devices. *Expert Systems with Applications*. [Online]. *40(6)*, pp. 2023–2031. Available: http://dx.doi.org/10.1016/j.eswa.2012.10.021

[16] R R. Oliveira, I. G. Cardoso, J. L. V. Barbosa, C. A. Costa, and M. P. Prado. (2015). An intelligent model for logistics management based on geofencing algorithms and RFID technology. *Expert Systems with Applications*. [Online]. *42(15-16)*, pp. 6082–6097. Available: http://dx.doi.org/10.1016/j.eswa.2015.04.001

[17] J. E. R. Tavares, J. L. V. Barbosa, I. G. Cardoso, C. A. Costa, A. C. Yamin, and R. A. Real. (2015). Hefestos: an intelligent system applied to ubiquitous accessibility. *Universal Access in the Information Society*. [Online]. Available: http://dx.doi.org/10.1007/s10209-015-0423-2

[18] W. Segatto, E. Herzer, C. L. Mazzotti, J. R. Bittencourt, and J. L. V. Barbosa. (2008). moBIO Threat: a Mobile Game based on the Integration of Wireless Technologies. *Computers in Entertainment*. [Online]. *6(3)*, article n. 39. Available: http://dx.doi.org/10.1145/1394021.1394032

[19] J. M. Silva, J. H. Rosa, J. L. V. Barbosa, D. N. F., Barbosa, and L. A. M. Palazzo. (2010). Content Distribution in Trail-aware Environments. *Journal of the Brazilian Computer Society*. [Online]. *16(3)*, pp. 163–176. Available: http://dx.doi.org/10.1007/s13173-010-0015-1

[20] J. H. Rosa, J. L. V. Barbosa, and G. O. Barcelos. (2016). ORACON: An Adaptive Model For Context Prediction. *Expert Systems with Applications*. [Online]. *45(1)*, pp. 56–70. Available: http://dx.doi.org/10.1016/j.eswa.2015.09.016

[21] A. Diaz, P. Merino, and F. J. Rivas. (2010). Mobile Application Profiling for Connected Mobile Devices. *IEEE Pervasive Computing* [Online]. *9(1)*, pp. 54–61. Available: http://dx.doi.org/10.1109/MPRV.2009.63

[22] M. Satyanarayanan, P. Bahl, P. Caceres, and N. Davies. (2009). The Case for VM-Based Cloudlets in Mobile Computing. *IEEE Pervasive Computing* [Online]. *8(4)*, pp. 14–23. Available: http://dx.doi.org/10.1109/MPRV.2009.82

[23] J. Hightower and G Borriello. (2001). Location Systems for Ubiquitous Computing. *Computer*. [Online]. *34(8)*, pp. 57–66. Available: http://dx.doi.org/10.1109/2.940014

[24] J. Hightower, A. LaMarca, and A. I. Smith. (2006). Practical Lessons from Place Lab. *IEEE Pervasive Computing* [Online]. *5(3)*, pp.32–39. Available: http://dx.doi.org/10.1109/MPRV.2006.55

[25] A. Dey, J. Hightower, A., E. de Lara, and N. Davies. (2010). Location-based services. *IEEE Pervasive Computing* [Online]. *9(1)*, pp.11–12. Available: http://dx.doi.org/10.1109/MPRV.2010.10

[26] S. J. Vaughan-Nichols. (2009). Will Mobile Computing's Future Be Location? *Computer*. [Online]. *42(2)*, pp. 14–17. Available: http://dx.doi.org/10.1109/MC.2009.65

[27] K. Petrova and B. Wang. (2011). Location-based services deployment and demand: a roadmap model. *Electronic Commerce Research*. [Online]. *11(1)*, pp. 5–29. Available: http://dx.doi.org/10.1007/s10660-010-9068-7

[28] A. Dey, D. Salber, and G. Abowd. (2001). A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware application. *Human-Computer Interaction*. [Online]. *16(2)*, pp. 97–166. Available: http://dx.doi.org/10.1207/S15327051HCI16234_02

[29] P. Bellavista, A. Corradi, M. Fanelli, and L. Foschini. (2012). A Survey of Context Data Distribution for Mobile Ubiquitous Systems. *ACM Computing Surveys*. [Online]. *44(4)*, pp. 1–24. Available: http://dx.doi.org/10.1145/2333112.2333119

[30] L. Atzori, A. Iera, and G. Morabito. (2010). The Internet of Things: A survey. *Computer Networks*. [Online]. *54(15)*, pp. 2787–2805. Available: http://dx.doi.org/ 10.1016/j.comnet.2010.05.010

