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Adaptive systems: a content analysis on technical side for e-learning environments

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Abstract Adaptive systems refer to autonomous interactive systems that adjust their behavior and functionality to environmental changes. In e-learning context, adaptive e-learning systems (AESs) adapt their services to users interests, knowledge and goals. In order to investigate the trend of researches in the field of adaptation in e-learning systems, a comprehensive survey of research papers in this context is presented. In this regard, 190 research papers, published between 2000 and 2012, from 45 journals are reviewed and analyzed. The basic contributions of the paper are manifold. First, it provides classifications of research papers from two different points of view: the adaptive technologies utilized in research papers in order to provide adaptation services for AESs and the application fields of research papers in AESs as research goals. Second, it presents statistical analyses on adaptive technologies and application fields. The analyses are carried out based on publication year of papers, the publication year versus adaptive technologies, the publication year versus application fields and adaptive technologies versus application fields. Third, the open problems, current state and prospective direction of researches in AESs are discussed. Finally, the paper suggests what adaptive technology might be the best choice for ongoing researches in each application field.

Keywords Adaptive technology · Machine learning · Soft computing · Adaptive e-learning system · Ontology · Application software

1 Introduction

Conventional e-learning systems are the systems that provide e-learning materials for all users, regardless of their background, interest and goals. These systems also present one way of learning for all users, resulting in dramatic degradation of learning performance. Because

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of these issues, the use of adaptive approaches in e-learning systems has been significantly increased (Brusilovsky 2001).

Adaptive approaches refer to the technologies employed in adaptive systems to dynamically change system behavior according to the feedbacks received from the environment. In terms of e-learning, adaptive technologies help AESs to tailor the provided content for the user needs, interests, goals and background. They also provide other services such as automatic learning style detection (Özpolat and Akar 2009), learner navigation (Chen and Duh 2008), performance assessment (Biletska et al. 2010), feeling evaluation (D'Mello et al. 2012) and concept map construction (Bai and Chen 2008).

Hitherto, numerous adaptive techniques have been employed in AES for different applications. It can be inferred from the past researches which techniques are the most appropriate ones with the objective of improving current AESs or proposing new components in these systems. Accordingly, in the current study, we investigate the research papers based on the adaptive technologies consisting of machine learning and soft computing algorithms, ontology techniques, application software, hybrid and innovative techniques. We will describe each of these techniques in Sect. 4.

Heretofore, there have been several literature reviews on AES field. Of which, some focus on learning style classification (Akbulut and Cardak 2012; Brown et al. 2005), some on personalized information retrieval techniques (Steichen et al. 2012) and a few on semantic techniques (Torre 2009) and hypermedia methods (Knutov et al. 2009). Furthermore, some research papers only concentrate on providing guidelines for AES designers (Brusilovsky 2001; Mdritscher et al. 2004; Verdú et al. 2008). To the best of our knowledge, none of the research papers have been completely devoted to adaptive technologies on AESs as well as their respective applications. In an attempt to provide a comprehensive study on adaptive e-learning research papers, this paper presents a classification framework based on adaptive technologies and their application fields. Future directions and open problems are further discussed in order to provide stimulation on adaptive e-learning issues.

In particular, we focus on the papers that have considered the adaptivity in AESs using techniques such as artificial intelligence-based algorithms (machine learning and softcomputing), semantic and ontology, ready-to-use application software, hybrid or innovative techniques for providing one or several services of AESs. In the current study, we found that about half of research papers focused on machine learning and softcomputing techniques whereas 23 % of them concentrated on semantic and ontology, 16 % on application software, 10 on innovative techniques and 3 % on hybrid techniques. The study also reveals that both learner's problem alleviation and presentation are the most important application fields that account for about half of research papers. As a result of this study, we explore the open problems, current state and the prospective direction of researches in AESs.

The proceeding parts of this paper are structured as follows. First, in Sect. 2, the applied methodology in this paper is presented. Second, a framework to classify research papers is proposed in Sect. 3. Third, research papers are examined and classified based on the proposed classification framework in Sect. 4. Forth, open problems and future direction on AESs are discussed in Sect. 5. Finally, in Sect. 6, the study is concluded and limitations and problems, which occurred during our study, are discussed.

We believe that this study will shed light on this topic and highlights the significance of adaptation in the next generation of e-learning systems. We also hope that this research leads researchers and practitioners to gain insight on which intelligent technology is better to be used in their proposed AESs.

2 Methodology

In order to study the AESs-related research papers, a systematic approach that falls each research paper into one specific category is utilized. In this approach, based on the adaptive technologies and their application fields, the papers are classified. Although there is a problem in categorizing the papers because some research papers have applied several different adaptive technologies, we manage to classify them based on their contributions.

In the systematic approach, the search area is confined by taking into account only the research papers published in the following online databases:

- Science Direct
- IEEE/IEE Library
- ACM Portal
- Springer Publisher
- Wiley online Library
- Taylor & Francis Online
- Emerald Library

Due to manpower limitation and the importance of reliability, we remove the papers published in conferences from our studying. We select the most AESs-related words as the search keywords, which are "adaptive e-learning systems", "adaptive educational hypermedia", "intelligent tutoring systems" and "adaptation in e-learning systems". As these keywords practically cover all aspects of adaptation in e-learning systems, it assures us that all research papers relevant to AESs are considered. Then, we conduct the search on the journals of each online database mentioned above. By reading the papers (two authors involved in reading the papers and the third in examining the results), we finally choose the most related papers to adaptive technologies in AESs. In particular, we take the four following major steps in order to categorize the papers.

1. Searching the electronic journal databases presented , based upon the keywords mentioned.
2. Classifying the selected research papers in accordance with the classification framework.
3. Verifying the paper classification.
4. Performing the final verification process on the categorized papers.

The flowchart of this approach is presented in Fig. 1.

Since this topic (AESs) is relatively new, we cover only the research papers from 2000 to 2012. This 12-year period can be considered as the representative of AES-related researches.

3 The proposed classification

The research papers, which have been collected based upon the methodology we employed, are categorized into five groups of adaptive technologies and seven groups of application fields. As mentioned before, adaptive technologies are computer science-based or mathematical techniques that help systems to either adapt themselves to users requirement, goals and background or to navigate users to appropriate learning paths. The general overview of the proposed classification framework is outlined in Fig. 2.

