A Survey of Context-awareness in Learning Environments in 2010-2016

Aziz Hasanov and Teemu H. Laine
Department of Software, Ajou University, Suwon, Republic of Korea

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Abstract: Context-aware learning environments can detect the learner's context and adapt learning materials to match the context. The support for context-awareness is essential in these systems so that they can make learning contextually relevant. Previously, several surveys on context-aware learning environments have been conducted, but they are either old or they do not consider several important aspects of context-awareness. To alleviate this, we first performed a literature search on context-aware learning environments in 2010-2016. After filtering the results, we analyzed 28 studies. Highlights of the results are: (i) PDAs and mobile phones are the most common client types, (ii) RFID/NFC are the most common sensors, (iii) ontology is the most common context modeling approach, and (iv) context data typically originates from the learner's profile or the learner's location. Additionally, we proposed a taxonomy for context categories in context-aware learning environments. Finally, based on our survey results, we gave directions for future research in the field. These results can be of interest to educational technology researchers and context-aware application developers.

1 INTRODUCTION

Recent development of advanced information technologies, such as wireless communications, sensors, and the Internet of Things, has enabled adaptive learning, including mobile and context-aware learning. In this paper, we use the definition of context as a set of entities that constitute the learner's situation (Laine and Nygren, 2016). Examples of these contextual entities in a learning environment are current place, time, other nearby learners, learning style, and learning history. The abilities of a learning environment to detect the learner's context and to adapt its behavior accordingly play a crucial role in personalized learning (Gómez and Fabregat, 2010). Context-awareness can make a significant difference in learning efficiency compared to traditional classroom-based learning because in context-aware learning environments learning resources and activities are adapted to match the learner's current situation. A body of studies in the field of context-aware learning show positive effects of context-aware technologies on learning (Hsu et al., 2016; Gomez et al., 2016; Wu et al., 2012).

Several surveys have been conducted on context-aware systems with diverse perspectives. A literature review on mobile and ubiquitous learning environments published in 2001-2010 focused on analyzing non-technical aspects, such as publication statistics, target groups, and learning domains (Hwang and Tsai, 2011). Pedagogical and technical aspects of context-aware learning environments were analyzed in another survey (Laine and Joy, 2009). Verbert et al. (Verbert et al., 2012) compared context-aware recommender systems for educational purposes. Finally, technological foundations of context-aware systems have been surveyed from the perspectives of mobile learning architectures (Baccari et al., 2015) and context-aware middleware architectures (Li et al., 2015). Despite these valuable surveys, there has not been a recent study which would thoroughly analyze contemporary learning environments from the perspective of context-awareness.

To understand the landscape and technical approaches of context-aware learning environments published between 2010 and 2016, we analyze 28 articles on context-aware learning environments for different purposes. We particularly focus on identifying and comparing the technical solutions through which context-awareness has been established. Moreover, we use the discovered information to discuss directions for future context-aware learning environments. Research contributions of this review are fourfold: (i) explore and compare context-aware learning environments in 2010-2016; (ii) identify various approaches in which context-awareness has been estab-

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lished in these systems; (iii) propose a taxonomy of context categories to help comparing context-aware learning environments; and (iv) give directions for future context-aware learning environments.

2 METHODOLOGY

In this survey we employed a simplified version of the systematic literature review methodology (Kitchenham and Charters, 2007). The original methodology comprises a set of guidelines for planning, conducting, and reporting a systematic literature review with a focus on software engineering field. In the following, we describe our adaptation of this methodology in terms of data collection and analysis.

2.1 Data Collection

First, we defined literature search criteria. The first-order criteria were defined as follows: a combination of predefined keywords (e.g., context-aware, education, system); publication time range 2010-2016; type of publication: conference and journal publications; digital libraries / search tools: Google Scholar, IEEE, and ACM. We also defined a second-order criterion as relevance to the field of context-aware education, thus selected publications should, in sufficient detail, describe a learning environment that is context-aware.

Data collection and filtering were performed in four steps using the aforementioned criteria. The initial filtering of search results was based on the first-order criteria. In this first step, we discovered 53 potential articles. Next step of filtering was based on the second-order criterion, which was applied to titles and abstracts of search results. Then, the same criterion was applied during skimming through the previously filtered results. Finally, we read thoroughly the remaining papers and applied the second order filtering criterion. As the result, we had 28 papers to be analyzed for this survey.

