Interactive Mixed Reality for Collaborative Remote Laboratories

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ABSTRACT
In distance learning, remote laboratories (henceforth RLabs), allow students to perform real-time tasks on laboratories over the Internet. However, existing tele-operations systems suffer from both the low fidelity of the representation of the remote site that hosts the instrument, and the lack of "group awareness" for collaborative learning during online hands-on sessions. In this paper, we discuss how Mixed Reality systems can improve the fidelity of such remote devices and how group awareness can be achieved. A software architecture for collaborative mixed reality for RLabs based on the MPEG-4 BInary Format for Scenes (MPEG-4 BIFS) is also presented.

Categories and Subject Descriptors
C.0 [**Systems Application Architecture**]: Middleware architecture

General Terms
Design, Human Factors.

Keywords
Remote labs, Collaboration, MPEG-4 BIFS, Mixed Reality, Software Architecture.

1. INTRODUCTION
Over the last decade, part of the researches conducted in the field of Online Engineering aimed at controlling real remote appliances over the Internet. Such researches were supported by:

- The industry, for computer-supported maintenance and remote control of processes in the distributed enterprise,
- Research institutes, to share expensive devices, mandatory for specific research, yet under-used in term of frequency over the year,
- Distance learning curriculum and Open Universities, in order to practice laboratories online instead of coming to the lab. "If you can't come to the lab, the lab will come to you" [1].

During engineering studies, laboratories contribute in the learner's construction of knowledge since they put the student in the situation to practice or acquire theoretical background. They are pedagogically based on observations on the studied subject as well as interaction between students' peers.

A lot of frameworks for building RLabs were proposed during the last decade. Most of them rely on the same architecture: the device to control, a local machine connected to the device, a middleware and a client application for interacting remotely [2] as illustrated by Figure 1.

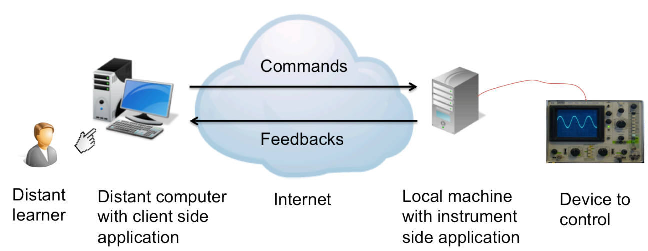

Figure 1. General RLabs architecture

One can notice that more and more RLabs architecture take into account collaborative control of devices.

Collaboration is a key component in remote tele-operation, especially in the field of engineering learning. In learning theories, socio-constructivism [3] is the theory that tries to make student learning from their own observations and from the interactions with others, both teachers and other students. As far, a RLab solution should be able to manage the "group awareness"

[4] mechanism; so that collaboration among teacher that occur in traditional local session can be reproduced online.

Previous researches did not encompass fidelity of the presentation of the remote laboratory. Web forms are usually used to post experiment parameters. Feedbacks from the device are represented as software components in the Web form or are delivered as streamed video. We consider that the first approach seriously lacks representational faithfulness and the second only provides observation and no action capabilities, a compulsory function for a lab.

At the Pervasive Computing area, RLabs are expected to be accessible anytime and anywhere. This is enforced in distance curriculum with different time zones for students, tutors and instrument locations. With the increase of mobile devices computing capabilities, remote devices should be controlled with any kind of terminals able to display multimedia content.

In this paper, we propose an architecture for Computer Supported Collaborative Learning (henceforth CSCL) systems applied to RLabs using interactive multimedia and Mixed Reality. It relies on the MPEG-4 BInary Format for Scene (MPEG-4 BIFS). This paper is structured as follows. The second section addresses the potentials of Mixed Reality systems and collaborative systems. The following section presents our system from the client side. The fourth section of this paper exposes how the middleware can handle collaboration in RLabs and discusses the usage of MPEG-4 BIFS for supporting group awareness. Finally, section 5 concludes the presentation.

2. RELATED WORKS

2.1 Mixed Reality applications

Augmented Reality is a view of a real scene where computed information is added. Added Information can be textual, sound, graphics, etc. Augmented Virtuality refers to the merging of real objects in a virtual scene. Mixed Reality encompasses both Augmented Reality and Virtuality [5], as shown in Figure 2.

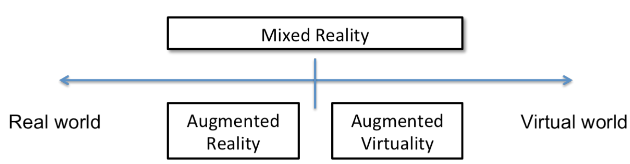

Figure 2. Mixed Reality continuum

Three fundamental rules must be respected in order to build an effective mixed reality application [6]:

- Combine the real world and the virtual world,
- Take into account the consistency and the coherence between the real and the virtual worlds,
- Handle the constraints of real-time and interactivity.

