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The design and implementation of intelligent ubiquitous learning multi-agent context-aware system

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Abstract

Advances in technology in education have had a profound impact on Human-Computer Interaction. In this article, we explore how emerging technologies can make learning more affordable and accessible. This study aims to present a new approach to ubiquitous learning, which uses a multi-agent system to facilitate the learning process. To develop the multi-agent system, we used JADE-LEAP (Lightweight and Extensible Agent Platform). The application developed adapts several parameters according to the dynamic situation of the learner's contextual information. We used contextual technologies such as GPS sensors and 4G networks to obtain the dynamic situation. This application provides a set of functionalities that can be used by learners via devices anywhere and anytime and supports formal learning. Finally, to verify the usefulness of this application, we conducted a case study with different scenarios. Computer science students from various Algerian universities took part in the study.

Keywords: Artificial intelligence; educational technologies; personalized education; smart learning; ubiquitous computing.

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1. Introduction

The emergence of COVID-19 as a global pandemic has created negative consequences in different areas of human life, causing individuals to adapt to this challenge. Particularly, in the areas of education, the impact of covid-19 has negatively affected the delivery of educational services (Marín-Díaz et al., 2021; Alvarez-Rivero et al., 2023). Coronavirus has caused extended university closings and interruptions in educational operations around the world (Olatunde-Aiyedun et al., 2021). In addition, in mid-April 2020, UNESCO reported that about 1.5 billion learners were impacted by the closure of schools or universities across 195 countries, it has forced the world to reconsider an alternate manner of providing uninterrupted education (Ukala, 2021; UNESCO, 2020; Hoffman et al., 2021). This has called for the need for instructors and teachers to become more engaged in designing innovative technology-enhanced learning activities for deep student learning (Kim 2019; Alt 2023). This sudden change has led most educators from all over the world to teach online courses.

Universities have employed a range of strategies, typically involving online platforms suitable for distance learning, such as blackboard, Team, Microsoft Team, and Zoom. Educators were given general and personal curriculums or instructions about how to adapt their learning activities to the needs of their students (García-Alberti et al., 2021; Viana & Peralta 2021). Thus, the fast development of information and communication technologies (ICT) and the availability of many new technologies have resulted in new digital learning communities, and the emergence of ubiquitous computing (Gao et al., 2021; Chen et al., 2021). Therefore, learners using different devices have the opportunity to learn anywhere, anytime (Mao et al., 2021).

Ubiquitous computing is a new advancement in the world of information technology (França et al., 2021), artificial intelligence, the Internet of Things (Mehrotra et al., 2021), 5G networks (Cheng et al., 2021), blockchain (Kim, 2021), cloud computing (Gandhi, 2021) and communication. It focuses on several sensor-connected devices, such as computers, cell phones, smart cards, etc., that allow people to interact with many activities (Sarker 2019). With this recent ubiquitous computer technology, a new learning called ubiquitous learning (U-learning) (Berrocal Villegas et al., 2021), has emerged. It allows anyone to get the information they need anywhere, anytime.

There are different definitions of U-learning from several researchers, reflecting the increasing sophistication of the technologies used for communication and learning (Hwang et al., 2008). The ubiquitous learning concept is that “anyone can learn anything, anywhere, anytime with new ubiquitous technologies and adapt to the learner's context” (Abou-Khalil et al., 2019).

The earliest validated infection in Algeria was reported in February 2020 as a case of COVID-19 (Bentout et al., 2021). Algerian Universities faced unknown challenges similar to other universities in the world. Therefore, the only possible solution to ensure the continuation of teaching was distance learning, which has been adapted by all universities in Algeria.

1.1. Purpose of study

In this work, we have proposed and developed a new approach that helps university students in computer science in Algeria to learn from anywhere, at any time despite the situation of COVID-19. In addition, we aim to facilitate the preparation of the courses and to provide effective adaptive distance learning using the advantages of the new ubiquitous technology such as GPS. This study proposes a ubiquitous learning system, which is evaluated in several computer science departments in different Algerian universities.

1.2. Literature review

Several different approaches, systems, and implementations to avoid the risk of exposure to the COVID-19 virus have been proposed, employing a variety of new ideas, technologies, and techniques, particularly ubiquitous learning. A number of proposed applications, systems, or techniques for ubiquitous learning have already been released. From the available Scopus database, research papers on multi-agent systems based on ubiquitous learning (Figure 1) have shown great promise, underlining the potential relevance of this field for existing and new research. In the paper (Simoes et al., 2021), the authors investigated a dynamic and adaptive ubiquitous learning environment for biological engineering. The concept of adaptive virtual learning frameworks was used in the development of this system. They evaluated the effect of this approach on teaching different courses. In addition, the authors are focused on a multidisciplinary approach combining knowledge, and providing students with several specific skills needed to solve real-world challenges.

An Authentic English Learning (AEL) application is developed based on the ADDIE development model (Putra & Wardani, 2021). This application is used and tested at a school in Lampung City. Their study aims above all to help students motivate and encourage them to learn at a distance in an authentically home environment. Furthermore, the students are motivated to improve their vocabulary by exploring things around them, using their smartphones. The learners communicate with each other using a wireless network. In addition, they comment on their classmates' achievements. On the other hand, the development and implementation of the system, are achieved using the available web API. The app's activities focus on taking a picture and then showing the object. Then, Students annotate by text and voice. During the last phase, the students have to save their work in the database. The result indicates that students who use the authentic English learning app to learn English at home are more motivated than those who learn by reading a book because they have fun exploring a real object in their environment.

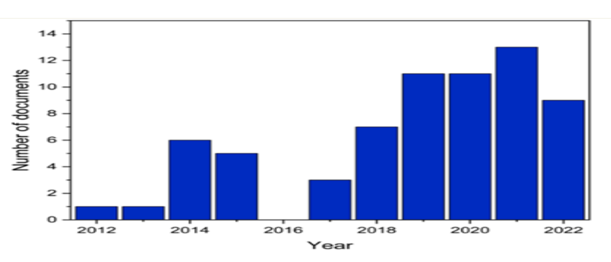
In a recent paper (El-Sofany & El-Seoud, 2022), the authors discussed the use of ubiquitous learning in some Saudi universities (King Khalid University and King Saud University), during the outbreak of COVID-19. To continue the learning process, the authors used a platform called Blackboard Learning Management System (LMS). This platform provides a variety of tools for learning and educator to evaluate and measure the comprehension of their students.

