Contextual Mobile Learning for Repairing Industrial Machines: System Architecture and Development Process

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***Abstract*—The convergence of mobile communication and wearable computers offers the opportunity to develop mobile learning systems which are able to assist individuals and groups in professional and industrial learning situations. In this paper we present a contextual mobile learning system aimed at assisting users in repairing industrial machines (or appliances) or learning this repairing procedure using mobile computing devices like PDA or tablet PC, using appropriate wearable input/output devices. After a short presentation of our perception of the contextual mobile learning IMERA platform (French acronym for Computer Augmented Environment for Mobile Interaction) will also follow a presentation of the development process organizing task analysis, production of learning units, contextualization with RFID tags and configuration of wearable computer used by the learner. Based on the platform the system framework will be explained. Finally we will describe a concrete industrial case study used to test and evaluate our system.**

***Index Terms*—mobile learning, contextualization, RFID, augmented reality, wearable computer**

I. INTRODUCTION

As mobile technologies are becoming more and more widespread in people's daily life, there has been a huge increase in studies and experiments regarding the use of mobile technologies for learning and training in professional and industrial situations. More and more people start to benefit from various mobile learning technologies, but in the meanwhile arguments for the mobile learning definition have never stopped evolving over the years.

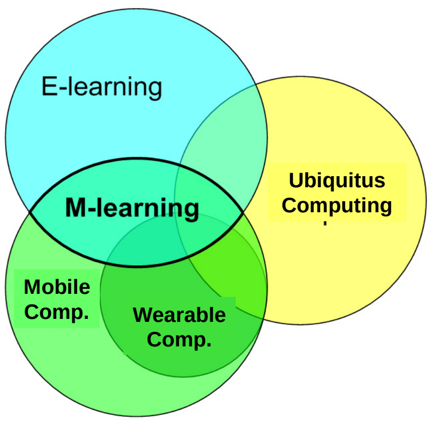

Figure 1. Mobile learning cartography

An early definition described mobile learning as e-learning through mobile computational devices like PDA, Tablet PC, or even smart phone [1]. Among different opinions, the most significant definition of mobile learning is as follows: "**mobile learning is any sort of learning that occurs when the learner is not at a fixed, predetermined location, or learning that occurs when the learner takes advantage of learning opportunities offered by mobile technologies**" [2]. Compared to e-learning, ubiquitous computing, mobile computing and wearable computing, a mobile learning cartography is shown in Fig. 1.

Four essential characteristics are proposed to describe mobile learning situations [3]: devices, mobility, context, and location. Several categories of mobile learning can be identified according to the variation of these characteristics. In this paper we mainly separate M-learning into two context related categories. **Either the learning activity is totally independent of the actor's location and the context** in which he is evolving, taking into account only the opportunity to use mobile devices to learn (in public transportation, waiting for the bus, etc.) or on the contrary, **the learning activity relates to the location (physical, geographical or logical) of the actor and the context** in which he is evolving. We are mainly concerned with this second category of mobile learning, which is also called **contextual mobile learning** or context-aware mobile learning.

The learning context in mobile learning is a very important aspect, which can be described as "any information that can be used to characterize the situation of learning entities that is considered relevant to the interactions between a learner and an application" [4]. Three categories are considered: computing context, user context, and physical context [5]. Thanks to the development of wearable computers which are complemented by accessorial sensors, such as GPS receivers, RFID readers [6], cameras, etc, and software sensors, such as network congestion manager, web log analyzer, user behavior analyzer etc, the learning context such as learners' location, activity, network connectivity, learning situation, etc, can be captured to improve the learning activities.

On the other hand, the Mixed Reality [7] better known as Augmented Reality, appeared in 1993 [8], becomes more and more essential. This technology attempts to merge the physical and numerical worlds in order to facilitate the user's task with special devices and particular interaction techniques. A lot of hardware materials (like see-through goggles) and software applications were developed, that are very helpful for the mobile learning research in specific situations.