We strongly believe Mixed Reality can improve the representation's fidelity of RLabs. Seeing the real scene and interacting with it, i.e. the remote device, leads in having a better comprehension of the manipulated device and improves the "sense of being there", which is an utmost issue in distant learning [7].

Mixed reality systems demonstrate their performances and benefits in various fields and applications, such as remote maintenance, telemedicine, education, serious gaming, or culture. For example, the US Navy uses the ARMAR system [8] Augmented Reality for Maintenance And Repair. It employs augmented reality technologies in order to assist the human operator in the realization of procedural tasks of maintenance or repair. This project requires wearing a Head-Mounted Device and is based on movement's detection to provide additional information to the human operator. The kinds of information added to the view of the scene are labels, real-time diagnostics of components, etc.

Wörn et al. developed a system for the "intraoperative visualization of preoperatively defined surgical planning data" [7]. This application helps surgeons dreading heavy operations.

In education, we can mention various examples from different engineering fields. Construct3D [10]-[11] is a geometric construction tool designed for mathematics and geometry education. Users can construct three-dimensional forms and visualize them while wearing a Head-Mounted Device. Students and teachers can also interact with each other since it is a face-to-face collaboration. In [11] the authors showed that their tool is well accepted by the students and is efficient for teaching purposes. Maier et al. designed an augmented reality application to show the spatial relation in chemistry [12]. They highlighted that the "application offers new opportunities for teaching and education. Students are no longer confronted only with the 2D representations of the chemical structures". Ardito et al. presented "A Game to Learn History" [13]. In m-learning situations, the students, equipped with mobile devices, are exploring an archaeological park. Their experiments also showed that the "game aims at stimulating in the students an understanding of history that would be otherwise difficult to engender".

Odeh et al. present in [14] a RLab with a distributed architecture applied to electrical courses. It is a Web based application which overlays real kits with virtual objects.

The literature shows that using mixed reality systems can lead to a better comprehension of the manipulated device. Most of the time, additional information is overlaid on the viewed scene, although the subject of study is in the same place than the user, the activity is limited to observation, and the application is single user. RLabs need to go beyond: the subject of study is distant, interaction with it is compulsory, and collaboration with peers lead to a better metaphor of laboratories on the Web.

2.2 Collaboration in RLabs

Collaboration generally refers to individuals or organizations working together to address problems and bring results that are not easily achieved by working alone. Collaboration entails the sharing of the same resource at the same time.

To ensure collaboration, a high level of trust has to be achieved and a frequent communication has to take place. Thus, collaborative systems should not only allow the sharing of a resource between the different protagonists, but it should also maintain group awareness. As said in [4], "Group awareness is the understanding of who is working with you, what they are doing, and how your own actions interact with theirs".

In CSCL systems, teachers are concerned by group awareness since it eases the management of student's achievement. To manage collaboration and thus group awareness in RLabs, different approaches are used.

In [15], Tuddenham et al. present a shared visual workspace for tabletop. Their system reproduces protagonists' arms when working on the remote tabletop and speakerphones are used to ease communication between the users.

Schaf and al. [16] propose a "learning-material module". Depending on the logged user, different kind of operations are allowed. Different "learning modes" are suggested by the system, such as "active learning" or "team learning".

Communication tools, such as video, audio, chat and shared workspace are not the only key issue when designing collaborative RLabs, especially in distance learning curriculum, as said in [17]. To support supervision, in [17], they decided to display multiple devices in the same time, like "a tutor being able to walk around the laboratories and observe each student or group of student".

Gravier et al. in [18] proposed to enforce the group awareness with a communication tool based on a chat, VoIP and a "group awareness enforcement service" which provides a tele-presence indicator and allocate a color for each user. When an interaction occurs, the widget's color of the front of the Human Computer Interface of the RLab changes to the user's color responsible for this interaction. In addition to those tools for computing the group awareness, a system based on ontologies and semantic rules is applied to manage the accesses to the resources [19]. This system was also adapted to run in a virtual word, Wonderland [20]. Virtual worlds can help increasing the group awareness, since all the users are virtually present in the virtual world, which already provides group awareness [21]. In addition, "the spatial layout of the 3D world coupled with the immersive audio provides strong cognitive cues that enhance collaboration" [20].

Different approaches can be considered in order to achieve group awareness in collaborative applications. Communication tools are the mandatory components, but other tools can be added in order to enforce the collaboration impression.

3. INTERACTIVE MULTIMEDIA AND MIXED REALITY

In this section, we describe the construction of the multimedia user interface of the proposed system. We present how multimedia technologies can be used to represent the scene of the remote device to interact with and how the Mixed Reality application constrains are handled.