In the work (Huo et al., 2021), the authors focused on the development of a Project Based Learning (PBL) based virtual reality (VR) course to train teachers to deal with intelligent education, ubiquitous learning, and learning style for kindergarten and elementary school children in visual media during the coronavirus era.

The authors (Huo et al., 2021) presented a prototype curriculum development framework for the smartphone-based version of the Adaptive Learning System for Science Education (ScEd-ALS), which supports ubiquitous learning after using a developmental research model. The research tools consist of observation papers, control papers, and a VARK questionnaires, that take into consideration students' choices of VARK Flemming learning style preferences. Figure 1 displays a number of Scopus-indexed documents on the u-learning-based multi-agent system.

Figure 1

A number of Scopus indexed documents on the u-learning-based multi-agent system



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Source: Guettala et al., 2022

2. Materials and methods

To create a system, it is first necessary to realize a design phase, which allows formalization of the preliminary steps of the system development and to identify its architecture, to propose a feasible solution. To customize learning content based on the individual learner's preferences, several features and details about the learner need to be understood. To achieve this goal, the location, learning style as well and the learner's profile were taken into account. This means that we need our ubiquitous learning system to be able to react automatically to these changes in a dynamic way. Furthermore, it is essential to provide each user with learning objects that are appropriate to his or her context. Our architecture must take advantage of 3G, 4G, Wi-Fi, and sensors such as GPS.

2.1. Procedure

The process of context acquisition is performed explicitly or implicitly:

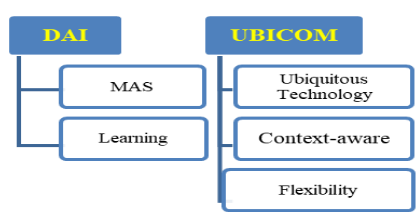
- *Explicit context acquisition:* The contextual data is collected as a result at the end of the user's interaction with the system. It enables each user to communicate to the system the information they need most so that it can provide them with the right answers. With our system, any user can select his preferences or according to their individual needs.
- *Implicit context acquisition*: Contextual data is captured using either physical devices or software. In this case, any user interaction is ignored, and the sensor techniques are used to provide the contextual parameters. GPS (Global Positioning System) is used to measure a user's location.

Thus, The three kinds of context:

1. *The Detected Context*: acquired the contextual information of location through physically based sensors including GPS. (Location awareness).
2. *The Derived Context*: The user's context parameters are created as the system runs.
3. *The context provided:* The context information is generated once the user explicitly submits the required data directly to the operating system.

Figure 2 presents the working area. This new approach is based on the principles of distributed artificial intelligence (DAI) technology and ubiquitous computing (ubicomp).

Figure 2
Working area



The basic design of our system is based on the agent paradigm. We used the concept of a multi-agent system because of its characteristics: provided by the agent: autonomy, intelligence, parallel processing, and cooperation.

2.2. The global architecture of the proposed U-Learning System

We aim to develop a multi-agent architecture for the implementation of a ubiquitous learning system. The actors present in our approach are shown in Figure 3.

Figure 3

The actors present in our approach

To reach the whole system objective, our system architecture is a layered structure that works together (as shown in Figure 4). Our system is composed of precisely three layers. The individual layers perform specific tasks.

1. *User layer*: the proposed system's interactive behavior with the user.
2. *Processing layer*: it executes all the operations necessary to provide recommendations that are customized to user preferences.
3. *Information layer*: it provides the interaction with the data sources of the ubiquitous learning system

2.3. Detailed architecture of the proposed U-learning system

Figure 5 shows the detailed architecture of the proposed system and the position of the agents that are used in the current system

2.4. Description of the agents

In this section, the structural and functional aspects of each agent are described in detail. Figure 21 (see appendix) presents the JADE platform GUI.

2.4.1. Interface agent

The interface agent represents the frontal part of the system, providing the learner with interaction with the system. This agent communicates directly with the user through an interface that runs on the user's device. The architecture of the interface agent is illustrated in Table 1.

The functions supported by the interface agent are:

1. Acts as a mediator between the learner and the backend of the system.
2. Provide the appropriate space for the user (student space, teacher space, administrator space) after the authentication step.
3. Manages the appropriate interfaces for the users.
4. Shows educational resources adapted to the student's learning style, profile, and location.
5. Send the queries to the appropriate agents to present the results to the learners.

2.4.2. Extraction agent

This agent searches for educational resources in a ubiquitous learning database. Table 1 illustrates the architecture of the extraction agent.

The functions of the extraction agent are:

1. It searches for pedagogical resources in a ubiquitous learning database. Teachers according to the context (location, specialty, level, and module) have created these resources.
2. It sends the search result to the content adaptation agent.

2.4.3. *Admin agent*

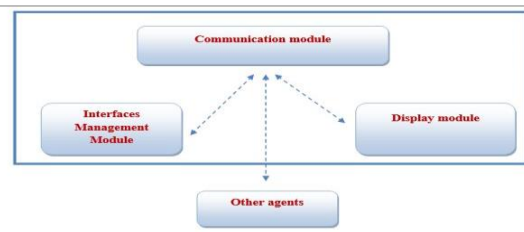
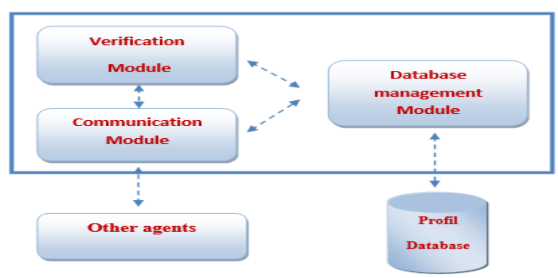
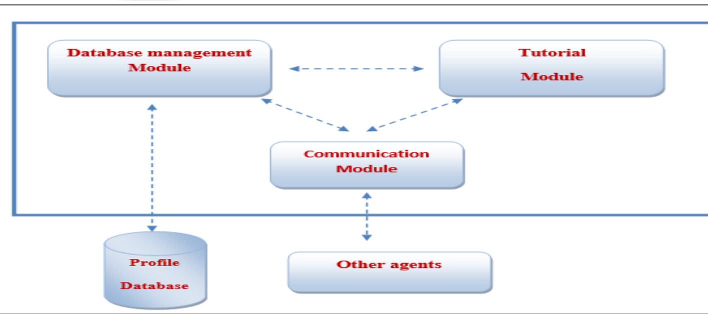
It is responsible for logging in and signing up users, as well as database storage and updates when any changes are made. The architecture of the administrator agent is presented in Table 1.