As shown in Fig. 2, according to adaptive technologies, the papers are classified into machine learning and softcomputing, semantic and ontology, application software, hybrid and innovative technologies. Based upon the application of adaptive technologies, the papers

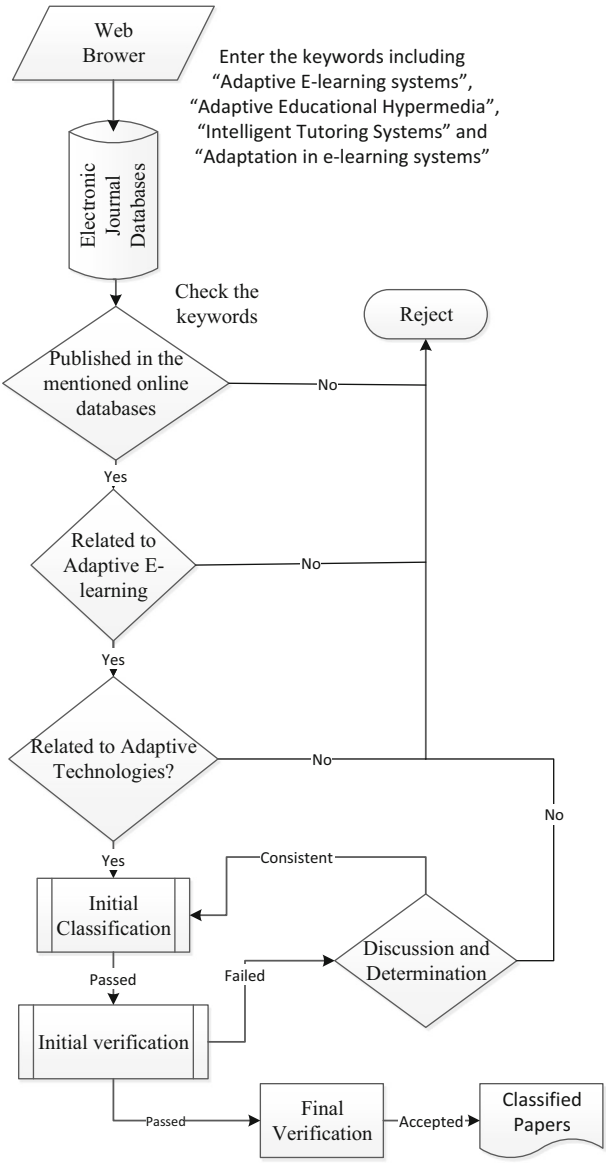

Fig. 1 Flowchart of the classification process

are also categorized into presentation, navigation, learning style detection, learner's problems alleviation, multi-dimensional support, concept maps construction and other.

Note that if two adaptive technologies are involved in a paper, for example decision tree algorithm and ontology, and the novelty lies in one of them, the paper is categorized into the group in which the paper has a contribution. The same goes for the application field. However, if the two adaptive technologies are novel, we classify the paper into the hybrid group. We also categorize the papers that propose many services for AESs as the multi-dimensional support.

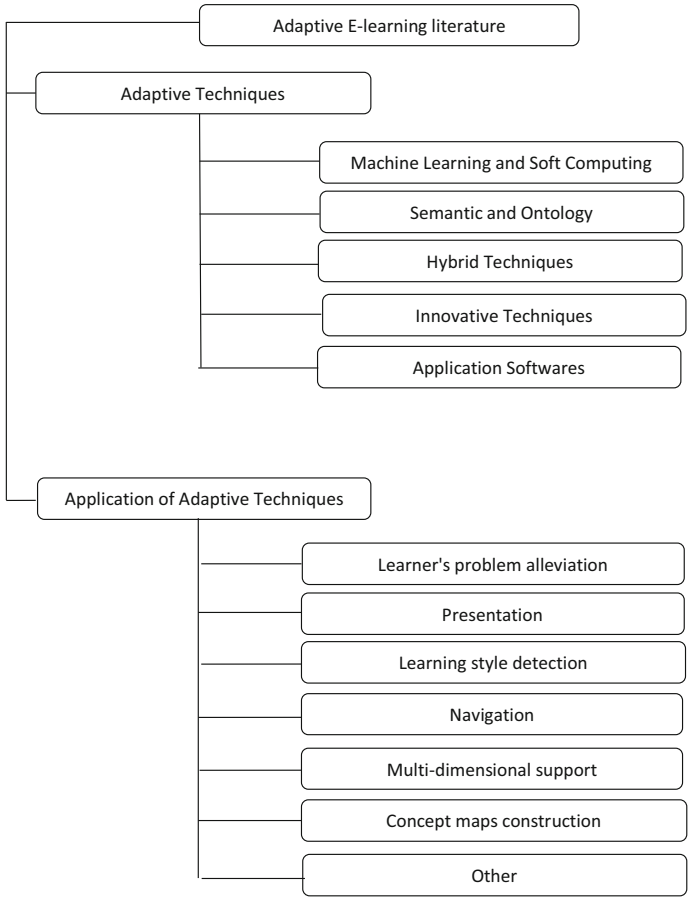

Fig. 2 Classification framework

3.1 Classification framework for adaptive techniques

The adaptive component generally provides the adaptation capability to e-learning systems. For example, ontology approaches can simply convert user's behavior to machine understandable instructions (Jia et al. 2011).

In particular, the adaptive technologies can be classified into five different categories: machine learning and soft computing, semantic and ontology, application software, special and hybrid techniques.