2.2 Data Analysis

To analyze the findings in a structured manner, we first established taxonomies through which the reviewed systems were to be compared. These taxonomies would enable us to classify various aspects of the reviewed learning environments and thereby understand their similarities and differences. Some of the taxonomies were discovered from previous publications and some of them we created out of necessity. After establishing the taxonomies, we performed an in-depth analysis of the selected papers to assign appropriate values to each aspect. Finally, based on this classification of learning environments into different aspects, we gave our own interpretations of the findings to provide useful ideas for future research in the field.

3 RESULTS

Here we present an overview of the reviewed learning environments and describe the technical approaches that were used in these systems to establish context-awareness. It must be noted that despite our best efforts we were not able to extract all required data from the analyzed articles due to lack of details in their presentation. Such cases are marked with 'n/a' as in not available. Non-existent aspects are marked with a dash ('-').

3.1 Overview

Table 1 gives an overview of the surveyed learning environments with a name (if available) and reference, description, and client type. As the table indicates, context-aware learning environments have been developed for various, mostly informal, learning scenarios and subjects to be used by both children and adults.

By 'client type' we refer to a device or software through which learners use the learning environment. We categorized clients used in the reviewed learning environments into six types: (i) Personal Digital Assistants (PDA), (ii) Mobile phones (including also smartphones), (iii) Tablets, (iv) Wearables, (v) Laptops/PCs, and (vi) Web browsers.

Mobile devices were often used as clients in the reviewed systems. In particular, mobile/smart phones and PDAs were the most common clients. There were seven systems with web browser clients, thus making them platform independent. Only one article proposed the use of wearables (smartwatches) in the learning process (Santos et al., 2015).

3.2 Context-awareness

To compare the technical approaches through which context-awareness has been established in contemporary context-aware learning environments, we defined a classification scheme using the following aspects: Context Acquisition, Context Modeling, Context Entities, and Sensors. In the following, before presenting the results, we explain these aspects with their respective taxonomies.

Table 1: Overview of context-aware learning environments.

System	Description	Client type
ALESS (Hsu et al., 2016)	Supports active learning in a museum for elementary school students	PDA
WoBaLearn (Zhang et al., 2016)	Guides professionals in office and factory environments to engage in work-based learning activities	Tablet
AICARP (Santos et al., 2015)	Provides interactive recommendations to support language learning	Wearables, Laptop/PC
(Gomez et al., 2016)	Delivers contextualized content to the students in nursery, medicine and systems engineering	Tablet, Mobile phone
CAALS (Chen and Lin, 2016)	Supports active learning in museum for elementary school students	Tablet
MobiSWAP (Harchay et al., 2015)	Semantic web-based system that supports personalized self-assessment in mobile environments for computer science students	PDA, Laptop/PC, Mobile phone
(Benlamri and Zhang, 2014)	Provides knowledge-driven recommendations to learn C++ programming and photography	Mobile phone
(Kim and Lee, 2014)	Provides learners with English conversation learning contents for the business sector. Recognizes trade names from signboard images	Mobile phone
UoLmP (Gómez et al., 2014)	Supports semi-automatic adaptation of learning activities, particularly for learning English	Tablet, Mobile phone
E-SoRS (Akbari and Taghiyareh, 2014)	Provides adapted exercises to a graduate-level students based on their learning styles	Web browser
(Yin et al., 2013)	Offers technicians learning opportunities during maintenance work	PDA, Mobile phone
SCROLL (Li et al., 2013)	Helps Japanese language learners to record their learning logs and gives them recommendations later	Tablet
(Kasaki et al., 2012)	A location-aware language learning with adaptive correlation computing methods	Web browser
MLAS (Chorfi et al., 2012)	Applies Case-Based Reasoning approach to determine appropriate content for the learner	PDA, Tablet, Laptop/PC, Mobile phone
SRL@Work (Siadaty et al., 2012)	Learning environment for workers at a car manufacturer, SMEs and at teachers' professional association	Web browser
CAULS (Chen and Huang, 2012)	Learning in museum with elementary school teachers and students	PDA
(Wu et al., 2012)	Supports cognitive apprenticeships in nursing skills training	PDA
(Alharbi et al., 2012)	Provides a student-centric approach to lifelong learning	Web browser
ePH (Vladoiu and Constantinescu, 2011)	Multi-agent system that provides support for various learning scenarios	PDA, Laptop/PC, Mobile phone
IWT (Capuano et al., 2011)	Provides personalized e-learning	Web browser
(Jia et al., 2011)	Workplace e-learning system using Key Performance Indicator and ontology-based approaches	Web browser
(Wang and Wu, 2011)	Ubiquitous learning system that gives courseware recommendations in a museum	PDA
(Yaghmaie and Bahreininejad, 2011)	Adaptive learning system using multi-agents that adapts course topics according to learners' experiences	n/a
(Wang and Wang, 2011)	Ubiquitous learning system based on a service-oriented architecture	PDA, Mobile phone (with RFID)
(Scott and Benlamri, 2010)	Collaborative learning space applied to university lectures	Web browser
(Yu et al., 2010)	Semantic learning space infrastructure and English learning assistant	Tablet
TANGO (Ogata et al., 2010)	Supports language learning (English, Japanese, Chinese and Spanish)	PDA
PCULS (Chen and Li, 2010)	English vocabulary learning based on the learner's location, learning time, English vocabulary abilities and leisure time	PDA