2.4.4. *Tutor agent*

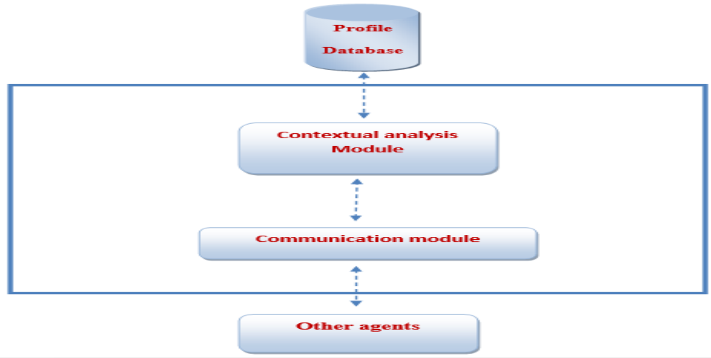
The main role of this agent is to communicate with learners, receive all requests for services, and choose modules depending specifically on the learner's context. Requests are forwarded to the context agent where they are filtered. Then; it sends the results from the content adaptation agent to the interface agent to display them to the learners. Table 1 shows the architecture of the tutor agent.

Table 1

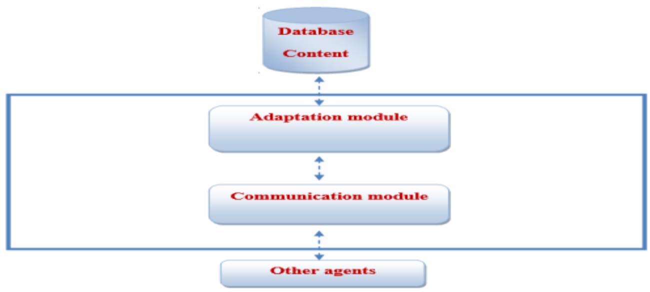
The architecture of each agent

The name of agent	The architect
Interface agent	
Admin agent	
Sensor agent	
Tutor agent	

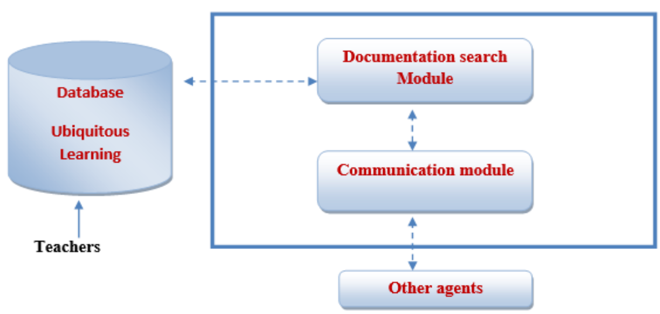
Context agent



Content Adaptation Agent



Extraction agent



The functions of the tutor agent are:

1. A communication point between the learners' devices and the system.
2. A receiver of learners' requests for pedagogical resources.
3. It is used to specify course modules that are personalized according to the learner's context.
4. Sends the requests to the context agent.
5. Receives replies from the content adaptation agent.
6. Sends the educational resources to the interface agent to display to the learner.

2.4.5. Context agent

A situated agent analyzes the learner's contextual information. Table 1 illustrates the architecture of the context agent.

In this approach, the following contextual information will be of interest to us:

1. Location of learner (University).
2. Learning style (how to present the subject...).
3. The learner's profile (skill level, specific field of study, etc.).

a. Contextual analysis Module

The contextual analysis module is responsible for aggregating information according to profile context, location context, and learning style context.

The goal is to formulate a contextual query that respects all the learner's contexts.

2.4.6. Content adaptation agent

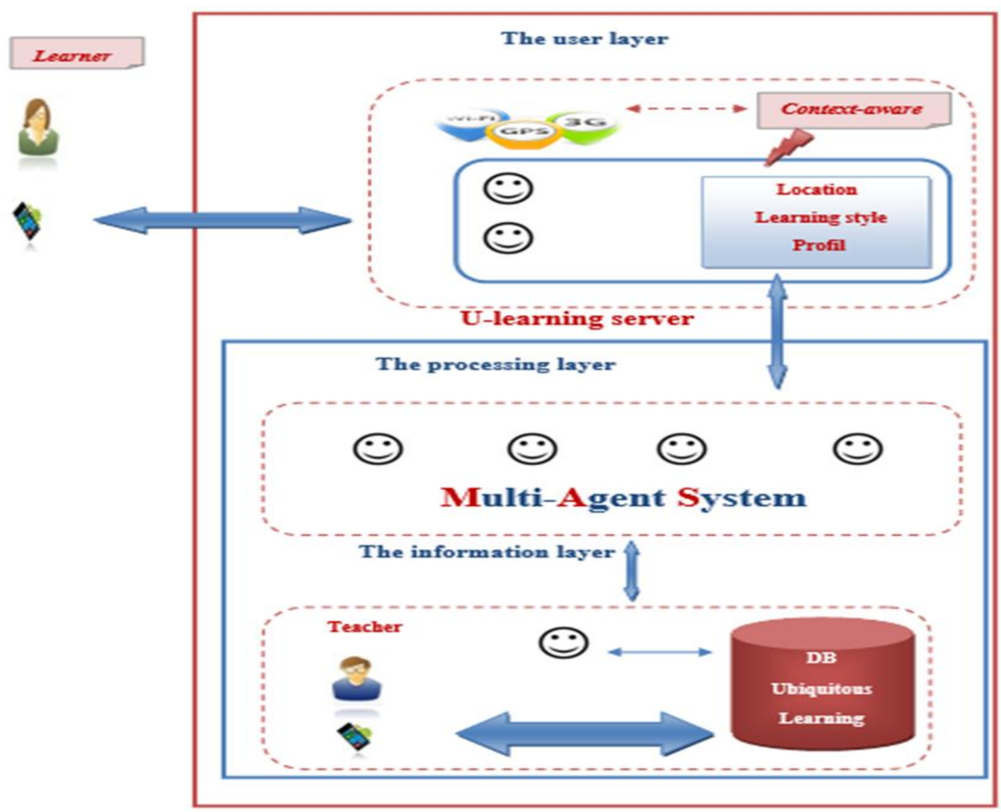
Because the learners have different learning styles and locations, the need to personalize learning objectives. This task is performed by the content adaptation agent. Table 1 shows the architecture of the content adaptation agent. Figure 20 (see appendix) illustrates part of the Content Adaptation Agent code. The functions of the content adaptation agent are:

1. Its role is to customize the learning object to match the individual context.
2. It sends a request to the extraction agent to search the learning contents according to the context.
3. After receiving the adapted content from the extraction agent, the adaptation agent then matches the received content with the context. Then it links contextual information with the content as a record to identify the content before sending it to the tutor agent.
4. It sends the adapted learning content to the tutor agent for display.

a. Adaptation module

The adaptation module is responsible for matching the results of the context agent to the content received by the search agent. Then, it will identify the content by the information stored in the content database. Finally, the content will be transferred to the tutor agent, which will display it to the learner.

Figure 4
Overall view of the U-Learning system



2.4.7. Sensor agent

This agent is called a "sensor" precisely because of its ability to sense the pervasive environment of learning and adapt to contextual changes.t. It performs a surveillance and feedback role. Contextual information (location) collected by sensors enables the system to function correctly. Figure 19 (see appendix) illustrates part of the sensor Agent code. The architecture of the sensor agent is shown in Table 1.

The sensor agent has the following functions:

1. It captures the ubiquitous learning environment.
2. It receives contextual information about the learner's location coordinates from the GPS location. The sensor is integrated into a mobile device.
3. It compares the learner's location coordinates with the stored coordinates in the database to detect the city name from the location database.

The sensor agent has the following modules:

a. Communication module

This module is responsible for sending and receiving messages to/from other agents.

b. Location module

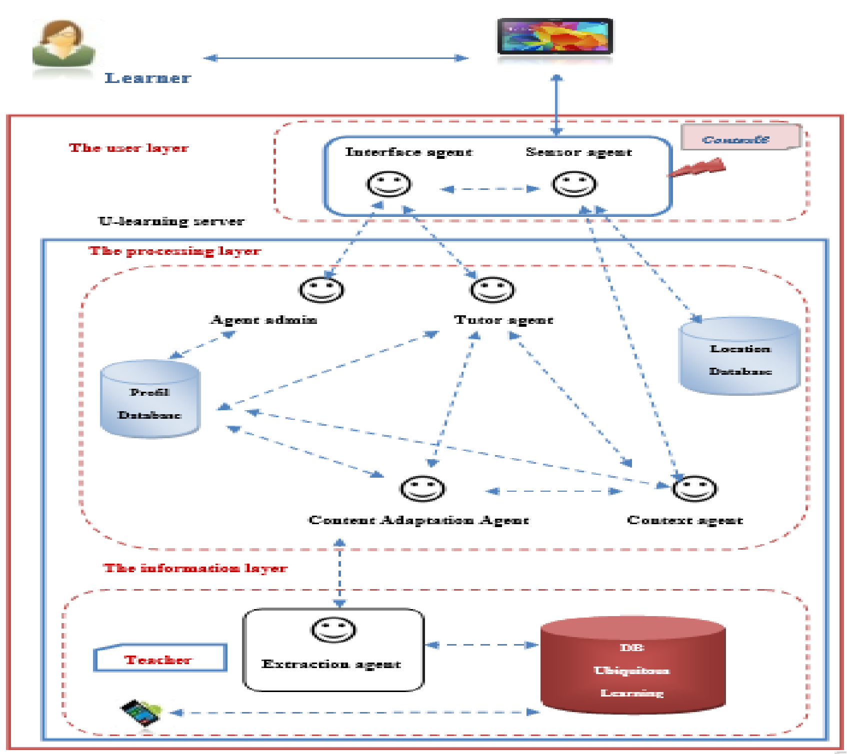
This module receives the coordinates from a satellite positioning system called GPS. Then, it sends the geolocation information to the database management module, to detect and display the current city name. In case of a change of position, it updates it automatically.

c. Database management module

This module manages (and updates) the location databases. When the sensor agent receives coordinates (X, Y), this module compares the detected coordinates to the coordinates in the database to detect the appropriate city name. Then it will send it to the localization module.

Figure 5

Detailed architecture of the proposed U-learning system



2.5. Functional modeling of our approach

We used UML language to model the interactions between the agents of our ubiquitous learning system. Different scenarios are used to show the system's functions.

2.5.1. Sequence diagrams

The sequence diagrams explicitly describe the interactions between different agents of the system and specify the chronology of these interactions. Next, we present the main sequence diagrams of our system.

2.5.1.1. Registration of a new user

Figure 6 shows the steps of the sequence diagram to register a new user.

1. First, the user must launch the application from her/his mobile device.
2. The interface agent displays the homepage and two commands "Sign in" for registration and "Log In" for "connect". If the user is new then he/she must choose to "Register".
3. The interface agent displays the registration fields, which must be filled by the user.
4. When she/he presses, "register", the interface agent sends a request that contains the information included in these fields to the administrator agent.
5. The administrator agent checks the existence of the identifier in the database of users' profiles. In case the same username exists, the Interface agent shows an error message that asks to choose another username, otherwise; the username is new, and it will create a new profile for this user.