1. *Machine learning and soft computing techniques* Machine learning refers to practical intelligent techniques, which can learn about system structure through useful information, extracted from raw data (Witten et al. 2011). In general, there are three types of machine learning techniques: supervised learning, unsupervised learning and reinforcement learning techniques. As the most utilized techniques in AESs, supervised learning techniques such as decision tree, association rule mining, artificial neural and Bayesian network have been extensively applied in AESs to fulfill several significant objectives,

ranging from learning object personalization (Baylari and Montazer 2009) to learning style detection (Özpolat and Akar 2009).
Similar to machine learning techniques, soft computing techniques combine knowledge, techniques and methodologies, aiming to adjust system responds and learn how to deal with complex and real world problems (Jang et al. 1997). They have been utilized progressively in e-learning systems in order to resolve an extensive range of issues in AESs, including the performance evaluation of e-learning systems (Yang and Wu 2009), presentation of appropriate learning objects (Yang and Wu 2009) and construction of optimal learning paths (Huang and Chuang 2008).
There are many machine learning and soft comptuing techniques, among which are decision tree, neural network, association rule mining, Bayesian network, evolutionary algorithm, fuzzy logic and hybrid algorithms that have extensively been utilized in AESs. These algorithms have usually been applied to AESs for detecting learning style (Castro et al. 2007; Lo and Shu 2005; García et al. 2007), storing and assessing user experiences during learning process (Romero et al. 2013; Kujala et al. 2010; Chrysafiadi and Virvou 2012), personalizing learning objects (Baylari and Montazer 2009), evaluating users' achievements (Cheng et al. 2011), extracting knowledge, mining user profile (Chen et al. 2007b) and finding learning contents more effectively (Yang and Wu 2009).

2. *Semantic web and ontology*
Ontology technique is a way of modelling a domain of knowledge using representative primitives like classes or sets. In order to guarantee easy transmission and interpretation of data, it provides a standard way to represent such primitives (Pathak et al. 2009). For AI purposes, however, it refers to an explicit specification of conceptualization, which is the process of specifying the meaning of concepts (Gruber 1993). Using the specification process of ontology, AESs have been enabled, in terms of semantically modelling users, to build formal and machine-understandable instruction in e-learning environments (Jia et al. 2011). For example, (Chu et al. 2011b) utilized the ontology technology in order to construct user's knowledge architecture through searching, customizing and integrating concepts.
Semantic web is a type of adaptive technology closely related to ontology. According to Tim Berners-Lee, the inventor of the World Wide Web, semantic web is "a web of data that can be processed directly and indirectly by machines". Semantic web is applied in e-learning systems to fulfill several purposes, including conceptualizing the learning contents (Aroyo et al. 2004) and mitigating learner's problems (Shafrir and Etkind 2006).

3. *Application software*
Application software as Commercial-Off-The-Shelf software (COTS) have been frequently used in AESs in order to provide less expensive components. These ready-to-use software components help AESs to provide a variety of applications. For example, (Medina-Medina et al. 2011) used JSEM-HP tool, by which teachers are able to create and manage learning process. Meanwhile, it provides a personalized learning path for each user. Generally speaking, application software can be categorized into two different classes: web applications and non-web applications. Web applications such as adaptive communication tools (Gogoulou et al. 2008) are referred to those applications which are accessed by end-users through internet or Intranet. In contrast, non-web applications such as assessing tools (Lazarinis et al. 2010) and documentation generator tools (Caumanns 2000) are those applications which are utilized to deliver services within an isolated computer system.

4. *Hybrid Techniques*
   These techniques are taken into account since a number of research papers integrated adaptive technologies to improve their proposed systems. Moreover, their contribution mainly lies in the integration of several adaptive technologies for enhancing the performance or the capability of AESs. For example, (Chang et al. 2009b) proposed an AES, which combined k-nearest neighbor (K-nn) with genetic algorithms in order to improve learning style classification method. Occasionally, artificial intelligence techniques such as fuzzy systems are not efficient when working alone; thus it would be more reasonable to be combined with other ones so as to improve their efficiency. For example, Verdú et al. (2012) combined a fuzzy system with a genetic algorithm in which the fuzzy system was used to classify questions that are applied to determine student's knowledge level and subsequently, it is combined with the genetic algorithm to enhance the classification results. Moreover, to detect optimal learning paths for learners, a combination of artificial intelligence techniques is applied in (Wang 2012). The author used fuzzy knowledge extraction and combined it with ant colony algorithm so that the large number of training cycles declined.
5. *Innovative techniques*
   Several research papers have proposed innovative approaches, which can not be categorized according to the aforementioned categories. Furthermore, since they are not sufficient to build a new category, we place them in a category called innovative techniques. For example, (Chang et al. 2009c) presented a browsing behavior model (B^2 model) which used high level petri nets in order to model and generate learner's behavior patterns.

3.2 Classification framework for application fields

In this section, the applications of adaptive technologies applied to the research papers we studied here are discussed. According to the application fields, the research papers are classified into learner's problems alleviation, presentation, learning style detection, navigation, multi-dimensional support, concept maps construction and other. The two application fields, presentation and navigation, were proposed by (Brusilovsky 2001). In attempting to classify adaptive hypermedia systems, Brusilovsky differentiated between the systems, which use adaptive technologies to deliver certain and related information to individual users and the systems which use adaptive technologies to direct users to certain goals. The remaining application fields arise from recognizing the fact that some recent research papers reflect the other topics in AESs.

1. *Concept maps construction*
   Concept maps, well-known as effective graphical tools, are employed to represent and organize the relationship between concepts. They have several significant characteristics, which make them attractive in applying to AESs. First, they represent concepts in hierarchical structure where most general concepts are placed in the top of the map and the specific ones in the lower-level. Second, through cross links, they enable us to see how concepts are relevant to other knowledge domain (Novak 2006). In AES context, they have been successfully employed to evaluate learning achievement and remove the ideas distracting student's attention when working with AESs (Cline et al. 2010). They are generally constructed by learning expert suggestions. However, with rapid recent progress of adaptive technologies, researchers have attempted to automatically construct concept

maps to decrease their developing costs. For example, (Bai and Chen 2008) proposed a new method based on fuzzy rules to automatically construct concept maps and evaluate the relevance degree between concepts.

2. *Learning style detection*
As learning style detection enables e-learning systems to adapt themselves to user's needs and interests more effectively, the number of research papers used adaptive technologies to classify and detect learning style has grown over the past few years. Particularly, machine learning techniques such as NBTree (Özpolat and Akar 2009), k-nearest neighbor (K-nn) (Chang et al. 2009b), neural networks (Lo and Shu 2005) and Bayesian networks (García et al. 2007), decision tree (Ortigosa et al. 2010) and association rules mining (Kardan and Ebrahimi 2013) are increasingly popular in detecting and classifying user's learning style.

