Adaptive and personalized educational ubiquitous multi-agent system using context-awareness services and mobile devices

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Abstract. In the last decade, some useful contributions have occurred to e-learning system development such as adaptation, ubiquity, personalization, as well as context-awareness services. The aim of this paper is to present the advantages brought by the integration of ubiquitous computing along with distributed artificial intelligence techniques in order to build an adaptive and personalized context-aware learning system by using mobile devices. Based on this model we propose a multi-agent context-aware u-learning system that offers several functionalities such as context-aware learning planning, personalized course evaluation, selection of learning objects according to student profile, search of learning objects in repository federations, search of thematic learning assistants, and access of current context-aware collaborative learning activities involved. In addition, several context-awareness services are incorporated within the adaptive e-learning system that can be used from mobile devices. In order to validate the model a prototype was built and tested through a case study. Results obtained demonstrate the effectiveness of using this kind of approaches in virtual learning environments which constitutes an attempt to improve learning processes.

Keywords: Ubiquitous MAS, Adaptive and Personalized Virtual Courses, Context-Awareness Services, Mobile Devices.

1. Introduction

The growth of digital information along with the boom in the creation of high-speed telecommunications systems and intelligent ubiquitous systems [1][2] provide tools for the development of customized recommendation systems focused on mobile devices. This fact gives way to a new paradigm where the users have a wide range of interfaces and devices in order to communicate with information systems wherein the context plays a very important role. To do so, new technologies and innovative approaches such as intelligent software agents, wireless devices, adaptive and custom-

ized information searchers are currently been used in order to create adaptive and personalized e-learning systems.

As defined in [3] context-aware ubiquitous learning is an innovative approach that integrates wireless, mobile, and context-awareness technologies to detect the situation of learners in the real world and thus provide adaptive support, personalized services or guidance accordingly. In the traditional e-learning environments [4] the lack of immediate learning assistance means the learner is unable to receive learning resources in a timely manner and incorporate them based on the actual context into the learner's learning activities. The result is impaired learning efficiency. In contrast, ubiquitous computing environments enable users to easily use huge amounts of information and computing services through network connections anytime and anywhere.

Moreover, context-awareness services play a very important role within ubiquitous e-learning environments since they are useful to provide immediate alerts to students through their mobile devices when the system detects significant events such as learning tasks completed, need for student's learning re-planning, educational resource recommendation, need for learning support through assistants, etc. Using context-awareness services within an e-learning environment aims to inform students about their performance and progress during their whole learning process.

The aim of this paper is to present the advantages brought by the integration of ubiquitous computing along with distributed artificial intelligence techniques [5] in order to build an adaptive and personalized context-aware learning system by using mobile devices. Based on this model we propose a multi-agent context-aware u-learning system that offers several functionalities such as context-aware learning planning, personalized course evaluation, selection of learning objects according to student profile [6], search of learning objects in repository federations [7], search of thematic learning assistants, and access of current context-aware collaborative learning activities involved. In addition, several context-awareness services are incorporated within the adaptive e-learning system in order to inform students about their performance and progress during their learning process through mobile devices considering the students' preferences, needs, and limitations.

The rest of the paper is organized as follows: Section 2 presents the conceptual framework of this research. Section 3 reviews some related works analysis. Section 4 describes the proposed model. Section 5 offers the model implementation and validation of the proposed model. Finally, the main conclusions and future research directions are shown in Section 6.

2. Conceptual Framework

This section provides main definitions used in this research work such as learning objects, repositories, federations, student profile, multi-agent systems, context-awareness services, among others.

2.1 Learning Objects, Repositories and Federations

According to the IEEE, a LO can be defined as a digital entity involving educational design characteristics. Each LO can be used, reused or referenced during computer-supported learning processes, aiming at generating knowledge and competences based on student's needs [7][8]. LOs have functional requirements such as accessibility, reuse, and interoperability. The concept of LO requires understanding of how people learn, since this issue directly affects the LO design in each of its three dimensions: pedagogical, didactic, and technological. In addition, LOs have metadata that describe and identify the educational resources involved and facilitate their searching and retrieval. LORs, composed of thousands of LOs, can be defined as specialized digital libraries storing several types of resources heterogeneous, are currently being used in various e-learning environments and belong mainly to educational institutions [9].