The study of learning methods is another important aspect of mobile learning. New and more appropriate methods are needed for the great revolution of mobile learning compared to the traditional classroom methods. We consider that these mobile learning methods should take into account particular conditions in which the learning occurs: limited time, particular working conditions and operational result orientation. Main learning method characteristics are such as problem-based learning [2], case-based learning [9], scenario-based learning [10], and just-in-time learning.

Several existent e-learning projects give us a lot of useful inspirations for designing new mobile learning systems. What we are interested in is applying the mobile learning theories to the industrial learning and training activities. Our contextual mobile learning system is a part of a larger project called Help Me to Do (HMTD) [11], which aims at assisting different users in domestic, public or professional mastering of appliances by wearable computer. The objective of this paper is to explain the design process and the architecture of our mobile learning system, which is able to allow the user to learn just in time diagnosis and repairing procedures.

In the following sections, we present our platform, its adaptation to M-learning and the development process based on a framework. We describe also an industrial scenario carried out in collaboration with a firm, allowing us to validate the feasibility of our approach and to evaluate the system. The conclusion and perspectives end this paper.

II. PLATFORM AND ITS ADAPTATION TO L-LEARNING

A. IMERA platform

The IMERA platform is composed of a main workplace and three auxiliary distant workspaces. The main working area is a CAE (Computer Augmented Environment) in which evolve different mobile actors. This CAE is a more or less large area covered by a WiFi network or another wireless network as adhoc network. The area is able to receive RFID tags, either freely set or integrated into real objects (augmented objects). The actors move freely in this area with their wearable computers each of them equiped with a WiFi card and an RFID reader. These wearable computers are thus connected to the network and are able to collect contextual data via RFID technology. The WiFi network allows actors to be both connected with one another and with central systems (database servers, etc) so they can communicate and access large amounts of data. Independently of this working area, three separate distant management and observation workplaces complete this platform [11].

A first workspace is intended to be a central workplace for observation and management of the collaborative activities involving coordination, i.e. supervising the actions of the actors moving on the platform. The second workspace is mainly observation oriented but can be used as a second supervision place. The last workspace is devoted to observation and evaluation of the platform experimentations. It contains a trace server which acts as a UI message loop hook, filtering and storing all the UI generated messages sent via different networks (Ethernet, WiFi, etc.).

The IMERA platform can be used in several collaborative situations, managing educational, industrial, cultural and sporting events. Its main working area is on the corresponding space while distant workplaces can be located anywhere provided where a WiFi network is accessible. For each situation, it is important to identify the actors and their tasks with the data to be collected and manipulated. We thereby determine the technologies to use on the main working area and the most appropriate interaction devices for each actor. Firstly scenarios are expressed and formalized in a structured way following the method proposed to describe as precisely as possible all collaborative aspects. Then, we are able to extract the roles of each actor by analyzing an elaborated model from the actors' point of view, jointly with the required environment, artifacts, etc. This process can help to choose wearable computers and necessary input/output devices for carrying out the tasks.

B. Production of learning units

The production of specific learning units for an appliance is carried out via the analysis of the manufacturer documentation. For this particular step an existent project IMAT (Integrating Manuals and Training) [12] gave us a good inspiration in the indexing and management of learning fragments, which however was initially designed for fixed expert users and didn't consider the mobile users and possibilities of contextualization.