2.5.1.2. User login

Figure 7 shows steps describing the "user login" sequence diagram.

1. First, the user must launch the application from her/his mobile device.
2. The agent interface displays the home page, which contains two commands "Sign in" for registration and "Log in" for logging in. If the user is already registered in the system, he/she must choose "Log in", then he/she must enter his/her credentials ("Username" and "Password").
3. Once the user presses "login", the interface agent sends a request containing the user's credentials to the Administrator Agent.
4. The administrator agent checks the existence of the username in the database of users' profiles and verifies the correctness of the password.
5. If the username does not exist in the profile database (i.e. the agent cannot find the user username), then it informs the interface agent, which displays a message to the user indicating that he/she must register before logging into the system.
6. If the password is not valid, then a message is displayed by the interface agent to the user indicating an incorrect password.
7. If the verification is successful, it informs the interface agent to open the appropriate space depending on the user (student space, teacher space, or administrator space).

2.5.1.3. Launching ubiquitous learning

Figure 8 shows the steps of the sequence diagram "Ubiquitous Learning Launch".

1. After the login, the interface agent becomes available for the learner to request services.

2. The interface agent sends the request to the sensor agent, to capture the learner's location and then sends the location to the context agent.
3. The interface agent sends the request to the tutor agent, to choose the appropriate modules based on the learner's context and sends the result to the context agent.
4. The context agent organizes and analyzes the context information that the sensor agent and the tutor agent have sent, and then matches it with the profile database information. After that, it sends the appropriate context to the content adaptation agent.
5. The content adaptation agent sends a request to the extraction agent to search for learning resources in the ubiquitous learning database and then determines the content based on the information in the content database, which is then sent to the tutor agent.
6. The tutor agent sends the answer to the interface agent, which displays the answer to the learner.

Figure 6
Registration sequence diagram

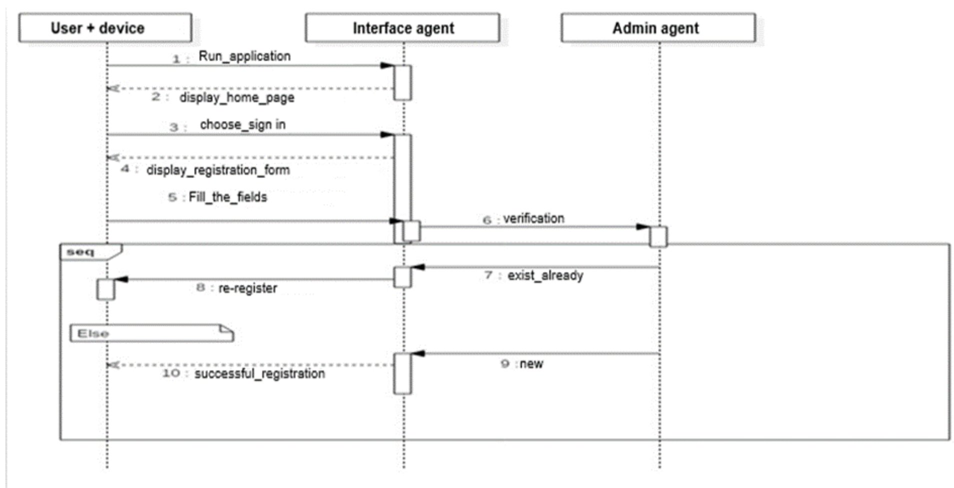


Figure 7
User login diagram

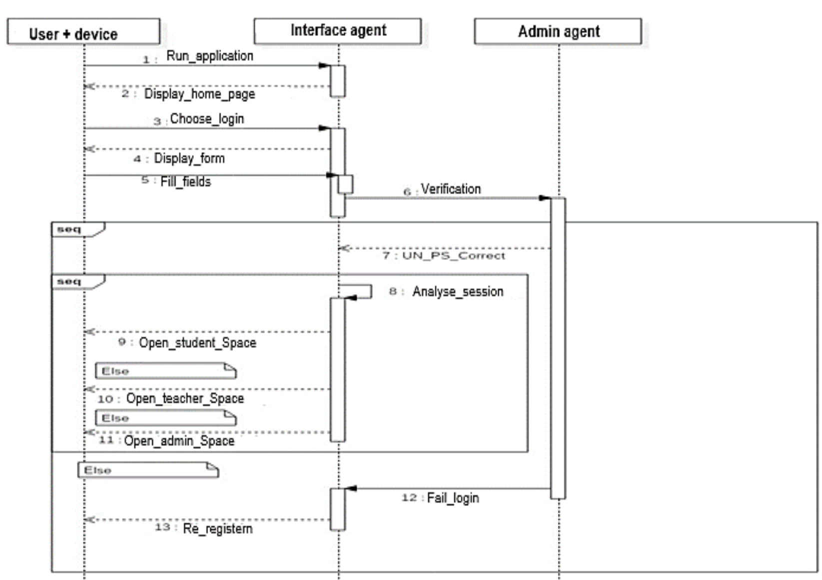
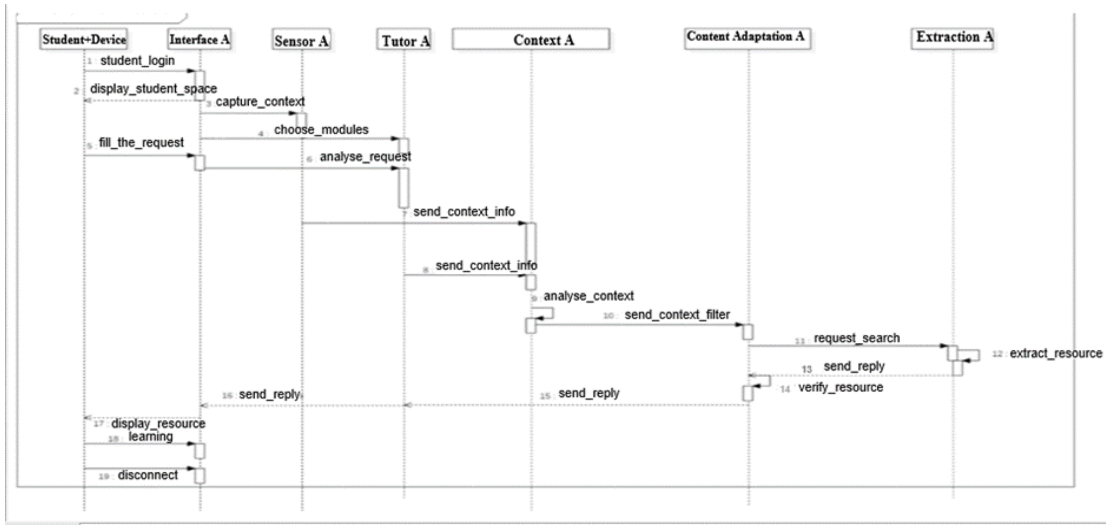