[31] N. Fernando, S. W. Loke, and W. Rahayu. (2013). Mobile cloud computing: A survey. *Future Generation Computer Systems*. [Online]. *29(1)*, pp. 84–106. Available: http://dx.doi.org/10.1016/ j.future.2012.05.023

[32] J. Yick, B. Mukherjee, and D. Ghosal. (2008). Wireless sensor network survey. *Computer Networks*. [Online]. *52(12)*, pp. 2292–2330. Available: http://dx.doi.org/10.1016/j.comnet.2008.04.002

[33] S. J. Rigo, W. L. Cambruzzi, and J. L. V. Barbosa, "Dropout Prediction and Reduction in Distance Education Courses with the Learning Analytics Multitrail Approach," *Journal of Universal Computer Science*, vol. 21, no. 1, pp. 23–47, 2015.

[34] J.-E. Lim, O.-H. Choi, H.-S. Na, and D.-K. Baik. (2009). A context-aware fitness guide system for exercise optimization in U-health. *IEEE Transactions on Information Technology Biomedicine*. [Online]. *13(3)*, pp. 370–379. Available: http://dx.doi.org/10.1109/TITB.2009.2013941

[35] A. K. Dey and D. Estrin. (2011). Perspectives on pervasive health from some of the field's leading researchers. *IEEE Pervasive Computing*. [Online]. *10(2)*, pp. 4–7. Available: http://dx.doi.org/ 10.1109/MPRV.2011.29

[36] J. E. Bardram and H. B. Christensen. (2007). Pervasive computing support for hospitals: An overview of the activity-based computing project. *IEEE Pervasive Computing*. [Online]. *6(1)*, pp. 44–51. Available: http://dx.doi.org/10.1109/MPRV.2007.19

[37] C. Orwat, A. Rashid, C. Holtmann, M. Wolk, M. Scheermesser, H. Kosow, and A. Graefe. (2010). Adopting pervasive computing for routine use in healthcare. *IEEE Pervasive Computing*. [Online]. *9(2)*, pp. 64–71. Available: http://dx.doi.org/10.1109/MPRV.2010.25

[38] N. Agoulmine, M. J. Deen, J.-S. Lee, and M. Meyyappan. (2011). U-Health smart home. *IEEE Nanotechnology Magazine*. [Online]. *5(3)*, pp. 6–11. Available: http://dx.doi.org/10.1109/MNANO.2011.941951

[39] F. Buttussi and L. Chittaro. (2010). Smarter phones for healthier lifestyles: an adaptive fitness game. *IEEE Pervasive Computing*. [Online]. *9(4)*, pp. 51–57. Available: http://dx.doi.org/ 10.1109/MPRV.2010.52

[40] G. Vanderheiden. (2008). Ubiquitous accessibility, common technology core, and micro assistive technology. *ACM Transactional on Accessible Computing*. [Online]. *1(2)*, article no. 10. Available: http://dx.doi.org/ 10.1145/1408760.1408764

[41] J. Abascal, R. Casas, A. Marco, J. Sevillano, and D. Cascado. (2009). Towards an intelligent and supportive environment for people with physical or cognitive restrictions, in *Proceedings of the 2nd International Conference on Pervasive Technologies Related to Assistive Environments*. Corfu, Greece, article n. 10. [Online]. Available: http://dx.doi.org/10.1145/1579114.1579124

[42] R. Hervás, J. Bravo, and J. Fontecha. (2011). Awareness marks: adaptive services through user interactions with augmented objects. *Personal and Ubiquitous Computing*. [Online]. *15(4)*, pp. 409–418. Available: http://dx.doi.org/10.1007/s00779-010-0363-z

[43] D. Vergados. (2010). Service personalization for assistive living in a mobile ambient healthcare-networked environment. *Personal and Ubiquitous Computing*. [Online]. *14(6)*, pp. 575–590. Available: http://dx.doi.org/10.1007/s00779-009-0278-8

[44] O. Postolache, R. N. Madeira, N. Correia, and P. S. Girão. (2009). UbiSmartWheel: a ubiquitous system with unobtrusive services embedded on a wheelchair, in *Proceedings of the 2nd International Conference on Pervasive Technologies Related to Assistive Environments*. Corfu, Greece, article n. 13. [Online]. Available: http://dx.doi.org/10.1145/1579114.1579127

[45] MIT Wheelchair Project. (2015). Vision: Designing Smart Wheelchairs of the Future. [Online]. Available: http://rvsn.csail.mit.edu/wheelchair