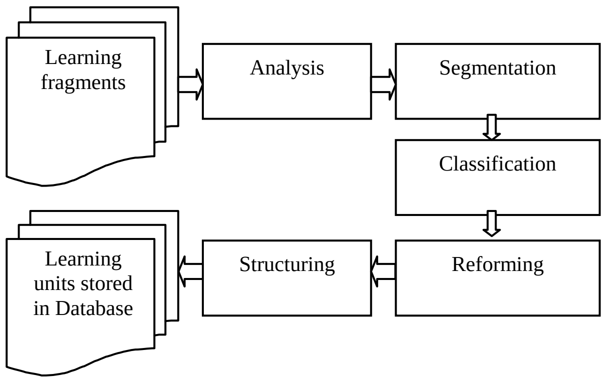

Figure 2. Production of Learning Units

Information provided is not limited to the textual description of the tasks to be carried out (and thus learning), but also contains diagrams, photographs, figures and models of elements (parts making up the equipment, its front face, its control panel, etc.). The goal is to build a computer supported model that is as complete as possible to be able to produce suitable learning units. The original source of documentation can be in various forms, like paper manuals, .doc, .pdf, video, voice, etc. Paper manuals are scanned and transformed to electronic versions with the OCR (optical character recognition) technologies; other documents are also transformed to the uniform formats, which become learning fragments. Learning fragments are analyzed and segmented according to their usability, after which the classification and reforming work (indexing work) are done in order to retrieve them in future, and finally learning units are created and stored in the database after the structuring work (Fig. 2). All these units are expressed in XML using the standard SCORM and LOM to allow adaptation.

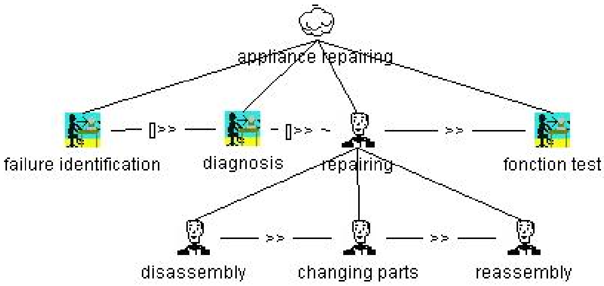

Figure 3. Tree of tasks: repairing activity

C. Modeling of user tasks

As the process of contextualization is to deliver right leaning units to the user to help him carrying out his tasks, learning units structuralizing has an important relation with the task types [13]. Different learning units are tagged, classified and affiliated with each other to fulfill beginners' actions, basic tasks, advanced tasks, expert tasks for mastering the use of appliance and also main tasks related to dysfunction identification, diagnosis process, repairing, dismounting the pieces and reassembling, etc. So for us it is necessary to model user tasks in an appropriate way. We chose the CTTE (Concur Task Trees Environment) as a tool to help us completing this work. Fig. 3 is a simple task tree describing the overall procedure of appliance repairing.

D. Contextualization with RFID technologies

Contextualization is a crucial aspect in mobile learning system design, which means to deliver the right learning content into the right learning context. One way of doing this is to use contextual information to determine the content that is relevant to what the user is doing, where and how this is done [14]. In our industrial scenarios, we mainly use RFID and other associated technologies to collect the contextual information.

Radio-frequency identification (RFID) is an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags and RFID readers. The RFID tag can be applied to or incorporated into a product, animal, or person for the purpose of identification using radio-waves, and it can be read from several centimeters to meters away and beyond the line of sight of the reader. In our scenarios, each appliance that is registered in the manufacturer's database has a RFID tag, which indicates its own product serial number. The user equiped with an RFID reader on his wearable computer is able to immediately get all the relative information and operation history about the appliance from the server. In this way, concerned learning units can receive precise context information which is used in the learning process of mastering or repairing the appliance.

E. Distant collaboration

As we mentioned in the previous section, with the support of WiFi access points to internet, the user also has the possibility to collaborate with other located actors elsewhere. The communication can take various forms: voice, text message, drawing or gesture and so on. During the repairing process of an appliance the repairer can sometimes reach the difficulty to check out the reasons of dysfunction. The repairer can ask for help and be guided in this activity by his technical supervisor. Other experts or even anyone helpful who can be anywhere in the world with the network access can contribute to this collaborative problem solving.

For this collaboration purpose, a collaborative MoUI (Mobile User Interface) and associated protocols are studied and developed in our laboratory.