Federation of LORs serve to provide educational applications of uniform administration in order to search, retrieve and access specific LO contents available in whatever of LOR groups [10].

2.2 Student Profile

The student profile stores information about the learner, its characteristics and preferences, useful to support a student or a teacher in the LO selection according to its personal characteristics, needs and preferences. A comprehensive structure that represents the student's information into several categories is considered as the student profile model, choosing among his/her most important or the most significant issues. These categories are: personal data (e.g. name, date of birth, sex, etc.) learning styles (e.g. active, reflexive, sensorial, intuitive, visual, verbal, sequential, global), psychology profile (e.g. dominant brain hemisphere), physiology profile (hearing, vision, etc.) contextual characteristics (e.g. access device, network state, operating system, etc.), historical issues (activities developed, study times), academic achievements (learning goal approved) and group work performance [11].

2.3 Multi-Agent Systems

Multi-agent systems (MAS) are composed of a set of agents that operate and interact in an environment to solve a specific and complex problem [5]. Agents are entities that have autonomy in order to perform tasks by achieving their objectives without human supervision and thus have been used for the development of virtual learning environments [7]. The desirable characteristics of the agents are as follows: reactivity, proactivity, cooperation and coordination, autonomy, deliberation, distribution of tasks, mobility, adaptation, mobility, adaptation, and parallelism.

2.4 Context-Awareness

The context-awareness concept, which is inherent to humans when performing any learning activity, becomes the main component for monitoring activities in virtual learning environments. Through context-awareness, students become conscious of all the changes produced within the learning environment by the action of their activities

while performing learning tasks. Thus, it is easier for them to direct their behavior and acquire new knowledge [12]. The awareness provided by virtual learning environments allows students to generate a context of their own activity, i.e., the information regarding their learning activities is constantly updated and thus improving the performance on their learning process.

3. Related Works

Wang & Wu applied context aware technology and recommendation algorithms to develop a u-learning system to help lifelong learning learners realize personalized learning goals in a context aware manner and improve the learner's learning effectiveness [13]. In fact, they established that when integrating the relevant information technology to develop a u-learning environment, it is necessary to consider the personalization requirements of the learner to ensure that the technology achieves its intended result. The Sharable Content Object Reference Model (SCORM) platform was used as the basis and integrated with Radio Frequency Identification (RFID) technology to develop an adaptive ubiquitous learning system. Collaborative Filtering (CF) and an association rules mining model was used to develop an adaptive smart ubiquitous learning system. Adaptive learning materials are recommended to lifelong learning learners using this association rules mining model in order to improve the learning motivation and effectiveness of lifelong learning learners. Finally, the adaptive ubiquitous learning system developed in this study offers the following features: (1) Context awareness, (2) Standardized courseware, (3) Personal learning management, and (4) Adaptive course recommendation.

Zervas et al. established in [2] that in order to achieve personalized and ubiquitous learning, those tools showing characteristics of context-aware adaptive learning designs (authoring tools) and context-aware adaptive delivery of learning activities (runtime tools) should follow some design requirements at both the learning design and mobile delivery process. To attain learning design purposes, for instance, the user should be able to: (1) define appropriate content adaptation rules according to the different values of the mobile context characteristics, (2) define context-aware content adaptation rules for each individual learning activity that a learning design incorporates (3) create profiles of content adaptation rules (for certain values of mobile context characteristics), which can be used during the authoring process of a new learning design, (4) graphically design learning designs based on the interconnection of user defined learning activities, among others. Concerning mobile delivery process, for instance, the tool should: (1) be able to automatically detect contextual information such as, place, time, and in some cases physical conditions according to the user situation and it should be able also to let the user input contextual information that it is not possible to be detected automatically, (2) be client-side, so it can be installed to the mobile device and no internet connection should be required during the execution of learning activities, (3) be able to handle the adaptation rules of the delivered learning design and match them with the values of contextual information automatically detected or provided by the user, so as to enable the content adaptation mechanism and

deliver adapted educational resources according to the type of user's mobile device, among others.

