State of the Art About Remote Laboratories Paradigms – Foundations of Ongoing Mutations

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***Abstract*—In this paper, we provide a literature review of modern remote laboratories. According to this review, we explain why remote laboratories are at a technological crossroad, whereas they were slugging for a decade. From various observations based on our review, we try to identify possible evolutions for the next generation of remote laboratories.**

***Index Terms*—Architectures, Computer Collaborative Learning, Distance Learning, Distributed, Interoperability, Learning Management Systems, Literature Review, Process Control, Remote Laboratories .**

I. INTRODUCTION

In this paper we focus on remote control of appliances, especially dedicated solutions for education. Such an approach is usually known as remote laboratories, and tries to address the issue of remote hands-on approaches within distance learning.

Although remote laboratories platforms are getting more mature, they are still built without the will to be reused. Of course, we strongly believed in the fact that software must be developed in order to be definitely used in practice. Nonetheless, dedicated software developments suggest to have searched for existing solution previously, in vain. On the contrary, every remote laboratory project implements its own software architecture, but each one obviously lack of a comparison among existing architectures. Therefore it is not easy to assess the future directions followed by our research community.

The goal of this paper is to identify the characteristics of the next generation of remote laboratories, on the various solutions observed in a literature review. This paper is based on our experiences in this domain and our perceptions of remote laboratories, therefore it does not try to be an ultimate reference, but to participate to the debate on challenges ahead remote laboratories.

The paper is organized as follows. Section 2 presents a literature review on remote laboratories for the last decade.

Subsequently, observations made from this review lead section 3 to expose possible challenges ahead remote laboratories in the future. Section 4 concludes.

II. CONTEXT AND LITERATURE REVIEW

A. Context

The acquisition of high technological devices can sometimes present a low ratio between its use in reality and its disbursement. It also implies a qualified technician with sufficient amount of skills in order to deal with the entire set of laboratory equipments.

As a consequence, the remote control of devices can be seen as a leverage for the frequency of use of laboratories devices. Creating a remote access allows to create networks of laboratories, industrials and schools interested in the same expensive equipment. Opportunities can occur for those actors to buy a shared workbench that we could not afford otherwise. This economical aspect is historically fundamental to understand the evolution of remote laboratories.

Although this explanation is still a reality, there is no denying that modern expectations aim at going some steps further. Not only remote laboratories can avoid an expensive purchase, but they also present:

- *security* of users, data and devices,
- *observability* if the session needs to be watch by a lot of people,
- *dangerousness* if the experimentation to conduct is dangerous,
- *accessibility* for handicapped people,
- *availability* because remote laboratories allows geographical and temporal cutting up.

B. Foundations of the review

In order to appreciate the future of remote laboratories, we will go through a literature review on what has already been achieved those past ten years. This study covers 42 publications ([1, 2, 3, 4, 5, 6, 22, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, 21, 23, 26, 27, 28, 30, 29, 32, 33, 35, 38, 39, 40, 41, 42, 44, 45, 46, 47, 48, 49, 50]) and focus on the deployment of remote laboratories in real conditions. We carefully tried to avoid duplicating references about the same project, and we limited ourselves on the last decade, while promoting the most recent papers. As a consequence, only 8 out of 42 items in our bibliography are prior 2001 (figure 1).