3. *Learner's problems alleviation*
Once interacting with e-learning systems, students may feel bored, tired or even depressed, causing steady reduction in learning concepts. To cope with this issue, adaptive technologies such as adaptive tutor are used to detect and alleviate user's problems. For example, (D'Mello et al. 2012) proposed an intelligent system called Gaze tutor, aiming at enhancing learning rate through an interactive intelligent method, which dynamically detects and responds to student's boredom and disengagement. Another application, considered in this category, is student evaluation during learning process. Evaluating students in order to determine whether the learning process is successful, is one of the topics which has gained a great deal of attention in recent years. Hence, several papers addressed this issue since AESs had been proposed. For instance, (Biletska et al. 2010) used a semantic-based technique, consisting of RDFS ontologies and POSL rules in order to assess learners' qualifications and credentials.

4. *Presentation*
Many research papers have focused on AESs in terms of designing personalized learning objects and presenting them based on user's interests. For example, an attributed-based ant colony system was presented in order to help users to customize learning objects more effectively in (Yang and Wu 2009). Using an authoring tool providing personalized learning objects for learners, the AES adapts its contents to the best learning style (Cabada et al. 2011).

5. *Navigation*
Tailoring student's knowledge, interest and background for learning environment is one of the underlying purposes of designing learning paths (Carchiolo et al. 2010). Several techniques have been utilized for addressing this issue, including soft computing (Wang 2012; Carchiolo et al. 2010; Huang and Shiu 2012), hybrid (Chen and Duh 2008) and innovative techniques (Chen et al. 2005).

6. *Other*
This category was considered since several research papers have proposed a number of annotative applications that cannot be covered in the aforementioned categories. This category includes a variety of applications, ranging from new tools for enhancing the efficiency of AESs (Ruiz-Calleja et al. 2012) to novel methods to analyze AESs (Kitakoshi et al. 2010).

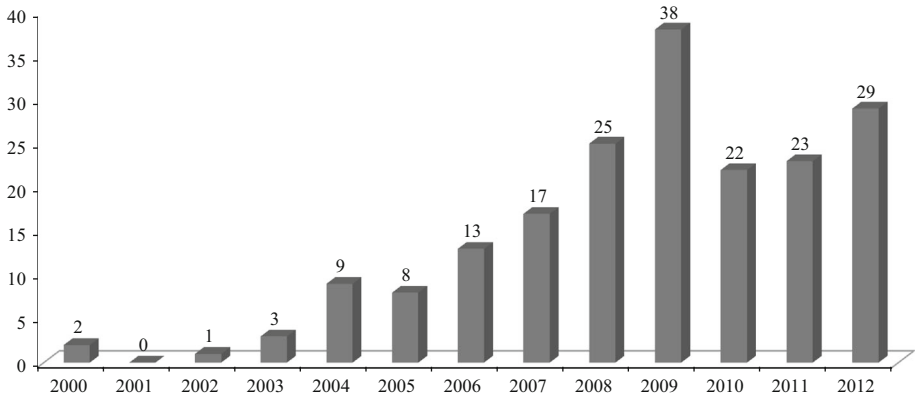

Fig. 3 Distribution of research papers by publication years

7. *Multi-dimensional support*
   In attempting to provide multi-dimensional support in adaptive e-learning environment, authors occasionally propose a structure, architecture or framework, which provides multi-services for AESs. For example, (Kozierkiewicz-Hetmańska 2011) proposed an AES which provides several services such as learner classification and learning path in order to improve learning satisfaction on e-learning environment. With respect to this goal, the proposed system classified learners based on learning style in which if the learning process were not successful, the system would modify learning scenario.

4 Classification of research papers

In this section, a complete survey of research papers relating to adaptive e-learning is provided. In this regard, 190 papers from 45 journals were selected and classified based on the proposed classification framework. The results of this analysis can be applied to provide a guideline for ongoing researches especially when adaptive technologies are going to be employed.

4.1 Distribution by publication years

The distribution of research papers published between 2000 and 2012 is depicted in Fig. 3. As seen, 2001 was an unusual year, in which nothing was published. This is due to the fact that AESs were formally initiated in 2001. Between 2002 and 2009, the number of research papers has grown gradually. Although it decreased in 2010, it started to rise again in 2011 and maintained its momentum in 2012. This may be as a result of innovative approaches, such as Oscar CITS (Latham et al. 2012) or as a result of new application fields such as concept map construction.

4.2 Distribution of research papers by adaptive technologies

Figure 4 represents the distribution of the research papers by adaptive technologies. As seen, the major part of the research papers focuses on machine learning and soft computing. Among these techniques, evolutionary algorithms are dominant techniques, and this is because they are not restricted to one specific algorithm. Fuzzy logic is another machine learning approach, accounting for 14 journal papers. It indicates that fuzzy logic techniques are still popular, even