A context-aware learning environment was developed by Hwang et al. to guide the beginner researchers through practical experiments concerning single-crystal X-ray diffraction processes [14]. The application domain of this research regards to scientific experiments and therefore, when a student arrives at the laboratory and is in front of an instrument, sensors are able to detect the student location and thus transfer this information to server. The system performs real-time analysis using the following parameters concerning students: (1) environmental and personal context, (2) student's profile, and (3) online portfolio. The learning system is able to guide students in the laboratory, showing relevant information at the appropriate time such as processes able to be applied, the laboratory rules, as well as the emergency management procedures. Experimental results showed the benefits of applying the ubiquitous learning and context-aware approach in learning sciences as well as taking advantage of the manpower savings to assist and monitor students.

Considering the research works previously reviewed one of the improvements proposed in this paper in order to enhance current ubiquitous computing and ontological learning-teaching models is the integration of awareness services along with the personalized resources recommendation. These features regarding context-awareness and alerts offered by learning environments allow students to become conscious of the advancement status of their own learning activities and to interact with adaptive and personalized educational resources. In this way, the system gives the student the opportunity to maintain updated information that helps them to improve their performance during their learning process.

4. Model Proposed

Functional requirements of the system are initially identified along with the needs and objectives associated to current e-learning problems. From this point several use cases diagrams were built which helped understand the needs to be solved and to establish guidelines for the subsequent analysis phase.

Several functionalities were found during this stage that focus on following main axes:

a. The adaptive virtual course planning: its main objective is the educational content organization using the structure proposed for the virtual course construction. The purpose is thus to guide the students through courses, enabling new topics and proposing new contents that will help them strengthen their learning process.

b. Educational content evaluation: this functionality is intended to assess the knowledge acquired by the student in order to enable new content, so this functionality complements the planning functionality since it provides vital information relating to the progress of the student and allows to separately highlighting the shortcomings or strengths of students.

c. Customized search and selection of LO: this is an extremely important functionality within the system that provides personalized educational content, always seeking

to awaken the focus and the interest of students along the AVC processing. In addition, the functionality provides the required content for the planning process. Another important feature that includes this functionality is the strengthening of knowledge throughout the adaptive virtual course, because at the time in which faults are presented in the student's learning process the system can recommend content outside of the virtual course structure in order to enrich learning as well as to address these faults. These educational contents are customized and adapted to characteristics, preferences, and limitations of students, which increases the interest of them and accelerates their learning process.

d. Search and placement of thematic learning assistants: allowing the search and allocation of learning assistants (advanced students) according to the temporal and spatial context of the student; i.e., the assistants will be assigned according to the spatial proximity that meets student, but also in agreement with the knowledge of the student's areas of interest as well as the time availability for both.

These functionalities were mapped or assigned to roles, allowing an initial division of tasks and goals. Created roles during this phase were associated with each of the functionalities. Following roles were thus considered: Planner, Content Recommender, Evaluator, and Assistants Recommender.