F. Configuration of wearable computers

According to the context, the choice of the wearable computer and its input/output devices is also important. Different actors evolving in a particular scenario and the actors in different scenarios need different configurations of wearable computers and associated peripherals. For example, to present appropriate information to the actor, screen integrating goggles or see-through goggles are carefully considered and chosen in order to create suitable Augmented Reality information allowing the actor to concentrate himself on the repair work. The elaboration of this configuration is based on a study of all actors' tasks, matching requirements concerning graphics information complexity (textual, graphic schemas or precise blueprints …), interaction complexity (writing, observation, manipulation) and working conditions (seating, standing, hands availability …), etc.

A precise selection process [15] has been defined based on a referential allowing to compare different types of interaction and system implementations. Typical devices for different types of interaction are organized onto axes according to their characteristics. Applying this selection process to our scenarios, we identified three main configurations with their purposes (TABLE 1).

TABLE I.
CONFIGURATIONS OF WEARABLE COMPUTER AND ITS ASSOCIATED DEVICES

Actor characteristic	Purpose	Equipments
Hands-free highly mobile actor	Eye continuity and at least one hand free	Goggles with integrated screen, Control through a data glove, Voice command with vocal feedback, Backpack computer.
Hands-free Mixed Reality mobile actor	Integration of numerical data in the real world for tasks normally in the real world	See-through goggles, Control through a data glove, Voice command with vocal feedback, Backpack computer.
Head free mobile actor	Sizeable data support and handheld device with interactions by pointing and writing	Tablet PC (WiFi) with RFID reader.

III. DEVELOPMENT PROCESS

A. *MOCOCO and associated concepts*

Our contextual mobile learning approach is based on the following main concepts:

- **MOCOCO** is the acronym which expresses the main aspects of our approach. Its aim is to show that we are creating an environment allowing MObility, COntextualization and COoperation for various actors while carrying out tasks. A mobile actor has access to precise and contextualized data and can collaborate with several other mobile or fixed actors to solve the problem.
- **Proactivity** characterizes the information propagation to actors enabled by an Ambient Intelligence Environment and transparent user interface adaptation.
- **CAE** (Computer Augmented Environment) expresses a real environment augmented by communicating objects (mainly RFID tags) allowing Augmented Reality and Context-aware Computing.
- **MoUI** (Mobile User Interfaces) denotes the user interfaces for wearable computers as those of PDAs, Smartphones, mobile phones and other devices appropriate for mobile users working in a collaborative way with elaborate contextualization (access to contextual and/or personal precise data) in a CAE.

B. *System framework*

A global framework is represented in Fig. 4. It briefly describes how the system is designed and works. The framework is based on the IMERA platform (French acronym for platform supporting Mobile Interaction in the Augmented Real Environment), which has been detailed in the previous section.

Starting point for each new learning system is the study of technical manuals accompanying different appliances and industrial machines in order to discover and modeling main tasks accomplished by the users and repairing technicians. Our objective is to identify and structure appropriate user related learning units and task characteristics i.e. beginner's actions, basic tasks, advanced tasks, expert tasks for mastering the use of appliance, and also main tasks related to the dysfunction identification, diagnosis process, repairing, dismounting the parts and reassembling, etc. From these studies, we defined a generic structure of main learning units. We also decided that the diagnosis process will be based on a fault tree analysis approach. Learning units are stored in a database in XML format. Contextualization is done via different markers, mainly RFID tags. This way precise information on the appliance can be transmitted to the learning system. The control engine organizes the whole learning activities. It plays the role of a manager able to link concrete working situations with database stored learning units and it is also in charge of adapting this information to visualization and interaction devices attached to the wearable computer. Actors (user, repairer) are using wearable computers to communicate with the system, between actors and if possible with the appliance.