Figure 8

Ubiquitous learning sequence diagram

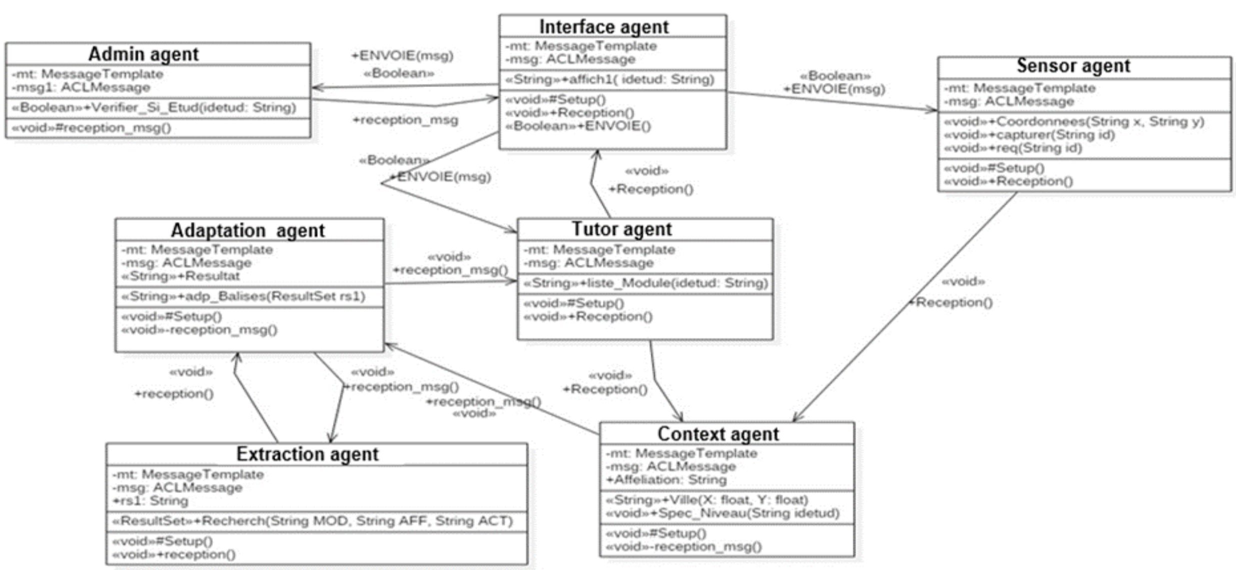


2.5.2. Class diagram

The class diagram presents the internal structure by providing an abstract representation of the agents in the system. Figure 9 illustrates the system's global diagram. This diagram demonstrates the associations between the different agents used in the system.

Figure 9

System class diagram



3. Results

3.1. System Development

3.1.1. Development environments

We used two development environments to achieve our objectives:

1. NetBeans IDE 8.1 for a multi-agent-based web application. It supports a wide variety of environments for running web and Java applications, Java Development Kit (JDK), Java Server Pages (JSP), Java Server Fac-es (JSF), Enterprise JavaBeans, and Apache. The application is developed in JAVA.
2. Android studio, which includes the essential components: Android SDK, and Android Virtual Device

3.1.2. The platform for context-aware localization

The application displays a map using the Google Maps API and geolocation data to locate the user with the GPS device. To include the functionality of the Google Maps API in our application, a script tag has been added in the head part of the JSP page. It enables the use of GPS with the parameter "sensor".

```
<script type="text/javascript" src="http://maps.google.com/maps/api/js"></script>
```

```
<script type="text/javascript" src="http://maps.google.com/maps/api/js?sensor=true'
```

3.1.3. Agent Development Environment

The application displays a map using the Google Maps API and geolocation data to locate the user with the GPS device. To include the functionality of the Google Maps API in our application, a script tag has been added in the head part of the JSP page. It enables the use of GPS with the parameter "sensor".

3.1.3.1. Platform JADE

The graphical interface of the JADE platform is a tool that provides an overview of the implementation of multi-agent systems.

3.1.3.2. Jade-LEAP platform

We used the Lightweight and Extensible Agent Platform (JADE-LEAP), which is an extension of the JADE platform that can be deployed not just on PCs and servers, but as well as on devices with limited resources, like mobile phones running Java. To achieve this goal, JADE-LEAP can be run on devices that support Android.

We chose the jade-LEAP platform for many reasons: namely because the JADE extension is written in Java. This platform has features such as the ability to execute multiple concurrent tasks (behaviors) in a single Java thread. These features fit well with the constraints imposed by resource-constrained devices.

3.1.4. Database management and Application server

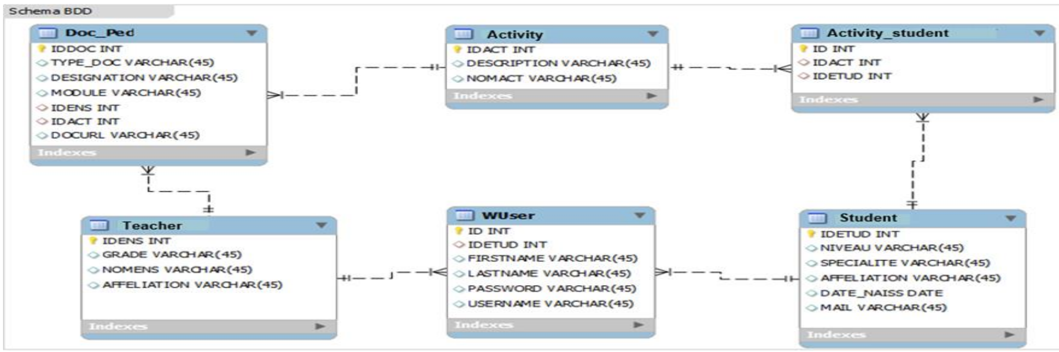
To create and manage the databases needed for our ubiquitous learning system, we used Apache Derby JDBC and for the server: Glassfish.