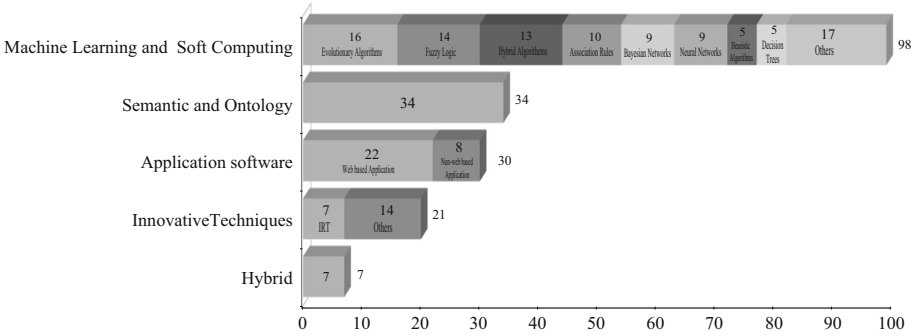

Fig. 4 Distribution of research papers by adaptive technologies

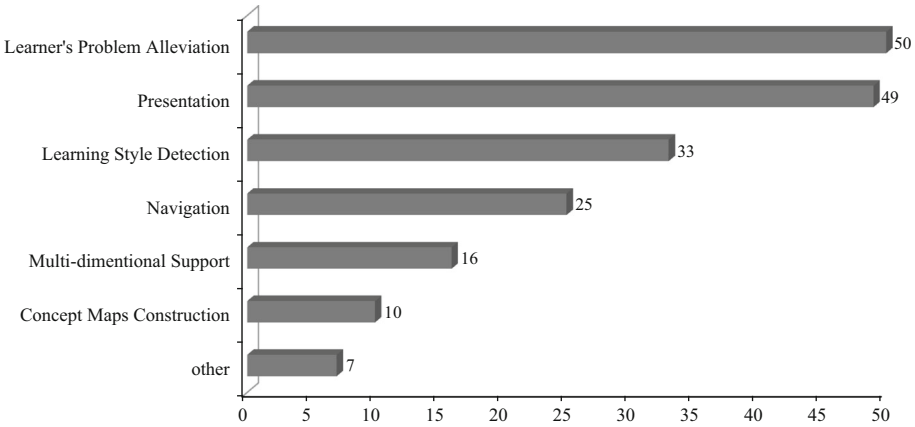

Fig. 5 Distribution of research papers by application fields

though several innovative machine learning techniques such as support vector machine have been proposed. Hybrid algorithms, which combine several machine learning and soft computing techniques have been employed quite frequently in AESs since when two or more artificial intelligence algorithms are combined together effectively, the results are highly promising.

4.3 Distribution of research papers by application fields and adaptive technologies

The goal of this section is to determine how many application fields have been addressed by how many research papers. Figure 5 shows the distribution of the research papers by their application fields.

Since learner's problems alleviation field includes an extensive range of issues such as detecting and alleviating learner's problems and evaluating student's achievements, it accounts for the majority of research papers in relation to all the other application fields. Presenting learning objects to individual user has always been an interesting topic in AESs; thus presentation field has earned the second place. The other application fields include: learning style detection, navigation, multi-dimensional support, and concept maps construction, respectively.

The distribution of all the research papers by application fields and adaptive technologies is presented in Tables 1, 2, 3, 4, 5, 6, 7. A summary of this is provided in Table 8.

Table 1 Learner's problem alleviation

Tools and techniques	References	Description
Machine learning and soft computing	Hwang (2003)	Fuzzy logic
	Rasmani and Shen (2006)	Fuzzy logic
	Chen et al. (2007a)	Fuzzy logic
	Meng et al. (2007)	Evolutionary algorithms
	Huang et al. (2007a)	Clustering
	DMello et al. (2008)	Natural language processing
	Chen and Bai (2009)	Fuzzy logic
	Huang et al. (2009)	Evolutionary algorithms
	Cocea and Weibelzahl (2009)	Hybrid (predictive algorithms)
	Colace (2009)	Bayesian networks
	Lee et al. (2009b)	Association rule mining
	Baylari and Montazer (2009)	Artificial neural networks
	Limongelli et al. (2009)	Heuristic algorithms
	Lykourentzou et al. (2009)	Support vector machine
	Lee et al. (2009c)	Decision trees
	Kujala et al. (2010)	Bayesian networks
	Peña Ayala (2010)	Fuzzy logic
	Gutierrez and Atkinson (2011)	Hybrid (SVM and CRF algorithms)
	Levy and Wilensky (2011)	Hybrid (logistic regression and association)
	Lin and Lai (2014)	Hybrid (collaborative annotating and data mining)
	Chu et al. (2011a)	Evolutionary algorithms
	Wang and Wu (2011)	Association rule mining
	Weng (2011)	Association rule mining
	Cheng et al. (2011)	Artificial neural networks
	Chrysafiadi and Virvou (2012)	Fuzzy logic
	Jeremić et al. (2012)	Fuzzy logic
	Gaudioso et al. (2012)	Hybrid (predictive algorithms)
	Lee (2012)	Bayesian networks
	Kotsiantis (2012)	M5rules algorithm
Application software	Lee and Chong (2003)	Community-based learning tool
	Zhuge and Li (2006)	Authoring tool
	Guzman et al. (2007)	Siette
	Ariga and Watanabe (2008)	Image-plot and the standard design table
	Lazarinis et al. (2010)	Adaptive assessment tool
	Hsiao et al. (2010)	Java programming
	Chen et al. (2011)	Online reflection learning system
	Lazarinis (2012)	Interoperable learner management tool
Semantic and ontology	Shafrir and Etkind (2006)	

Table 1 continued

Tools and techniques	Reference	Description
	Gladun et al. (2009)	
	Fernández-Breis et al. (2009)	
	Biletska et al. (2010)	
	Castellanos-Nieves et al. (2011)	
	Chu et al. (2011b)	
Innovative techniques	Pahl and Kenny (2009)	Syntax trees
	Chen (2009)	Item response theory
	Barla et al. (2010)	Item response theory
	Klinkenberg et al. (2011)	Item response theory
	Özyurt et al. (2012)	Item response theory
	D'Mello et al. (2012)	Gaze tracking
Hybrid	Cho et al. (2007)	Collaborative and content-based filtering

As shown in Table 8, most machine learning and soft computing algorithms have targeted the problems of learners while working with AESs. In other words, if a researcher wanted to apply an adaptive technology for evaluating users' problems such as student boredom and depression, it would be a good choice to employ one of the machine learning or soft computing algorithms. The same goes for presentation, learning style detection, navigation and concept map construction. For proposing a new framework, structure, or in general providing several services (multi-dimensional support), ready-to-use application software like Tutorweb and ZOSMAT would be a remarkable choice. For other applications such as logical characterization of AESs (Henze and Nejdl 2004), using ontology and semantic techniques is recommended.

4.4 Distribution of research papers by publication years and adaptive technologies

Classifying research papers by publication years and adaptive technologies provides an index for comparing adaptive technologies. It determines which adaptive technologies have been generally used. Moreover, it provides a guideline for researchers for their ongoing researches. Figure 6 illustrates the classification of the research papers according to the year they were published and the adaptive technologies they have used.