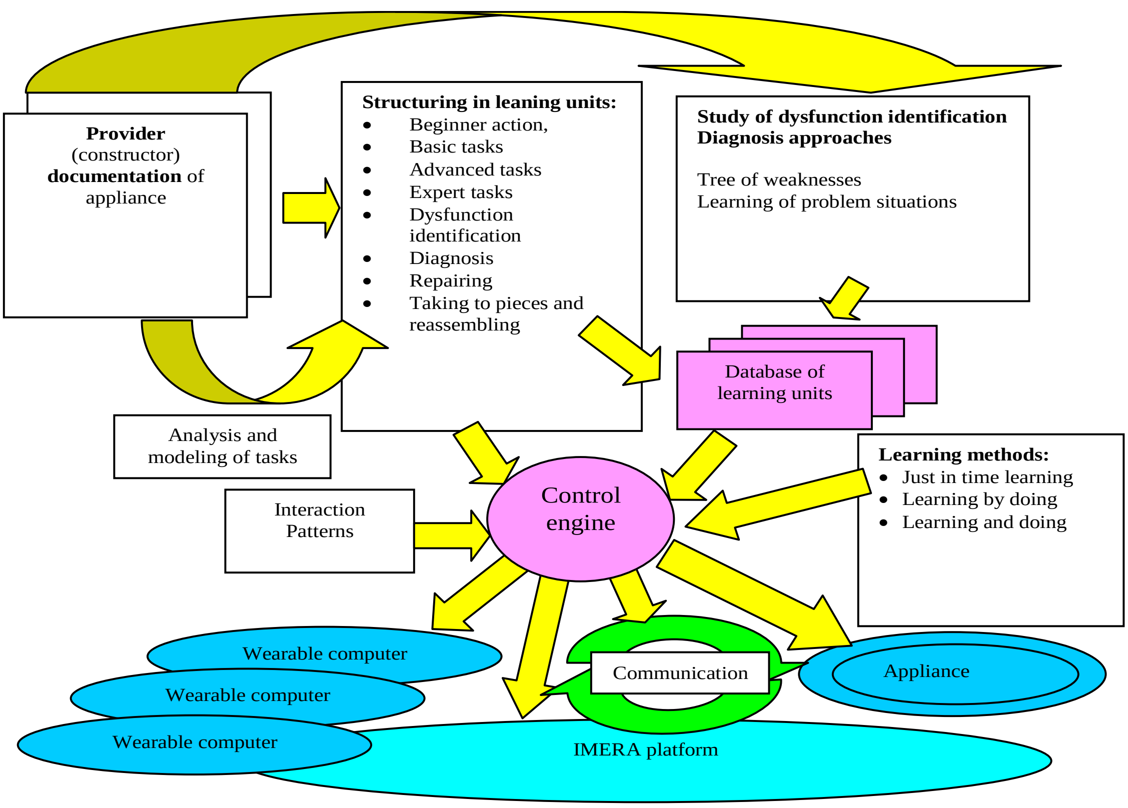

Figure 4. Contextual M-learning development process global schema

IV. INDUSTRIAL SCENARIO

As explained before contextual mobile learning system is a part of a larger project called Help Me to Do (HMTD) of which the main objective is to propose to the user (in charge of use, maintenance, diagnostic or repairing) to appropriately learn about the appliance to understand the functioning principles and commands or other actions in a precise situation. The repairing procedure of a machine is considered as one of the most important industrial scenarios in our approach. A local firm offered us a test and evaluation environment. A testing bench of staplers and perforators was chosen to be repaired (Fig. 5).

The scenario process is supposed to occur as described in Fig. 6: An engineer in charge of maintenance and repairing of the machine is called on the factory when the machine is out of order. Once in the factory, he equips himself with See-Through goggles connected to a PDA with WiFi and RFID reader. By reading machine RFID tag, he gets all its features and its repairing history from the internet database server where appropriate information is stored (Fig. 6), through an available WiFi access point. He proceeds to a first analysis and tries to formulate a diagnostic. At each moment, he can stop his activity and choose to learn about it, i.e. to receive more complete and precise information either about functioning principles or about actions (commands) which he is asked (guided) to execute. If he has complementary questions or if he failed in carrying out the action alone, he can contact his supervisor or another expert. He can contact them via chat or contextualized email in which machine references are automatically included to avoid typing error and to provide exhaustive information. They then try to produce the diagnostic together.