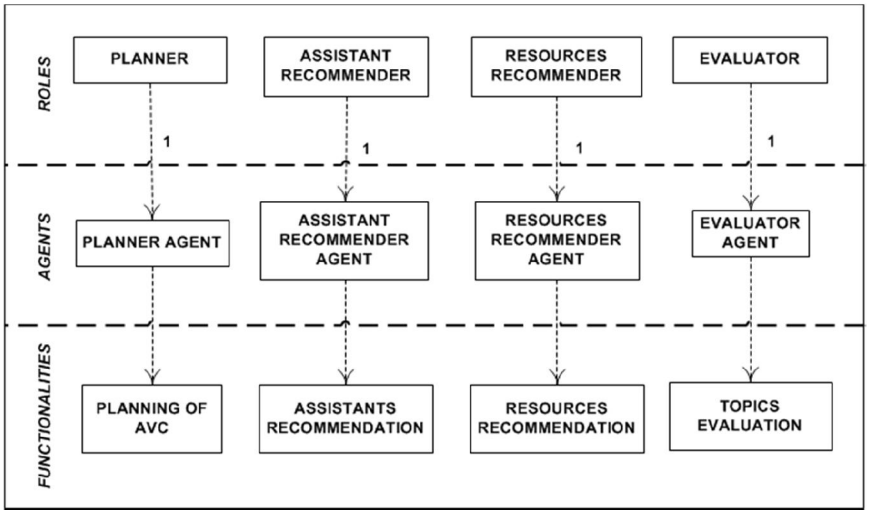

Fig. 1. Agent Model Overview

As the first activity in the analysis stage establishes that roles being initially identified be mapped in software agents and we decided to slightly extend the agent model adding the system's functionalities with the intention of better assign all the tasks and goals that would have associated each of system's agents. Figure 1 shows the agent model overview in which every system's functionality (being assigned to a role) is associated to a single agent. In this way all the functional requirements of the system

are covered, however, during this phase new needs and non-functional requirements emerged that we have to be faced.

System Architecture and Agent Description

Figure 2 shows the u-MAS architecture of the model proposed. This architecture was used to develop the context-aware educational multi-agent system, implemented using JADE (Java Agent Development Framework) agents [15].

- User Agent: the role of this agent, which communicates directly with the human user, is representing him within the system. This agent communicates with other agents such as Recommender and Planner. Moreover, the user agent manages the user profile, enabling the creation and modification of profile's characteristics and preferences. Most of the system's functional scenarios start and finish their execution with this agent who sends requirements and receives their corresponding answers.

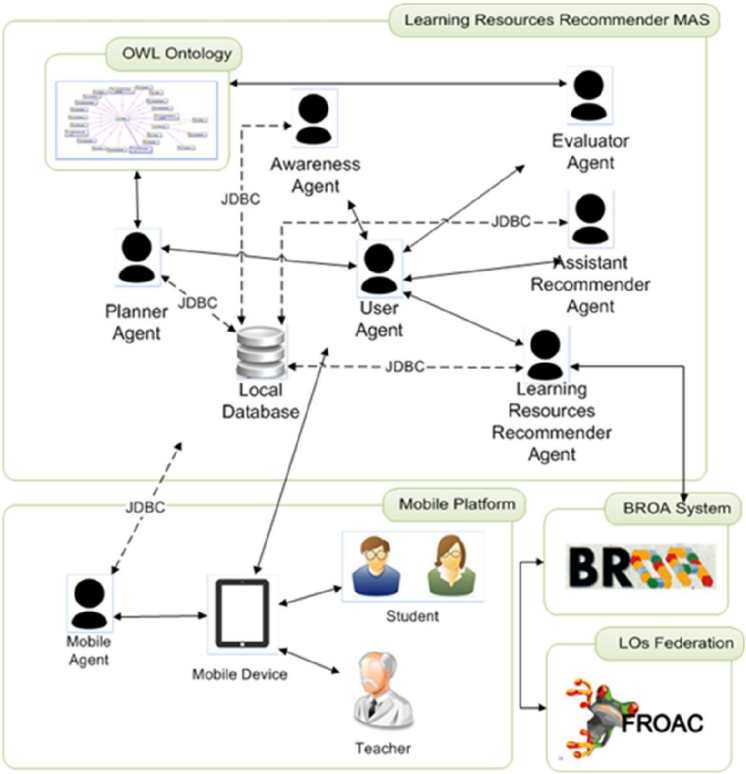

Fig. 2. Architecture of the adaptive U-MAS based on context-awareness services and mobile devices.