It can be inferred that most research papers have focused on machine learning and soft computing techniques specifically after 2007. It can further be implied that ontology techniques and application software have drawn attention in recent years. As seen, before 2006, machine learning and soft computing techniques have been used in many papers as the other adaptive technologies. However, after 2006, the number of research papers that has addressed these techniques has notably increased. In contrast to machine learning and soft computing techniques, it seems that other adaptive technologies have mediocre progress after 2006.

4.5 Distribution of research papers by publication years and application fields

Studying the research papers by publication years and application fields has a number of notable benefits. First, it can be used to determine researchers' fields of interest on AESs. Second, it can also be useful to find the most crucial research areas in adaptive e-learning

Table 2 Presentation

Tools and techniques	Reference	Description
Machine learning and soft computing	Alfonseca et al. (2007)	Natural language processing
	Tzouveli et al. (2008)	Clustering
	Huang et al. (2008a)	Evolutionary algorithms
	Chen (2008)	Evolutionary algorithms
	Fournier and Sansonnet (2008)	Evolutionary algorithms
	Yang and Wu (2009)	Evolutionary algorithms
	Wang and Tsai (2009)	Evolutionary algorithms
	Chu et al. (2009)	Clustering and heuristic
	Romero et al. (2009)	Text and web mining
	Iglesias et al. (2009)	Reinforcement learning
	García et al. (2009)	Association rule learning
	Cabada et al. (2011)	Artificial neural networks
	Li et al. (2012)	Evolutionary algorithms
	Verdú et al. (2012)	Hybrid (evolutionary algorithms and fuzzy logic)
	Sevarac et al. (2012)	Hybrid (neuro-Fuzzy)
	Lo et al. (2012)	Artificial neural networks
	Jeong et al. (2012)	Heuristic algorithms
Semantic and ontology	Aroyo et al. (2004)	
	Sancho et al. (2005)	
	Melis et al. (2006)	
	Shabajee et al. (2006)	
	Kontopoulos et al. (2008)	
	Sangineto et al. (2008)	
	Biletskiy et al. (2009)	
	Huang and Yang (2009)	
	Žitko et al. (2009)	
	Jiang and Tan (2009)	
	Lee et al. (2011)	
	Biletskiy (2012)	
	Vesin et al. (2012)	
	Jeong et al. (2012)	
Application software	Caumanns (2000)	Documentation generator tool
	Wang et al. (2006)	CooTutor
	Thyagharajan and Nayak (2007)	Web service
	Reategui et al. (2008)	Item descriptors
	Gogoulou et al. (2008)	Adaptive communication tool
	Wang et al. (2010)	ADAM
	Essalmi et al. (2010)	Web service

Table 2 continued

Tools and techniques	Reference	Description
	Medina-Medina et al. (2011)	JSEM-HP tool
	De-la Fuente-Valentín et al. (2011)	Generic service integration paradigm
	Ruiz-Calleja et al. (2012)	ICT tools
Innovative techniques	Brafman et al. (2004)	CP-net
	Muntean and Muntean (2009)	Peacock
	Chang and Chu (2010)	Petri net
	Fernández and Borrajo (2012)	Linear programming
Hybrid	Huang et al. (2008b)	Fuzzy logic and petri nets
	Melia and Pahl (2009)	Authoring tools
	Ullrich and Melis (2009)	Semantic web and HTN-planning
	Acampora et al. (2011)	Evolutionary algorithms and ontology

topic. Figure 7 represents the distribution of research papers by year of publication and their application fields.

As seen, between 2000 and 2007, the number of papers relating to learner's problems alleviation field has been increased as the same pace as the other application fields. However, between 2008 and 2011, the majority of the research papers have addressed this application field. In 2012, most research papers were divided between learner's problems alleviation and navigation fields.

5 Open problems

As a result of this study, several open problems arise. For instance, application of biometric techniques in user modelling for AESs is one of the areas that draw our attention. However, biometric techniques are being used only to authenticate users during e-learning exam taking (Michelle and Yair 2007) and they are not being employed sufficiently for other purposes such as finding out user's problems through facial expression and gestures. In fact, user's boredoms or anxiety can be detected by investigating emotional behaviors especially through face recognition techniques. Biometric techniques can be applied to measure users confidence as well.

Social Learning is considered as another active area which is growing rapidly. Social or collaborative e-learning is a learning process in which users learn about certain issues by participating in social activities (Dekson 2010). For instance, in social environments such as Facebook, when an individual comes up with an idea and intends to share it with his/her friends, he/she can easily put it on the internet and his/her friends can fortify the idea by actively taking part in the discussion. Therefore, social groups play an important role in social learning. Recognizing these groups and their relationships will assist us to manage learning and knowledge sharing more effectively. Therefore, considering the huge number of individuals in a social network, real time processing of their behaviors and grouping them to right groups can be an important issue. Hence, it will be worthy to investigate how the aforementioned techniques in this study can be utilized with this objective, and which one is the most promising option for any desired case.

Table 3 Learning style detection

Tools and techniques	Reference	Description
Machine learning and soft computing	Tsiriga and Virvou (2004)	K-nn
	Kavcic (2004)	Fuzzy logic
	Stathacopoulou et al. (2005)	Hybrid (neuro-fuzzy)
	Yeh and Lo (2005)	Artificial neural networks
	Lo and Shu (2005)	Artificial neural networks
	Villaverde et al. (2006)	Artificial neural networks
	Mussi (2006)	Bayesian networks
	Bien and Lee (2007)	Fuzzy logic
	Zarikas (2007)	Bayesian networks
	García et al. (2007)	Bayesian networks
	Yudelson et al. (2008)	Bayesian networks
	García et al. (2008)	Bayesian Networks
	Legaspi et al. (2008)	Hybrid (clustering and weighting algorithms)
	Gu et al. (2008)	Web mining
	Özpolat and Akar (2009)	Decision tree
	Wang et al. (2009)	Decision tree
	Chang et al. (2009b)	Hybrid (K-nn and evolutionary algorithms)
	Carmagnola and Cena (2009)	Heuristic algorithms
	Bousbia et al. (2010)	Decision tree
	Chang and Chu (2010)	Decision tree
	Romero et al. (2013)	Hybrid (web mining and classification methods)
	Jong et al. (2012)	Clustering
	Latham et al. (2012)	Natural language processing
	Dorça et al. (2013)	Reinforcement learning
Innovative techniques	Conati and Merten (2007)	Eye tracking
	Guzmán et al. (2007)	Item response theory
	Chang et al. (2009a)	Petri net
	Güyer (2009)	Graph theory
	Gütl et al. (2005)	Eye tracking
Semantic and ontology	Hofmann (2004)	
	Zeng et al. (2009)	
	Aroyo and Houben (2010)	
Application software	Papanikolaou et al. (2003)	INSPIRE