Context Acquisition is the process of capturing the learner's current context and its methods vary significantly depending on available technology and the system's intended use of context data. There are three fundamental ways for context acquisition (Perera et al., 2014): (i) context can be sensed directly through sensors; (ii) context can be derived from sensed raw data (or other data source) through computation; or (iii) context can be provided by user input. Accordingly, our context acquisition taxonomy consists of classes *Sensor*, *Derived* and *User input*.

Context Modeling defines a way of representing the context in format that can be understood and processed by the computer. There are six context modeling approaches that have been classified previously (Strang and Linnhoff-Popien, 2004) and used in context-aware systems: Key-value, Markup scheme, Graphical, Object-based, Logic-based, and Ontology-based. In addition to this list, we added Database-based models that employ a database (e.g., relational, NoSQL) to store the learner's context data. This amendment was required because we found that several context-aware learning environments store context data in a database instead of using a specific context modeling technique.

There are many ways to categorize *Context Entities* into taxonomies (Verbert et al., 2012; Li et al., 2015; Constantino Martins et al., 2008; Gómez et al., 2014) but none of them were found to be sufficient for our survey. Based on the analysis of previous work, we established a taxonomy that comprises five context entity groups: User, Technical, Spatio-Temporal, Pedagogical and Environmental. Figure 1 illustrates our taxonomy with example entities for each group.

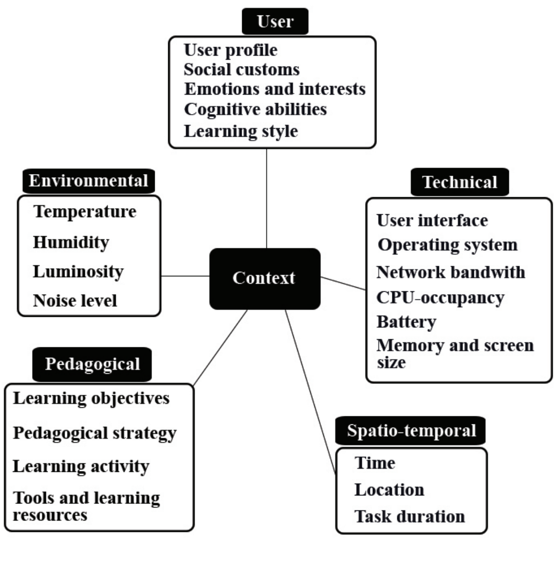

Figure 1: A taxonomy of context entities.

Sensors refer to hardware and software (virtual) sensors that were used in the reviewed learning environments. We identified six groups of sensors that have been used as sources for context data: RFID/NFC, GPS, Camera, Microphone, IR (infrared)-based sensors, and network (e.g., bandwidth). One of the surveyed studies (Santos et al., 2015) only specified groups of sensors, thus we reported this case as "physiological and inertial sensors".

Table 2 compares the surveyed context-aware learning environments according to the aforementioned classification aspects. Due to lack of technical details available, we could not find information for all cells in the table.

Sensors (S) and user input (UIn) were the most common sources for context acquisition with 20 and 19 instances, respectively, and many learning environments used a combination of the two. A typical example would be a learning environment that asks the user to insert learning preferences and background information before learning, and during the learning process the learner's location is sensed with RFID (Santos et al., 2015; Zhang et al., 2016). Using these context entities, the system can then provide personalized materials that suit the learner's preferences and location. Derived data (D), which is based on refining raw data into information with a higher degree of abstraction, was much less common. An example of how derived data is used is the distance between learners or the learner and learning target, which are computed based on location coordinates (Hsu et al., 2016).

We hypothesized that ontologies would be the most common context modeling approach today, but there also would be representatives of other approaches. Our analysis proved the first part of the hypothesis correct. Ontologies were found in 13 surveyed systems, thus making them the most popular context modeling approach. Databases were also common with 8 instances, but other approaches were nearly non-existent. Some articles described also the types of ontologies, such as learner ontology, device ontology, domain ontology, and content ontology.