[46] T. Deborah, J. Roschelle, P. Vahey, and W. R. Peneul. (2003). Handhelds go to school: Lessons Learned. *Computer*. [Online]. *36(9)*, pp. 30–37. Available: http://dx.doi.org/10.1109/MC.2003.1231192

[47] A. Z. Saccol, J. L. V. Barbosa, E. Schlemmer, and N. Reinhard. (2011). Mobile Learning in Organizations: Lessons Learned from Two Case Studies. *International journal of information and communication technology education*. [Online]. *7(3)*, pp. 11–24. Available: http://dx.doi.org/10.4018/jicte.2011070102

[48] I. Augustin, A. C. Yamin, L. C. Silva, R. A. Real, G. Frainer, and C. F. R. Geyer. (2006). ISAMadapt: Abstractions and Tools for Designing General-Purpose Pervasive Applications. *Software: Practice and Experience*. [Online]. *36(11-12)*, pp. 1231–1256. Available: http://dx.doi.org/10.1002/spe.756

[49] B. Malachowski. (2011). Competence-based management of knowledge workers in project-oriented organizations. *Knowledge Science, Engineering and Management*. [Online]. pp. 281–292. Available: http://dx.doi.org/10.1007/978-3-642-25975-3_25

[50] J. Hong, E.-H. Suh, J. Kim, and S. Kim. (2009). Context-aware system for proactive personalized service based on context history. *Expert Systems with Applications*. [Online]. *36(4)*, pp. 7448–7457. Available: http://dx.doi.org/10.1016/j.eswa.2008.09.002

[51] C. Driver and S. Clarke. (2008). An application framework for mobile, context-aware trails. *Pervasive and Mobile Computing*. [Online]. *4(5)*, pp. 719–736. Available: http://dx.doi.org/10.1016/j.pmcj.2008.04.009

[52] F. Huq, F., T. F. Stafford, M. K. S. Bhutta, and S. Kanungo. (2010). An examination of the differential effects of transportation in supply chain optimization modeling. *Journal of Manufacturing Technology Management*. [Online]. *21(2)*, pp. 269–286. Available: http://dx.doi.org/10.1108/17410381011014404

[53] E. W. T. Ngai, T. K. P. Leung, Y. H. Wong, M. C. M. Lee, P. Y. F. Chai, and Y. S. Choi. (2012). Design and development of a context-aware decision support system for real-time accident handling in logistics. *Decision Support Systems*. [Online]. *52(4)*, pp. 816–827. Available: http://dx.doi.org/10.1016/j.dss.2011.11.016

[54] B. Hofmann-Wellenhof, H. Lichtenegger, and J. Collins, *Global Positioning System:Theory and Practice*. New York, USA: Springer, 2001.

[55] A H. M. Shamsuzzoha, M. Ehrs, R. Addo-Tenkorang, D. Nguyen, and P. T. Helo. (2013). Performance evaluation of tracking and tracing for logistics operations. *International Journal of Shipping and Transport Logistics*. [Online]. *5(1)*, pp. 31–54. Available: http://dx.doi.org/ 10.1504/IJSTL.2013.050587

[56] W. He, E. L. Tan, E. W. Lee, and T. Y. Li. (2009). A solution for integrated track and trace in supply chain based on RFID and GPS, *In Proocedings of the IEEE Conference on Emerging Technologies and Factory Automation*. Mallorca, Spain, pp. 1–6. [Online]. Available: http://dx.doi.org/10.1109/ETFA.2009.5347146

[57] G.-H. Yang, K. Xu, and V O. K. Li. (2010). Hybrid cargo-level tracking system for logistics, in *Proceedings of the IEEE 71st Vehicular Technology Conference*. Taipei, Taiwan, pp. 1–5. [Online]. Available: http://dx.doi.org/10.1109/VETECS.2010.5493655

[58] E. Papatheocharous, and P. Gouvas. (2011). eTracer: An Innovative Near-Real Time Track-and-Trace Platform, in *Proceedings of the 15th*

Panhellenic Conference on Informatics. Kastonia, Greece, pp. 282–286. [Online]. Available: http://dx.doi.org/10.1109/PCI.2011.54

[59] W. Zhengxia and X. Laisheng. (2010). Modern Logistics Monitoring Platform Based on the Internet of Things, in *Proceedings of the International Conference on Intelligent Computation Technology and Automation*. Changsha, Chine pp. 726–731. [Online]. Available: http://dx.doi.org/10.1109/ICICTA.2010.650