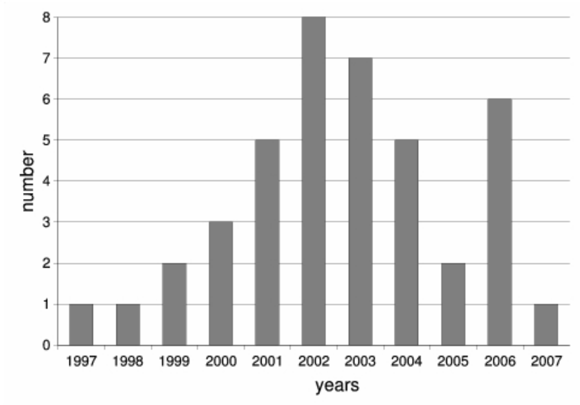


Figure 1. Repartition by year the items in our review

C. Remote laboratories back to the front

From figure 1, we can notice that there is a peak around 2002/2003, which corresponds to a top period of activity in the scientific community. While the amount of publications decreased after 2003, it has increased again in 2006. This tends to be a sign of a revival of interest in remote laboratories. Moreover, the fact that literature reviews on the subject are a new matter for this domain [36] also shows this subject is not fully covered, and that scientists are beginning to organize the existing.

Those two observations lead us to think that remote laboratories are under a strong current of evolution. Based on those remarks, we will study, in the next section, what are the characteristics of remote laboratories in our review.

D. Classification per scientific field

Remote laboratories target a large range of devices, from different scientific areas. Because the devices belong to several scientific domains, researchers who are building remote laboratories work in different scientific communities (figure 2).

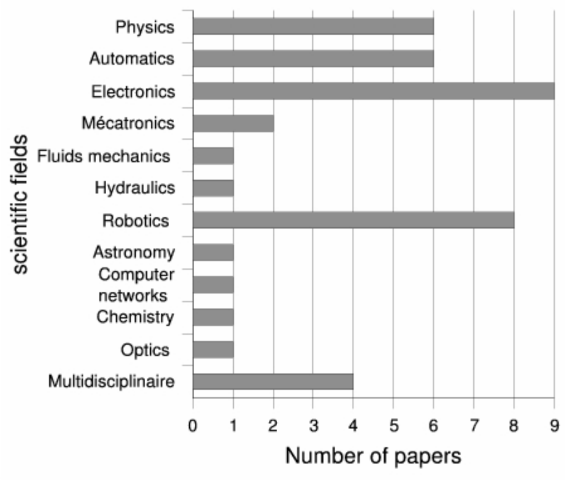


Figure 2. Repartition by scientific area of the device remotely handled.

This means that remote laboratories are not restricted to a single educational topic, but are being used for most devices that can be controlled using a computer.

Inverted pendulums are the most widespread devices used in remote laboratories [12, 49, 41, 18]. This can be explained by the need for engineering schools and universities to promote hands-on exercises in order to deliver an enhanced learning experience to their students. On top of that, there is no denying that it is more difficult to provide remote hands-on sessions in chemistry or astronomy rather than in robotics for example.

E. Classification per technology used

1) Software architectures

Remote laboratories architects belong to different scientific fields, but are they using the same technologies to perform remote hands-on approaches ?

Actually, all publications dealing with remote laboratories we read are based on the same software architecture paradigm. The common software architecture is composed as follows: the device itself, a local computer connected to the device, which plays the role of a gateway between the device and the remote computer of the user, and the associated middleware, through which information is exchanged between the local and the remote computers. There is, of course, a reason why this architecture is so widespread. In fact, most devices must be locally handled by a computer in order to be remotely controlled over the Internet.

There is no denying that some appliances directly provide an Internet connection, but this is only because they embed a modern operating system inside the device, which therefore does not require a dedicated local computer; yet it does not make much difference.

As a result, remote laboratories architects have no choice but to build a middleware allowing remote clients to connect to the local computer that handles the device. That is the reason why the first remote laboratories were using software solutions such a VNC[1], as it provided them the remote control over the local computer connected to the corresponding device. Nonetheless, those solutions were given up as they lack security and they require a lot of bandwidth.

2) Programming languages for the link between device and local computer

Three major classes emerge for this criteria:

- dedicated proprietary software. The two most cited are Matlab (with simulink) and LabView (with datasocket). It represents 10 publications out of 42 for our review. From the authors themselves, such technologies prevent reusability of existing hands-on approaches, and require additional skills (since the architect must master the dedicated proprietary software).
- programming language which is not common in software architecture for remote laboratories. We report here some use of Visual basic or even Python programming language [13] for instance.
- the remaining category bring together papers where no distinct technology is clearly identified. It is quite a large category as 17 out of 42 publications did not explicitly mention the technology used for connecting the device to the local computer.