- Recommender agent: this is a kind of deliberative agent whose main role is to filter search results coming from searcher agent based on student's profile. In addition, this agent offers to students as a service support the possibility of performing searches of teaching/learning assistants for specific topics of a virtual course that have

more knowledge and know-how on certain topics. Those learning assistants can give to the students with advice or answers questions on a particular sub-items or learning activities. This functionality is available from students' mobile devices.

- Searcher agent: this is a reactive kind of agent that is in charge of performing searches of Learning Objects (LO) based on some characteristics such as LO name, educational resource, language, format, among others.
- Planner agent: its role is to adapt learning plans to students in such a way that the student be guided by the system through a teaching-learning process in the same way as it could be performed by a real teacher.
- Evaluator agent: this agent manages the knowledge level evaluation performed by the system to the learner taking into consideration the topics already learned and the LG attained by the student.
- Awareness agent: The awareness agent plays an important role in the model since it is responsible of providing all the context-awareness services needed by the system either at the request of users or by effects of proactivity. The main available services provided by this agent are the following: (1) participation_level (gives the level of participation for a specific student considering the different learning activities proposed by the system), (2) graph_of_progress (gives the overview of student's status in the course and learning activities still pending), (3) assistant-student interaction_graph, (4) learning activities historical view, and finally (5) alarms and reminders.

5. Implementation and Validation

The adaptive and personalized U-MAS was implemented using JADE, a FIPA compliant framework [15]. This feature provides interoperability to the platform, what is needed for interconnect platforms and repositories. JADE was developed using JAVA language, this feature allows to integrate the ontology through JENA framework that was developed for JAVA environments as well.

Concerning the connection between the platform and user's mobile devices it was necessary to use Android platform, which allows the integration of mobile devices with the JADE Main Container hosted on the server. It is important to highlight that the platform which offers support to each AVC is self-authorship, and it was developed in the same server that deploys the U-MAS.

In order to validate the proposed model a case study is used to illustrate each of the functionalities of the adaptive and personalized U-MAS learning environment.

Functionality 1: Virtual Course Planning

As mentioned before, this scenario is handled by the Planner agent, who interacts with the Recommender agent to retrieve LO relating to the virtual course's topics. This agent then recovers the student's profile stored in the profile system database, and so it maps this retrieved information into the created ontology having semantic description of the knowledge associated to the AVC. This ontology, called PCVAOntology and specified in OWL language, was developed using Protégé and allows the system to select educational resources associated to AVC from SWRL rules. IEEE-

LOM standard was used to represent the LO structure within the ontology, taking advantages of hierarchical relations and its cardinalities offered by this standard. Thinking on enhancing the selection process of LO, it was necessary also to extend the model proposed by Arias [16] for depicting the AVC structure. This model proposes a hierarchical structure where the virtual courses break down into learning basic-units which in turn are broken down into topics. Such topics have associated some educational objectives that need to accomplish certain prerequisites in order to be accessed. Finally, each topic has linked to several activities along with their respective LO for learning purposes.

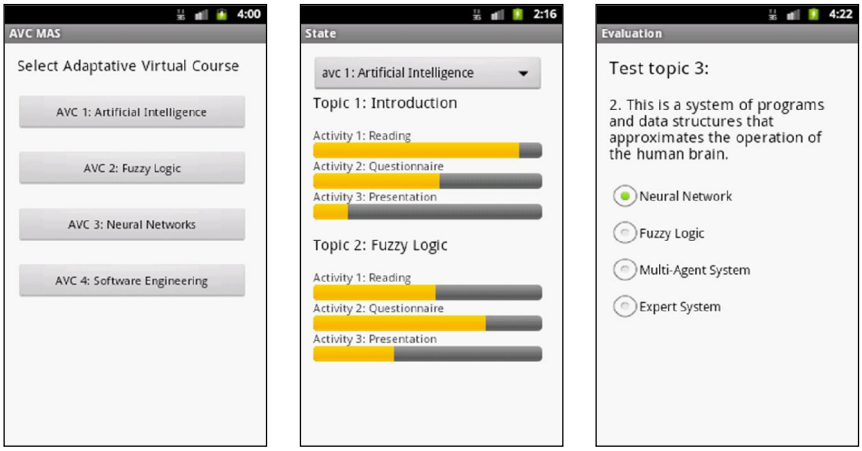

Fig. 3. Planning scenario and topic assessment functionalities.