[60] A. Musa, A. Gunasekaran, Y. Yusuf, and A. Abdelazim. (2014). Embedded devices for supply chain applications: Towards hardware integration of disparate technologies. *Expert Systems with Applications*, [Online]. *41(1)*, pp. 137–155. Available: http://dx.doi.org/ 10.1016/j.eswa.2013.07.017

[61] F. Reclus and K. Drouard. (2009). Geofencing for fleet and freight management, in *Proceedings of the 9th International Conference on Intelligent Transport Systems Telecommunication*. Lille, France, pp. 353–356. [Online]. Available: http://dx.doi.org/ 10.1109/ITST.2009.5399328

[62] P. Benou and C. Vassilakis. (2010). The conceptual model of context for mobile commerce applications. *Electronic Commerce Research*. [Online]. *10(2)*, pp. 139–165. Available: http://dx.doi.org/ 10.1007/s10660-010-9050-4

[63] P. Eugster, B. Garbinato, and A. Holzer. (2009). Pervaho: A specialized middleware for mobile context-aware applications. *Electronic Commerce Research*. [Online]. *9(4)*, pp. 245–268. Available: http://dx.doi.org/10.1007/s10660-009-9042-4

[64] U. Panniello and M. Gorgoglione. (2012). Incorporating context into recommender systems: an empirical comparison of context-based approaches. *Electronic Commerce Research*. [Online]. *12(1)*, pp. 1–30. Available: http://dx.doi.org/10.1007/s10660-012-9087-7

[65] G. Roussos, *Ubiquitous and Pervasive Commerce: New Frontiers for Electronic Business*. New York, USA: Springer, 2006.

[66] L. Zhang, Q. Liu, and, X. Li. (2009). Ubiquitous Commerce: Theories, Technologies, and Applications. *Journal of Networks*. [Online]. *4(4)*, pp. 271–278. Available: http://dx.doi.org/10.4304/jnw.4.4.271-278

[67] R. T. Watson. (2000). U-commerce: the ultimate. *Magazine Ubiquity*. *2000*, Article 4. Available: http://dx.doi.org/10.1145/353165.353882

[68] H. Galanxhi-Janaqi and F. F.-H Nah. (2004). U-commerce: emerging trends and research issues. *Industrial Management and Data Systems*, [Online]. *104(9)*, pp. 744–755. Available: http://dx.doi.org/ 10.1108/02635570410567739

[69] A. Gershman. (2002). Ubiquitous commerce: always on, always aware, always proactive. in *Proceedings of the Symposium on Applications and the Internet*, Nara, Japan, pp. 37–38. [Online]. Available: http://dx.doi.org/10.1109/SAINT.2002.994443

[70] K.-J Lin, T. Yu, and C.-Y Shih. (2005). The design of a personal and intelligent pervasive commerce system architecture, in *Proceedings of the 2nd IEEE International Workshop on Mobile Commerce and Services*, Munich, German, pp.163–173. [Online]. Available: http://dx.doi.org/ 10.1109/WMCS.2005.25

[71] S. Shekar, P. Nair, and A. S. Helal. (2003). iGrocer: a ubiquitous and pervasive smart grocery. In *Proocedings of the ACM Symposium on Applied Computing*, Melbourne, USA, pp. 645–652. [Online]. Available: http://dx.doi.org/10.1145/952532.952658

[72] G. Roussos and T. Moussouri. (2004). Consumer perceptions of privacy, security and trust in ubiquitous commerce. *Personal and Ubiquitous Computing*. [Online]. *8(6)*, pp. 416–429. Available: http://dx.doi.org/ 10.1007/s00779-004-0307-6

[73] D. A. Mazzari, P. Seraphine, S. I. Ahamed, and S. G. Balasubramanian. (2007). Design and implementation of EPARK wireless parking payment system using pervasive computing. in *Proceedings of the 21st International Conference on Advanced Information Networking and Applications – Workshops*. Niagara Falls, Canada, pp. 219–224. [Online]. Available: http://dx.doi.org/10.1109/AINAW.2007.145

[74] D. K. W. Chiu and H.-f Leung. (2005). Towards ubiquitous tourist service coordination and integration: a multi-agent and semantic web approach. in *Proceedings of the 7th International Conference on Electronic CommerceI*. New York, USA, pp. 574–581. [Online]. http://dx.doi.org/10.1145/1089551.1089656

[75] T.-Y. Liu and Y.-L. Chu. (2010). Using ubiquitous games in an English listening and speaking course: Impact on learning outcomes and motivation. *Computers & Education*. [Online]. *55(2)*, pp. 630–643. Available: http://dx.doi.org/10.1016/j.compedu.2010.02.023