Another emergent field, which is considered as the latest form of e-learning platform, is ubiquitous learning. Mobile technologies and artificial intelligence provide a strong foundation for ubiquitous learning. Therefore, e-learning can be served at anywhere and any time. The important question is that how learner modeling can be achieved by considering the dynamic context of learner, which is a mobile learner these days.

Table 4 Navigation

Tools and techniques	Reference	Description
Machine earning and soft computing	Huang et al. (2007b)	Evolutionary algorithms
	Wang et al. (2008)	Evolutionary algorithms
	Lazcorreta et al. (2008)	Association rule mining
	Tai et al. (2008)	Artificial neural networks
	Guo and Zhang (2009)	Clustering
	Hwang et al. (2010)	Evolutionary algorithms
	Hsieh and Wang (2010)	Association rule mining
	Carchiolo et al. (2010)	Fuzzy logic
	Hogo (2010)	Fuzzy logic
	Chiou et al. (2010)	Heuristic algorithms
	Al-Muhaideb and Menai (2011)	Evolutionary algorithms
	Marquez Vazquez et al. (2011)	Hybrid (bayesian networks and evolutionary algorithms)
	Pushpa (2012)	Evolutionary algorithms
	Wang (2012)	Hybrid (fuzzy logic and evolutionary algorithms)
Semantic and ontology	Baldoni et al. (2004)	
	Beydoun et al. (2007)	
	Pilato et al. (2008)	
	Sah and Hall (2012))	
Hybrid	Chen and Duh (2008)	Item response theory and fuzzy logic
	Huang and Shiu (2012)	Item response theory and pattern mining
Application software	Longpradit et al. (2008)	Inquiry tools
	Chen et al. (2008a)	e-News delivery system
	Verbert et al. (2012)	Classifier tools
Innovative techniques	Chen et al. (2005)	Item response theory
	Chen et al. (2006)	Item response theory

Hitherto, nearly all researches in the field of adaptive learning focused on traditional learning style models. In fact, they paid attention to the common features in any learning environments. An important issue is E-learning Style, which can be opened to consider the role of technological elements of e-learning. This consideration can be utilized to provide more accurate modelling of learning styles. Certainly with respect to recently used hardware such as mouse, keyboard and touch-screen monitors, e-learning style enables AESs to personalize learning process and activities.

In general, pedagogy and learning are important in terms of directing users and specifically students more effectively. Despite of pedagogy importance, learning issues in cyber and online environment have attracted more attention than pedagogy issues. How engineers can deal with this issue and design the necessary tools and techniques to support e-pedagogy. The answer to this question may open another opportunity to utilize the aforementioned techniques in this paper for adaptation of learning by considering the e-pedagogy.

Table 5 Multi-dimensional support

Tools and techniques	Reference	Description
Application software	Papanikolaou et al. (2002)	INSPIRE
	Stefansson (2004)	Tutorweb
	Avgeriou and Retalis (2005)	CRITON
	De Meo et al. (2007)	Web service
	Retalis (2008)	Game tools
	Keleş et al. (2009)	ZOSMAT
Semantic And Ontology	Xu et al. (2005)	
	Huang et al. (2006)	
	Jia et al. (2011)	
	Mikic Fonte et al. (2012)	
Machine learning and soft computing	Woo et al. (2006)	Natural language processing
	Xu and Wang (2006)	Fuzzy lOGIC
	Schiaffino et al. (2008)	Bayesian networks
Application software	Heylen et al. (2005)	Design environment method
	Debevc et al. (2008)	Hypervideo tools
	Kozierkiewicz-Hetmańska (2011)	Designing method

Table 6 Concept maps construction

Tools and techniques	Reference	Description
Machine learning and soft computing	Tseng et al. (2007)	Association rule mining
	Bai and Chen (2008)	Fuzzy logic
	Chen et al. (2008b)	Text and web mining
	Lau et al. (2009)	Fuzzy logic
	Lee et al. (2009a)	Association rule mining
	Chen and Bai (2010)	Association rule mining
	Chen and Sue (2013)	Association rule mining
	Lee and Segev (2012)	Text and web mining
Application software	Cline et al. (2010)	Concept mapping tool
Innovative techniques	Gnel and Asliyan (2010)	Item response theory

6 Conclusion

Using adaptive technologies in AESs is becoming one of the most popular topics in e-learning systems in recent years. The study has investigated the research papers between 2000 and the end of 2012 and stated important implications which can be summarized in the following paragraphs.

– Since the formal initiation of AESs has traced back to 2001, there was a few number of research papers involving adaptation in e-learning systems between 2000 and 2002. However, between 2004 and 2009, the significant increase of the number of research papers can be observed. After 2009, a decline in research papers is observable. Two

Table 7 Other

Tools and techniques	Reference	Description
Semantic and ontology	Henze and Nejdl (2004)	
	Bittencourt et al. (2009)	
	Cuéllar et al. (2011)	
Machine learning and soft-computing	Heinemann (2000)	Adaptive learning modelling with artificial neural networks
	Romero et al. (2004)	Evolutionary algorithms
	Molina et al. (2011)	Evolutionary algorithms
Application software	Correia and Romero (2006)	Generic hypermedia model

Table 8 The frequency of research papers in adaptive technologies and their application fields

	Learner's problem alleviation	Presentation	Learning style detection	Navigation
Machine learning and soft computing	**29**	**17**	**24**	**14**
Application software	8	10	1	3
Semantic and ontology	6	14	3	4
Innovative techniques	6	4	5	2
Hybrid	1	4	0	2
	Other	Multi-dimensional support	Concept maps construction	
Machine learning and soft computing	3	3	**8**	
Application software	1	**6**	1	
Semantic and ontology	**3**	4	0	
Innovative techniques	0	3	1	
Hybrid	0	0	0	

The categories that hold the first rank are typed in bold

reasons for this can be expressed. First, special techniques have been increasingly used before 2009; however, they encountered a declined afterward. The second reason relates to the saturation of study regarding navigational approaches. Fortunately after 2010, the published studies in the field of AESs indicate a reasonable growth.