A myriad of context entities were employed to establish context-awareness in the reviewed learning environments. The results in Table 2 suggest that user (U) context and spatio-temporal (ST) context were the most common entity groups with 21 and 19 occurrences, respectively. A typical context entity was user profile with information such as previously studied learning materials and learning preferences. Within the spatio-temporal context, location of the learner was the most common entity. Location was often used with timestamp to determine where the learner is at a

Table 2: Context-awareness in learning environments.

System	Context Acquisition	Context Modeling	Context Entities	Sensors
ALESS (Hsu et al., 2016)	(S)	DB (relational)	(P), (ST)	RFID
WoBaLearn (Zhang et al., 2016)	(S), (UIn)	Ontology based, DB (relational)	(U), (ST)	n/a
AICARP (Santos et al., 2015)	(S), (UIn)	n/a	(U), (E)	Physiological and inertial sensors
(Gomez et al., 2016)	(S)	Ontology based	(U), (P), (ST)	RFID/NFC, GPS
CAALS (Chen and Lin, 2016)	(S)	DB (relational)	(ST)	RFID
MobiSWAP (Harchay et al., 2015)	(UIn)	Ontology based (object, learner, context, portfolio, domain)	(T), (P), (ST)	-
(Benlamri and Zhang, 2014)	(S), (UIn)	Ontology based (domain, activity, learner, device, environment)	(U), (T), (P), (ST)	Network (connection/ bandwidth)
(Kim and Lee, 2014)	(S)	DB (relational)	(ST)	GPS
UoLmP (Gómez et al., 2014)	(S), (UIn)	n/a	(U), (P), (ST)	GPS
E-SoRS (Akbari and Taghiyareh, 2014)	(UIn)	Ontology based (learner, content)	(P)	-
(Yin et al., 2013)	(S), (D), (UIn)	Markup scheme (XML)	(U), (T), (E), (ST)	GPS, Camera
SCROLL (Li et al., 2013)	(S), (D), (UIn)	DB (relational)	(U), (T), (ST)	RFID, GPS, Camera
(Kasaki et al., 2012)	(S), (D)	n/a	(U), (ST)	GPS
MLAS (Chorfi et al., 2012)	(UIn)	Markup scheme	(U), (T)	-
SRL@Work (Siadaty et al., 2012)	(UIn)	Ontology based	(U)	-
CAULS (Chen and Huang, 2012)	(S), (UIn)	n/a	(U), (ST)	RFID
(Wu et al., 2012)	(S), (UIn)	DB	(U), (ST)	RFID
(Alharbi et al., 2012)	(D), (UIn)	DB	(U)	-
ePH (Vladoiu and Constantinescu, 2011)	(S), (D), (UIn)	Ontology based	(U), (T), (E), (P), (ST)	GPS
IWT (Capuano et al., 2011)	(UIn)	Ontology based	(U), (T), (P)	-
(Jia et al., 2011)	(UIn)	Ontology based	(U)	-
(Wang and Wu, 2011)	(S), (UIn)	DB	(U)	RFID
(Yaghmaie and Bahreininejad, 2011)	(UIn)	Ontology based	(U)	-
(Wang and Wang, 2011)	(S)	Ontology based (learning method, learning domain, location context)	(P), (ST)	RFID
(Scott and Benlamri, 2010)	(S), (D), (UIn)	Ontology based	(U), (T), (ST)	IR-based
(Yu et al., 2010)	(S)	Ontology based (context, content, domain)	(U), (T), (P), (ST)	RFID, GPS, Camera, Microphone
TANGO (Ogata et al., 2010)	(S)	n/a	(ST)	RFID
PCULS (Chen and Li, 2010)	(S)	DB (relational)	(U), (ST)	Network (WLAN positioning)

given time. Technical (T), pedagogical (P) and environmental (E) contexts were utilized in 9, 10 and 3 cases, respectively.

Location-awareness was clearly visible in popularity of sensor technologies with RFID/NFC and GPS occurring 10 and 8 times, respectively. A typical example of using RFID/NFC in the reviewed systems was to provide location-sensitive learning content when the learner reads a tag with a mobile device (Wu et al., 2012). Adaptations of media type and size of resources were done by sensing through network properties such as connection type (IEEE 802.11 or GPRS) and bandwidth (Benlamri and Zhang, 2014). Camera and microphone were used only in a handful of systems, for example when the learner captures his learning log or the system senses audio signals (Li et al., 2013; Yu et al., 2010). Infrared was used for indoor positioning (Scott and Benlamri, 2010). Some of the reviewed systems did not use sensors or details about sensors were omitted.