3.1 Scene representation

Binary Format for Scene, BIFS, a specification part of the MPEG-4 standard [22], is a scene description formalism designed to represent efficiently dynamic and interactive scenes. Its description capacities range from natural audio or video object to 2D or 3D synthetic objects and scenes.

Scenes are described as hierarchical trees, where multimedia objects (audio-visual objects) are leafs. When designing animation and complex behaviors, one can update, modify, add or delete branches or leafs of the tree [22]. It is possible to represent the scene using the XML-based language eXtended MPEG Textual, XMT, format or using the YAML-based BIFS Text, (henceforth BT). A dedicated compression schema is offering efficient representation.

While designing mixed reality application, an analysis of the scene has to be done. Figure 3 represents a real device in a laboratory.

Figure 3. A spectrum analyzer in a laboratory

Applied to RLabs, we can therefore encounter 3 types of areas in the scene:

- A video area, where objects are changing during time (the display in Figure 3),
- A graphics area where are added extra information and enabling device functionalities with interactive elements,
- A background (static pixels elements over the session).

MPEG-4 BIFS allows the description of scene using any kind of media. Since the background of the scene is unchanging in time, we can represent it with a simple JPEG image. The video region of the scene can be encoded using MPEG-4 AVC, which offers a very efficient video compression [23]. The construction of this video region is explained in the next subsection. The graphics regions can be designed with MPEG-4 BIFS graphics elements [22] and the interactive elements can be rendered using MPEG-4 BIFS *sensors*. The interactivity is handled in MPEG-4 BIFS using VRML ROUTE mechanism. Since MPEG-4 BIFS can also embed ECMAScript, the sensors of the Human Computer Interface can be linked with Asynchronous JavaScript And XML (AJAX) requests. These AJAX requests are sent to the middleware, which delivers them to the remote device according to their destination.

MPEG-4 BIFS gives also the ability to stream the scenes just like any other media, in opposition to other scene descriptors [24]. Using a player that can decode BIFS scenes, users can "see and interact with" the remote device with the streamed BIFS scene.

3.2 Designing a Mixed Reality application

In order to build an effective Mixed Reality application, three fundamental constraints are mandatory: the fusion of virtual and real objects, the coherence between real and virtual worlds and the real-time aspect.

In order to respect the first two constraints, we need spatial references objects in the scene. These objects are very important because they enable the computation of the spatial representation of the scene, needed at anytime in Mixed Reality systems.

In the Mixed Reality fields, the tracking of rigid objects consists in following their orientation and position within a video. Most techniques are derived from whether marker-based tracking or marker-less tracking. The tracking with markers consists in placing references objects that are easily identifiable in the scene. The system described in [25] is a typical example of augmented reality application running with markers for medical application. The system needs to detect the objects in every image of the sequence. The marker-less tracking systems are based on feature points detection algorithm in the images. Those algorithms lay on salient features of certain regions of images. They are often based on contour methods (contour intersections, points of high curvature, etc.) or on image intensity (often "Hessian-based") [26].

While the marker-dependent methods offer important robustness and efficiency in computational terms compared to the marker-free methods, the latter does not compel *a priori* intervention in the scene. Such markers would also entail a very high calibration phase because the system would have to know every elements relative positions and orientations in the scene from the marker.

Based on Tuytelaars et al. categorization [26], our system uses the Speeded-Up Robust Feature descriptor, SURF, to compute the local features of the scene. Using the authoring tool of the system, one can add the background image while designing the interface of the device. The SURF descriptors of this reference image are then stored in the middleware database. Figure 4 is a capture of the authoring tool.

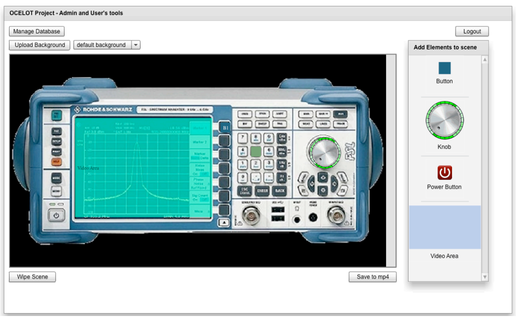

Figure 4. Authoring tool

The user also has to define the video region of the scene. In our case, the video region corresponds to the display of the instrument. The coordinates of the video region are also stored in the database.

The SURF descriptors are computed at every captured image and compared with those in the database using the Fast Library for Approximate Neighbor [27]. The Zhang algorithm [28]-[29] then provides an estimation of the pose estimation of the device in the scene. Knowing this pose estimation, the device display is cropped, encoded with MPEG-4 AVC and then streamed with the whole multimedia content to the end user [30].