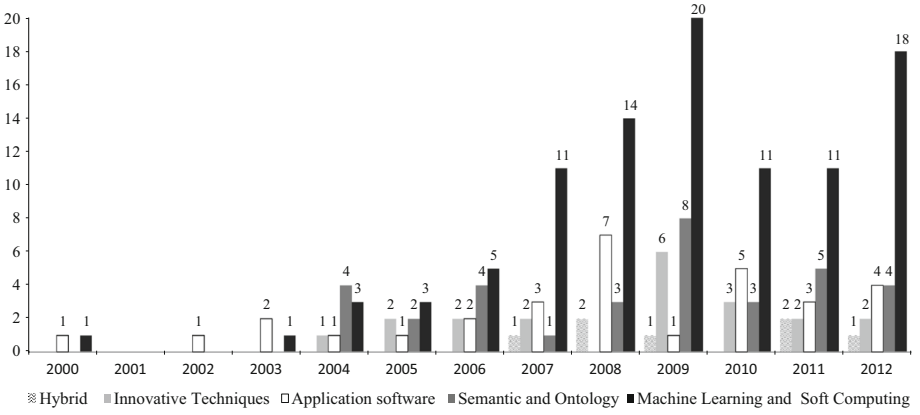

Fig. 6 Distribution of the research papers by publication years and adaptive technologies

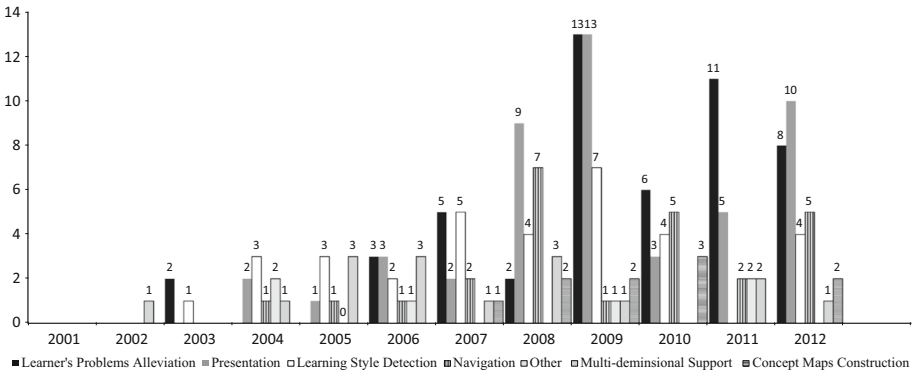

Fig. 7 Distribution of research papers by publication years and application fields

- Machine learning and soft computing techniques, which accounts for about 98 research papers, are the dominant group of adaptive technologies. In contrast, only 34 research papers used semantic web and ontology. Furthermore, 31 research papers have applied application software in order to enhance the efficiency of AESs. Innovative techniques and hybrid ones were employed only in 27 research papers.
- In machine learning and soft computing group, evolutionary algorithms which obtain the highest score have been used in 16 research papers; the second stage belongs to fuzzy logic with 14 research papers. Interestingly, hybrid algorithms, which are the combination of several machine learning and soft computing techniques, have gained 13 research papers. These three categories, recognized as the most applicable techniques in this study. In addition, association of rule mining has been used by 10 research papers and each of neural and Bayesian network came up with 9 research papers. Moreover, each of decision trees and heuristic algorithms has been applied by 5 research papers. Other techniques, such as clustering, text mining, reinforcement learning and natural language processing and support vector machine techniques have been utilized by 17 research papers in total.
- Fuzzy logic techniques will maintain its growth in the future; since it is widely applied to several application fields including learner's problem alleviation, navigation, learning

style detection and concept maps construction fields are observed between 2000 and 2012.
- Innovative techniques to tackle AES-related issues is another hot topic that we will hear more about it in the future, since the results of our studying demonstrated that innovative techniques are very popular specifically after 2009. Another reason that makes our educated guess more reasonable is that since innovative techniques are not confined to one special technique, they can be any novel technique, e.g. petri net.
- Most research papers have addressed learner's problems alleviation and presentation especially after 2008. In particular, learner's problems alleviation field have gained 50 research papers (approximately 27 % of all) and presentation field has been referenced by 49 research papers (about 24 % of all). Moreover, learning detection, navigation, multi-dimensional support, concept map construction and other have been addressed by 33, 25, 16, 10 and 7 research papers, respectively.
- We discovered that for solving the problems concerning learners such as learner performance assessment or learner boredom alleviation, machine learning and softcomputing techniques would be a remarkable choice. This inference came from the fact that in the past 12-years, machine learning and softcomputing technique have been used more than other techniques. This could also be true for presentation, learning style detection, navigation and concept map construction. We also found that if integration of several adaptive services is involved, the application software would be a good choice. For other applications like the logical description of AES, the semantic technique would be the best choice.

We hope that this study will shed light on the researches into AESs and will encourage the researchers and practitioners to employ the machine learning and soft computing techniques, specifically evolutionary algorithms and fuzzy logic, to their proposed e-learning systems. However, there were several difficulties and limitations during the current study. First, the limited time and manpower made it impossible to review the research papers before 2000. Second, the study was limited to top journals of the aforementioned databases and the research papers were surveyed based on technical side. As a result, other e-learning aspects such as human science were omitted from our study. Third, the study was based on journal papers and the conference articles were left out. Therefore, if conference papers were studied, the results might be more diverse. Finally, the research papers were only reviewed based on the four following keywords: "adaptive e-learning systems", "adaptive educational hypermedia", "intelligent tutoring systems" and "Adaptation in e-learning systems" and other keywords such as "computer-based learning" were ignored in the present study.

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