It is rather difficult to establish an accurate taxonomy of the technologies used. It can be explained by the fact that the device usually proposes only one way to be connected

[1] Virtual Network Computing

to a computer, using a proprietary API[2] . Therefore this limits the choice of technology for the remote laboratory designer. Even if standards such as VISA[3] or IVI[4] aim at closing that gap, it is not a silver bullet yet as devices are heterogeneous and legacy systems do not support such standards.

3) Programming languages for the link between local and remote computers

The link between local and remote computers is a subject of fewer issues, as it is easier to identify the technologies involved for this link in our panel (figure 3). The sum of annotated publications is 60 here. In fact, some architectures marry different technologies to fit their needs. For example, [28] couple Java and VRML (Virtual Reality Markup Language), or [8] uses Java with C++ and CORBA in the same architecture. Such software solutions go to the credit of each technologies that compose it, and that leads to a total above 42, as some publications serve several technologies.[5]).

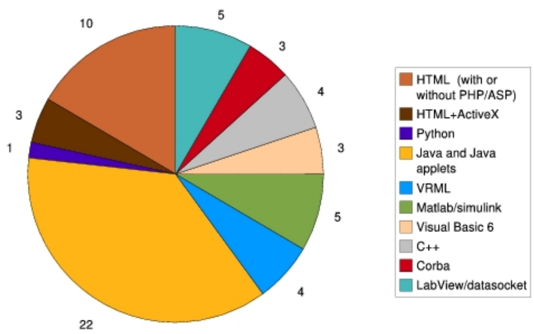


Figure 3. Repartition by technologies used, for the middleware and the graphic user interface.

Besides the domination of proprietary software (LabView and MatLab) and Java programming language, the remaining technologies are heterogeneous. The multitude of different technologies used implies that few efforts are made towards the reusability of existing remote laboratories performed elsewhere. Consequently, this means that we are reinventing the wheel each time we want to expose an appliance online. In the same way, the few projects, that report software developments for new hands-on approaches based on a previous one, emphasis a heavy need of re-engineering to fit the mould.

4) Summary

Existing solutions rely on the same software architecture. Nevertheless, the technologies used vary a lot from one remote laboratory to another, which prevent reusability and interoperability for remote laboratories.

[2] Application Programming Interface

[3] Virtual Instrument Software Architecture

[4] Interchangeable Virtual Instruments

[5] Please note the use of the following acronyms: HTML (HyperText Markup Langage), CORBA (Common Object Request Broker Architecture), ASP (Active Server Pages), PHP (PHP Hypertext Preprocessor)

III. CHALLENGES AHEAD

We will now try to infer, from the previous observations, improvements that can be made in remote laboratories. This is something important to identify since universities and engineering schools are expecting real solutions today, for the distance learning they will propose tomorrow to their students.

A. Remote laboratories lack reusability

In the literature review, several papers underline that a remote laboratory is very expensive. Indeed, it requires a large amount of time, money and skills. Unfortunately, software developments for remote laboratories tend to be dedicated, and are not supposed to be reused for other similar hands-on approaches.

Whereas the development of remote laboratories suffers from the lack of reusability for the software they rely on, there is an exponential growth of demands for remote hands-on approaches. That is the reason why we think that some formalization on the software architecture is needed, so that more remote laboratories could be created at a lower cost.

Propositions partially covers this need [25]. Nonetheless, a single point of view cannot reflect all the possibilities, and there is definitely more to gather in this area in order to reach a certain degree of maturity of the underlying software. A major issue is to propose solutions that decrease the time of integration, but also the amount of skill required in order to do it.