Figure 3 shows the navigation interface through the student's AVC planning scenario (Figure 3 at left) allowing the student to select the courses to be accessed as well as the current learning state of the student in the course (figure in the middle). It is important to highlight that resources selected from the planning process concerning any of topics can be proposed to the student in order to strengthen its learning process.

Functionality 2: Topics Assessment

This scenario is activated at the moment in which the user concludes a topic, or wishes itself to skip it. Questions are initially selected from a question repository previously created and associated to each of the topics composing the AVC. According to the assessment structure proposed by Jimenez et al. [17] for each question there is one or may be more answers and they are validated through a 2-value field (1 when the answer is correct and 0 otherwise). One of the most important parameters is the average response time so that the student can answer the question as well as the question type that describes if the question is false, multiple choices, single choice, etc.

Functionality 3: Context-Awareness Services

This functionality allows the MAS to generate alarms at any time during the execution of the system (see Figure 3). The awareness agent is in charge of performing

cyclic behaviors that allow the system to continuously monitor the activities of the student on the database, in order to keep in real time the teacher and the student to be informed of student learning performance. These alarms can be related to activities next to expire or relevant information send to students intended to monitor and communicate their progress during learning process while they are using the virtual course platform. It is important to highlight that the information regarding students' learning activities is constantly updated and thus the fact to be aware of these changes might surely improve the performance on their learning process.

Fig. 4. Context-awareness services (progress-graph, historical-learning-activity-view and participation-level)

Functionality 4. Educational Resource Service Recommendation

This scenario includes a proactive behavior performed by the content recommender agent since it offers new educational virtual resources in case of the student presents faults in the topics assessment evaluation or if the student decides to apply for them (see Figure 3 at right). In addition, this functionality provides topic specialized assistants, previously selected by the Recommender agent, who also provides a communication channel between students and assistants allowing them an enriched interaction to enhance learning.

The system's validation based on a case study on different functionalities shows quite satisfactory results. In addition, a ubiquitous MAS learning environment is presented where robust calculations and inferences are performed on the server while mobile devices are only in charge of generating system's interfaces. Stress tests were performed at the server by connecting a number of mobile devices (approximately 10) to see how the system behaves. This system validation demonstrates optimal advantages that supply to use a MAS approach by dividing the tasks on different nodes, hence the response times are reduced and the information is delivered in a more agile way.

6. Conclusions and Future Work

This paper presented the advantages brought by the integration of ubiquitous computing-oriented along with distributed artificial intelligence (DAI) techniques in order to

build adaptive and personalized context-aware e-learning systems. Based on this model a context-aware U-MAS was developed that offers functionalities as follows: the context-aware learning planning, the course evaluation process, the selection of learning objects according to student profiles, the search of learning objects in repository federations, the search of thematic learning assistants, and the access of current context-aware group activities involved. The development of a context-awareness services module within the ubiquitous recommendation and planning MAS highlights significant contributions mainly at the level of the students' interaction within the system, since it allows them to be aware of their status and progress within the e-learning system. In addition, it allows teachers to know the interest shown by each student within the virtual course. As future work we will attempt to improve and expand context-awareness services incorporated into the U-MAS. Other context-awareness services could also be implemented such as the visual graph assistant-student interaction since in the current prototype it is described through a textual manner. Finally, it is expected to improve the experimentation of the different modules of the ubiquitous MAS using new case studies.

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