3.3 Discussion

We can infer from the results presented in Table 2 that the most popular clients for context-aware learning environments are PDAs and mobile phones. This is probably due to their high mobility, which allows the learner to traverse within a context and between contexts. Mobility is a great affordance for learning environments that are based on informal learning contexts, such as museums, science centers and parks. Technological advances of mobile devices have made them truly smart in terms of processing power and sensing capabilities. Moreover, many PDA devices and smartphones provide RFID or NFC reader modules, which allow learners to interact with surrounding objects. Finally, the popularity of PDAs is somewhat surprising given the fact that smartphones have taken over the markets of high-performance mobile devices since the launch of the first iPhone in 2007.

The popularity of mobile phones and PDAs was expected given their pervasiveness in our lives. We were surprised that the recent boom in wearable technologies was not evident in the reviewed learning environments. Wearable technologies have been identified to possess considerable affordances for learning applications (Bower and Sturman, 2015). Perhaps educators and educational technology researchers are not yet convinced about this, or the cost of devices may be a barrier. Regardless of what the reasons are, we expect that the era of wearables in context-aware learning environments has begun.

Location-awareness was strongly present in the reviewed learning environments. According to our interpretation, the reason for this is that most context-aware learning environments are not developed to be used in classrooms; they are informal learning environments located beyond the physical school boundaries. In such systems it is essential that the learning environment can adapt its behavior to match the learner's whereabouts. The popularity of RFID/NFC and GPS sensors proves this point, and it is aligned with the popularity of the spatio-temporal context entity group. Interestingly, these findings match with the findings of our survey on context-aware learning environments published in 2009 (Laine and Joy, 2009). In the previous survey, we also discovered that RFID was the most common sensor technology, and predicted that RFID would become the next big thing in wireless mobile communications. Our current results suggest that this has been the case in context-aware learning environments, but a question remains as to how long will the popularity of RFID/NFC as an object identification technology last, given the recent advances in internet of things, indoor positioning, augmented reality and automatic object recognition through machine vision.

We can notice from Table 2 that the least used context acquisition method is derivation. The other two methods (sensors, user input) are almost equally popular with approximately 70% of the surveyed learning environments using them. We make a prediction that in future learning environments there will be a growing interest toward generating context data by performing refinement operations on raw sensor data. Consquently, the popularity of derived context acquisition will increase. This prediction is heralded by the recent boom of machine learning approaches, such as deep learning (LeCun et al., 2015), which allow sophisticated derivation of abstraction levels based on raw data inputs.

As Table 2 shows, ontology and database-based context modeling approaches were commonly used for context modeling in the reviewed learning environments. The main advantage of ontologies is that they support reasoning and data content validation, thus making them a popular and effective way to model the context. We expect that ontologies will keep their dominant place as a context modeling approach in context-aware learning environments in the near future, although novel approaches based on machine learning are likely to emerge.

Given large amounts of context data acquired by the reviewed context-aware learning environments, it was surprising to us that there was very little consideration on data security and privacy. It seems to us that innovative use of technology and good learning outcomes have been prioritized over data safety.

Many learning environments, and mobile applications in general, follow the learner's location in real-time. Will the issues of data security and privacy become more topical when future learning environments will be able to detect far more personal data from the learner, such as emotions and intentions? We suggest that these issues should be tackled sooner than later.

There are some limitations that should be considered when applying these results. Firstly, we were not able to insert all information to Tables 1 and 2 due to lack information in the source articles. We were also planning to include context reasoning techniques used in the reviewed learning environments, but only a few studies reported about them. Secondly, although we searched popular databases, there may be articles that were not found during the search. Moreover, a few articles were inaccessible due to paywalls. In spite of these limitations, the results of this survey shed light into contemporary context-aware learning environments and therefore they can be useful to interested parties.

4 CONCLUSIONS

Context-aware learning is a promising research field that can change the way in which we learn especially in informal learning contexts. In this survey, we compared state-of-the-art learning environments in this field. We provided a general overview of the surveyed systems as well as technical details of their context-aware architectures. In particular, we highlighted the most used technologies and methods for acquiring and modeling context data. Moreover, we proposed a taxonomy for context categories used in context-aware learning environments. These results could be good references for context-aware learning environment designers and researchers who intend to contribute to this field.

The popular technologies and approaches identified in this survey will remain to dominate context-aware learning environments for some time, but we can already see changes in the horizon. The future of context-aware learning environments looks bright given the unprecedented availability of affordable smart gadgets that form the Internet of Things. These devices, together with highly sophisticated reasoning algorithms, will form the backbone of future learning environments that not only serve but also self-evolve. Our next step is to propose a conceptual model for building future context-aware learning environments. Moreover, it is important to consider the aspects of security and privacy, as these topics were largely ignored by the reviewed studies.

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