Figure 5 presents a multimedia user interface of a device using this method at the end-user point of view. The MPEG-4 player is the Osmo4 player from the GPAC project [31].

Figure 5. The interactive Multimedia Interface running under the GPAC player

The Osmo4 player can run under a lot of different platforms, such as PCs, Linux, Mac OS X, iPhone and Android. Thus, pervasive situations can be addressed.

4. COLLABORATION AND REMOTE CONTROL OF DEVICES

The previous section of this paper exposes how we can use MPEG-4 BIFS to represent RLab with Mixed Reality technics. In this section, we expose how collaboration and group awareness can be achieved. Some of the aspects presented in this section are still at an implementation phase.

4.1 A collaborative middleware

The middleware part of our framework is designed using the Java Enterprise Edition (JEE) Application Server JOnAS. It is 4-tiers application. When an interactive element in the multimedia is activated, an AJAX request is sent to the middleware, as explained in previous section. This AJAX request, using HTTP POST, contains a message formatted as JavaScript Object Notation (JSON). This message contains the identification of the widget element, the user login, the nature of its interaction and an optional value. It is relayed to the middleware using a java httpservlet. The httpservlet then serialize the message in a Java Message Service (JMS) queue, implemented in JOnAS with Java Open Reliable Asynchronous Messing (JORAM). A message broker then relays the message to the instrument side application and to the different users. This mechanism is known as Message Oriented Middleware, MOM, which relies on the publisher/subscriber paradigm, as explained in [32] and illustrated in Figure 6.

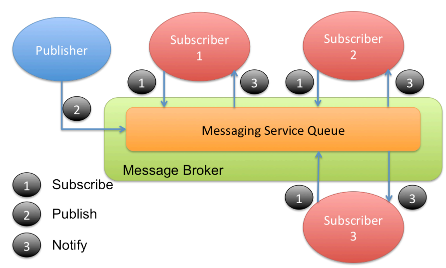

Figure 6. MOM's message mechanism

MOMs provide important features when designing collaborative RLabs:

- Asynchronism in the delivery of the response,
- Robustness and availability,
- Guarantees of scheduling that ensure that messages are caught in the order they were emitted.

On the instrument application side, the message distributed by the message broker is interpreted and the corresponding hardware function is sent to the device.

On the client side, depending on the activated widget, additional information can be embedded in the multimedia content as shown in Figure 7.

Figure 7. Additional information inserted in the scene

4.2 A proposal for enforcing group awareness in multimedia applications

Proposing a middleware that supports collaboration is necessary but yet not efficient for users to sense the group awareness. In this subsection we present how group awareness is supported in our system. This work is the following-up of [17], while this previous work did not rely on multimedia but on a stand-alone Java application. Group awareness functionalities are a chat and VoIP tool for communication and changing colored based widgets for seeing "who is doing what".

For the VoIP tool, the FMOD libraries [33] combined with the ffmpeg libraries [34] are used to realize the acquisition of the voice of users in the client part, packetized and stream them to the application server. The application server then multiplexes the digitalized voice within the BIFS scene, which is delivered to the end-user. A full communication tool is not implemented here because acquiring and streaming "full-time" audio data for each user would require too much CPU and bandwidth capabilities, especially on mobile devices. We preferred to implement a "talky-walky" tool, which offers voice communication without continuously acquire and stream data. On the client side, this "talky-walky" tool is designed as a module for the Osmo4 player.

The BIFS-Command protocol enables streaming scene changes like inserting scenes or objects, deleting objects, etc. Then in order to provide both the chat tool and the changing colored widgets, our system needs to implement the BIFS-Command. This part is currently under development.

5. CONCLUSION AND FUTURE WORKS

In this paper, we presented the interests of using both Mixed Reality systems and collaboration in RLabs for educational purposes. Mixed Reality systems can enhance the comprehension of the manipulated remote device since real objects are presented to the end-user with optional additional information (virtual or real). Collaboration applied to distance learning can help students achieve more complex objectives since it allows communication, between both students and teachers.

We presented a multimedia user interface based on MPEG-4 BIFS, which allows building a Mixed Reality system for RLabs. We also presented a middleware architecture based on MOM, which support collaboration for RLabs. We discussed the possibilities of improving the group awareness of the proposed system using BIFS-Command protocol to add a chat tool and color-based widgets.

Our future works will focus on proof testing this collaborative and interactive multimedia middleware for different RLabs, and even different use case. Eventually, the mixed reality middleware should be agnostic to the remote device. This middleware is released as the project "Open Collaborative Environment for the Leverage of Online Instrumentation" (OCELOT), and open source software under the GNU Lesser Public General License, hosted by the OW2 consortium.

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