[76] A. Ciaramella, M. G. C. A. Cimino, B. Lazzerini, and F. Marcelloni. (2010). Using context history to personalize a resource recommender via a genetic algorithm, in *Proceedings of the 10th International Conference on Intelligent Systems Design and Applications*. Cairo, Egypt, pp. 965–970. [Online]. Available: http://dx.doi.org/10.1109/ISDA.2010.5687064

[77] S. Smith. (2008). Who controls the past controls the future - life annotation in principle and practice, University of Southampton, School of Electronics and Computer Science, PhD Thesis. [Online]. Available: http://expertise.ecs.soton.ac.uk/16554/1/thesis.pdf

[78] A. R. Doherty, N. Caprani, C. O. Conaire, V. Kalnikaite, V., C. Gurrin, A. F. Smeaton, and N. E. O'Connor. (2011). Passively recognising human activities through lifelogging. *Computers in Human Behavior*. [Online]. *27(5)*, pp. 1948–1958. Available: http://dx.doi.org/ 10.1016/j.chb.2011.05.002

[79] A. J. Sellen, and S. Whittaker. (2010). Beyond total capture: a constructive critique of lifelogging. *Communications of the ACM*. [Online]. *53(5)*, pp. 70–77. Available: http://dx.doi.org/ 10.1145/1735223.1735243

[80] D. Baur, F. Seiffert, M. Sedlmair, and S. Boring. (2010). The streams of our lives: Visualizing listening histories in context. *IEEE Transactions on Visualization and Computer Graphics*. [Online]. *16(6)*, pp. 1119–1128. Available: http://dx.doi.org/10.1109/TVCG.2010.206

[81] G. Fischer. (2001). User modeling in human–computer interaction. *User Modeling and User-Adapted Interaction*. [Online]. *11(1)*, pp. 65–86. Available: http://dx.doi.org/10.1023/A:1011145532042

[82] I. Konig, C. Voigtmann, B. N. Klein, and K. David. (2011). Enhancing alignment based context prediction by using multiple context sources: experiment and analysis, in *Proceedings of the 7th International and Interdisciplinary Conference on Modeling and Using Context*, Karlsruhe, Germany, pp. 159-172. [Online]. Available: http://dx.doi.org/ 10.1007/978-3-642-24279-3_18

[83] S. Sigg, D. Gordon, G. von Zengen, M. Beigl S. Haseloff, and K. David. (2011). Investigation of context prediction accuracy for different context abstraction levels. *IEEE Transactions on Mobile Computing*. [Online]. *11(6)*, pp. 1047–1059. Available: http://dx.doi.org/ 10.1109/TMC.2011.170

[84] S. Sigg, S. Haseloff, K. David. (2010). An alignment approach for context prediction tasks in ubicomp environments. *IEEE Pervasive Computing*. [Online]. *9(4)*, pp. 90–97. Available: http://dx.doi.org/ 10.1109/MPRV.2010.23

[85] M. Ballings, D. Van den Poel, N. Hespeels, and R. Gryp. (2015). Evaluating multiple classifiers for stock price direction prediction. *Expert Systems with Applications*. [Online]. *42(20)*, pp. 7046–7056. Available: http://dx.doi.org/10.1016/j.eswa.2015.05.013

[86] A. Bala and I. Chana. (2015). Intelligent failure prediction models for scientific workflows. *Expert Systems with Applications*. [Online]. *42(3)*, pp. 980–989. Available: http://dx.doi.org/10.1016/j.eswa.2014.09.014

[87] I. Burbey and T. L. Martin. (2012). A Survey on Predicting Personal Mobility. *International Journal of Pervasive Computing and Communications*. [Online]. *8(1)*, pp. 5–22. Available: http://dx.doi.org/ 10.1108/17427371211221063

[88] S. Lee and K. C. Lee. (2012). Context-prediction performance by a dynamic Bayesian network: Emphasis on location prediction in ubiquitous decision support environment. *Expert Systems with Applications*. [Online]. *39(5)*, pp. 4908–4914. Available: http://dx.doi.org/10.1016/j.eswa.2011.10.026

[89] V. Pejovic and M. Musolesi. (2015). Anticipatory Mobile Computing: A Survey of the State of the Art and Research Challenges. *ACM Computing Surveys*. [Online]. *47(3)*, article n. 47. Available: http://dx.doi.org/10.1145/2693843

[90] D. Ameyed, M. Miraoui, and C. Tadj, "A Survey of Prediction Approach in Pervasive Computing," *International Journal of Scientific & Engineering Research*, vol.6, no.5, pp. 1–11, 2015.