- *Diagram of the database*

We used six tables to present data from the ubiquitous learning application. Figure 10 illustrates the database schema.

Figure 10

The database schema



3.2. Implementation

In this section, we present the graphical interface for our system agents and the different interfaces of our ubiquitous learning system. GPS sensor and the different devices (tablet, smartphone), and the 4G network are used in this application. The application is tested under different contextual information. We have chosen three case studies to demonstrate the usefulness of this system.

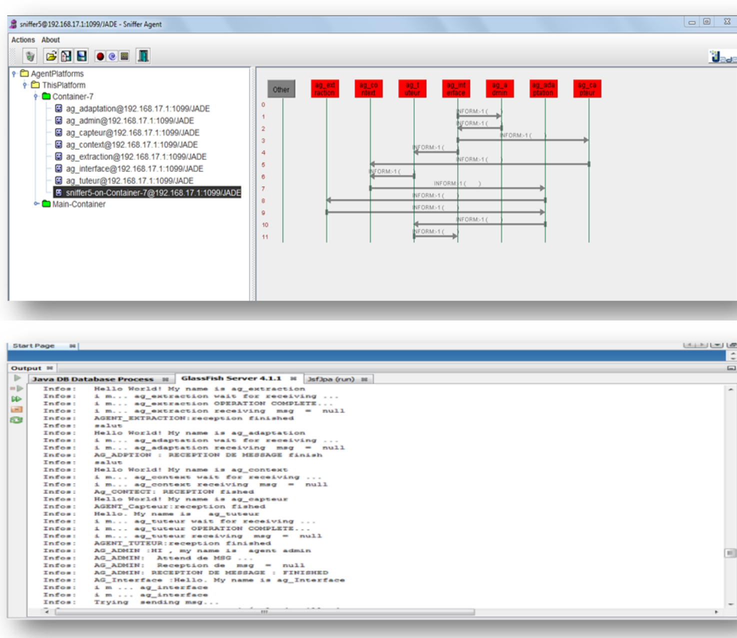
3.2.1. Implementation

Our System is composed of seven agents: interface agent, administrator agent, sensor agent, tutor agent, context agent, content adaptation agent, and extraction agent.

Jade offers a graphical interface tool that allows the visualization of messages exchanged between the different agents in the system. It is the "sniffer" agent, which keeps track of the messages in the platform. As shown in Figure 11.

Figure 11

Communication between agents

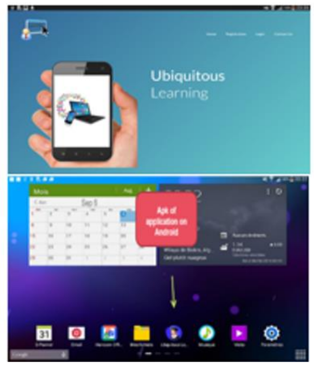


3.2.2. System Features

The different interfaces used in our ubiquitous learning system are discussed. Figure 12 shows the Android (APK) on a tablet interface and the home interface of our application.

Figure 12

Mobile application on Android



To register in the system, a user requests a registration number from the administrator by clicking on the word "contact us" on the main page as shown in Figure 13, and to log in as shown in Figure 14.

Figure 13

Login interface

Figure 14

Register interface

In our application, there are three workspaces: teacher, student, and manager space.

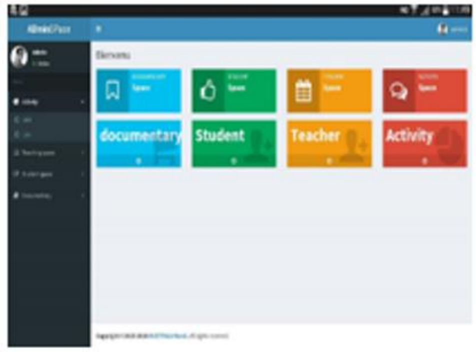
1) *Teacher space*: Figure 15 shows this workspace. The teacher's main role is to add educational resources.

Figure 15

Teacher space interface

2) *Manager space*: The administrator has a role to control all the systems either Add/Modify/Delete users, and activities or Modify/Delete resources. Figure 16 shows the administrator workspace.

Figure 16
Manager space interface

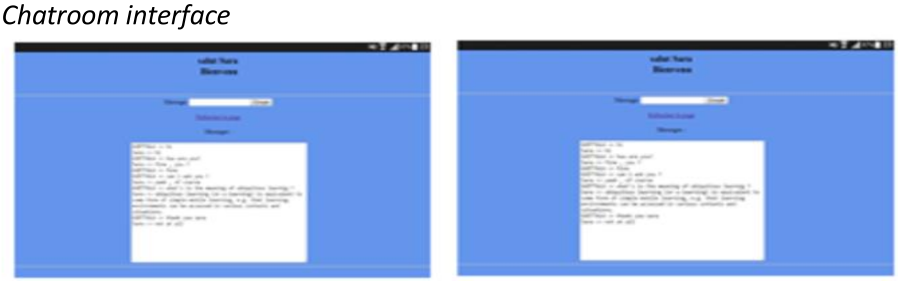


3) *Student space:* The student has a wide range of pedagogical activities, such as course selection based on the dynamic situation of the learner's contextual information (learning style, profile, and location), tutorials, exams, group discussions, and other additional activities. Figure 17 shows the student workspace.

Figure 17
Student space interface

4) *Chat room interface: The* chat room interface is illustrated in Figure 18. It is a forum, where students can share their knowledge. It is another method for ubiquitous learning ("Interactivity: Learners can interact with other learners using synchronous and/or asynchronous communications") (Guettala et al., 2021).