Accurate product plans and guides are at the disposal of the actor through the internet connection to help him on the recognition of the different pieces. He can visualize them on his see-through goggles whereas he is looking at the machine. Simple vocal commands are enabling him to browse the guide (Fig. 7). These commands are captured by his wearable computer (PDA) microphone and are processed either on the server, being transferred through WiFi and internet or directly on the wearable computer, depending on the complexity of the command, and the capabilities of the wearable computer. If diagnostic is still not successful, he can contact a machine manufacturer expert to help him realize the diagnostic.

Figure 5. The testing bench of staplers and perforators to repair

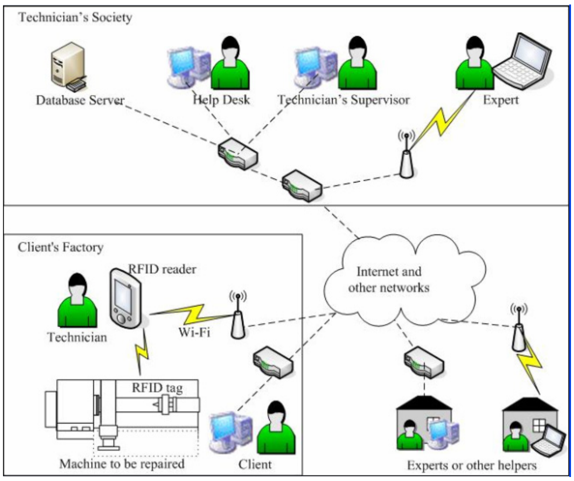

Figure 6. Industrial machine repairing scenario

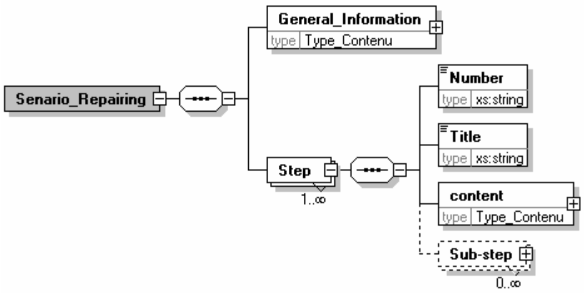

Figure 7. Repairing scenario data

As soon as the diagnostic is established, and the malfunctioning pieces are determined, he highlights them via his wearable computer on a blueprint of the machine displayed on his augmented goggles. Afterwards, the availability and delay for future reparation is computed. Later, when the parts are delivered, the reparation process is described on his wearable computer with eventually the visualization on his see-through goggles of an assembly plan or other relevant data. As soon as the machine is repaired, he updates the machine reparation history and replaced parts, on the server.

V. CONLUSIONS

We presented our development process of a contextual mobile learning system based on the IMERA platform, after considering MOCOCO concepts. Studying the production of learning units with associated approaches like task modeling is the starting point of our research. Structuring of learning units in respect with LOM and SCORM is also one important aspect to be studied in the near future. According to the different scenarios and contexts, appropriate configuration of wearable computer and associated interaction devices should be chosen carefully, in order to propose appropriate working and learning environment. IMERA platform offers an experimentation environment supporting different situations for collaboration work of mobile actors in a Computer Augmented Environment. Tests and evaluations can be carried out and analyzed thanks to the supervision and trace of different workspaces. Integrating new mobile or grounded communication objects like the most recent sensors and effectors, including position and orientation sensors or original captors as presence detectors, the platform is also an Ambient Intelligence Environment. The platform supports the appraisal of concrete scenarios derived from various industrial situations, such as using, maintaining and repairing of machines, for the discovery and validation of new interaction methods and devices. We are open to other applications to validate our approach and various scenarios are currently being studied, mainly in the industrial field.

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