Figure 8
Chatroom interface



3.2.3. Case studies

We performed three case studies to validate our application. The students who participate in these studies have different contextual information.

3.2.3.1. Case Study 1

In this case study, the contextual information is:

- Location: BISKRA University - Computer Science Department.
- Learning style: Course, in PowerPoint presentation.
- Students' Profile: Students are graduate students in a Master's program, specializing in artificial intelligence. The course is a multi-agent system.

Step 1: Contextual information acquisition

Through the GPS sensor of the student's device and the Google Maps tool, the location of the student in the BISKRA University at the computer block was detected as shown in Table 2 (a).

When the system detects the student's location, the list of modules is automatically added according to the context. Then the student fills in the remaining fields to complete the contextual information as shown in Table 2 (b).

Step 2: Contextual information filtering

Table 2 (c) shows the interface, where the student contextual information is collected. It is used for filtering tasks and choosing the resources adapted for this student.

Step 3: Results

Table 2 (d) (e) shows the pedagogical results interface. It is used to display the results adapted after the filtering. In addition, similar results (with respect to the context) to this student's result are displayed.

In cases 2 and 3, the same steps of case 1 with different contextual information are followed.

3.2.3.2. Case Study 2

In this case study, the contextual information is:

- Location: Ouargla University, Algeria - Computer Science Department.
- Learning style: Thesis, in PDF format.
- Students' Profile: Students are graduate students in a Master program, specializing in academic computing.

Through the GPS sensor of the student's device and the Google Maps tool, the location of the student in the Ouargla University in the Department of Computer Science was detected as shown in Table 2 (case study 2).

3.2.3.3. Case Study 3

In this case study, the contextual information is:

- Location: Constantine 2 University, Algeria - Computer Science Department.
- Learning style: Exam, in image form.
- Students' Profile: Students are graduate students in a Master program, specializing in software engineering.

Through the GPS sensor of the student's device and the Google Maps tool, the location of the student in the Constantine 2 University in the computer science department was detected as shown in Table 2 (case study 3).

Table 2

Three case studies to validate our application

<table>
<tr><th>Case study 1</th><th>Case study 2</th><th>Case study 3</th></tr>
<tr>
<td>
(a)


(b)</td>
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(a)</td>
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(a)</td>
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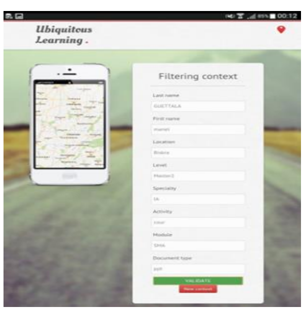
<tr>
<td>

(c)</td>
<td>

(b)</td>
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(b)</td>
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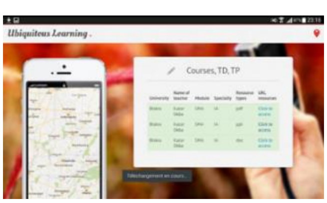
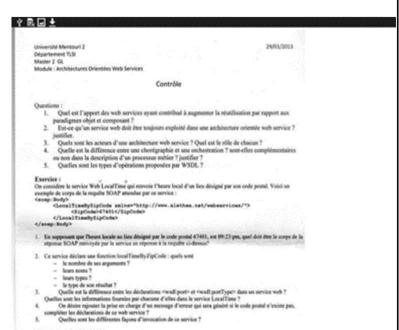
<tr>
<td>

(d)


(e)</td>
<td>

(e)</td>
<td>

(e)</td>
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</table>

4. Conclusion

In this paper, the emergence of new technology creates a new type of learning even more transparent and comprehensive. We presented a new personalized application, based on multi-agent systems which were designed as part of the ubiquitous learning process. The agent technology is suitable for ubiquitous learning applications because it is flexible, modular, and autonomous. One of the main objectives of a ubiquitous learning environment is to give students the appropriate learning content they need, at the right time and in the right place. For this purpose, our approach has been to adapt learning content to contextual information, based on the learner's profile, learning style, and location awareness using satellite positioning.

In this investigation, the researchers have chosen a case study for computer science students from different universities and regions of Algeria. As the application is based on context sensitivity through ubiquitous technologies such as sensors, only the GPS sensor was used. In the future, other sensors such as RFID and QR codes should be considered. In addition, we plan to explore the possibility of storing educational resources on the cloud for efficiency.

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Conflict of Interest

The authors declare no conflict of interest in any form for the work presented in the present article.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Figure 19

Part of sensor agent code

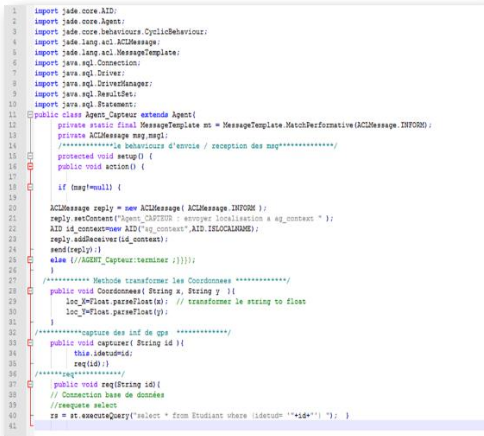

Figure 20

Part of Content Adaptation Agent code

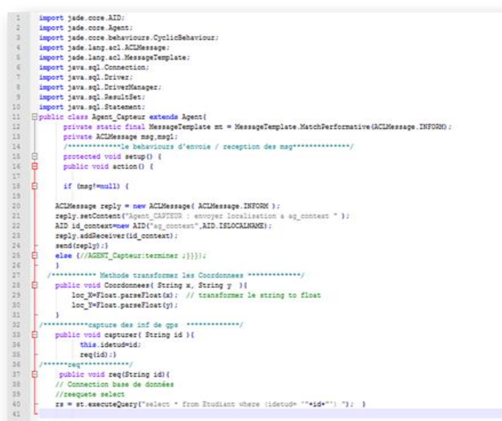

Figure 21

JADE platform GUI