B. Interoperability in software implementation

1) Localization transparency

Interoperability of remote laboratories architectures is also a strong possibility for the future.

In practice, local laboratories can be composed of several devices, that create an experimental workbench when connected together. As a matter of fact, today's remote laboratories only address the remote control of one device at a time. In order to provide complete workbenches to the students, remote laboratories need to connect different devices. In other words, this implies to create a workbench which is geographically distributed among different information systems. Such an aggregated appliance can be composed of a temperature probe, a motor ... These do not consist of a subject for a remote laboratory by themselves, but they compose an experimental workbench when meshed together. By extension, such workbenches are not meant to be bound in the same room: they can be distributed among different places (which implies in different information systems). This proposal is close to issues belonging to machine to machine (M2M) field of interest, as it requires to embed the software in the devices. It has to be noticed that some works emphasis how interoperability can be reached in remote laboratories using web services [47]. Figure 3 presented earlier stressed that the technologies involved in remote laboratories platforms are heterogeneous. That is another reason why interoperability is mandatory for the leverage of remote laboratories: it would allow to connect already existing systems together.

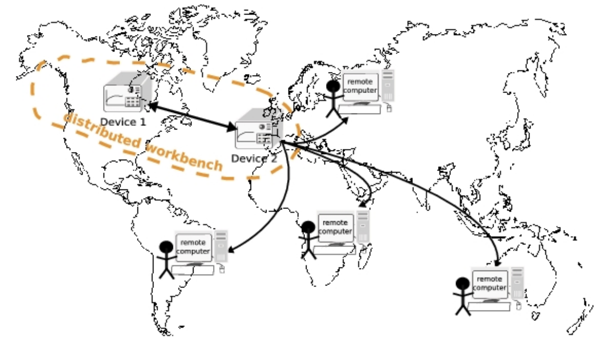


Figure 4. Repartition by technologies used, for the middleware and the graphic user interface.

If the appropriate glue is provided, it would be possible to assemble a distributed workbench that uses components from different places, and the learners are not supposed to know where the device they are actually handling is. We named this possibility the ”localization transparency of devices” (an illustration is provided at figure 4).

An even more exciting possibility would be to begin a hands-on session on a first distributed workbench, and to finish it on another if the first one is no longer available (reservation pending, breakdown, . . .). The original idea is that the transition from one workbench to another would be transparent for the users.

2) Remote laboratories service discovery

Localization transparency for learners requires the knowledge of the location of the instruments available around the world by the remote laboratories platforms. Moreover, it implies to know who is authorized to use the hosted appliances, and thus leading to the creation of the subsequent circle of trust for people and institution allowed to share hands-on approaches with one another. This suggests to discover and store remote laboratories properties in a directory, in order to see them as potential devices for distributed workbenches. Remote laboratories will benefit from a service discovery, as it would ease the discovery of existing and available hands-on approaches, when creating a brand new remote laboratory (to prevent reinventing the wheel) or when building a distributing workbench (to prevent unnecessary investments).

The major difficulty in such a compelling forecast, resides in the enlargement of scientific issues for the remote laboratories research community, while it already suffers from the large spectrum of scientific area it is struggling with.

3) Substitution of devices

The geographical distribution of actors lead to a tight management of available resources. Whereas it is rather easy to use a reservation planing in a laboratory, it is more difficult to manage reservation when the appliances are available through the Internet. In implies to identify all participating devices, who is supposed to use them and when, is their any preemptive clearance, ... Such reflexions lead to resource planning issues.

However, an interesting feature for remote laboratories is the localization transparency exposed earlier (III.B.1). If users do not know where the device they are currently using is, it allows:

- to switch between appliances in case of network failure device-side (roll-back on another distant device without the user being noticed),
- to use optimize usage of appliances if the session is started on a first appliance and finished on another one that is similar (see illustration at figure 5).

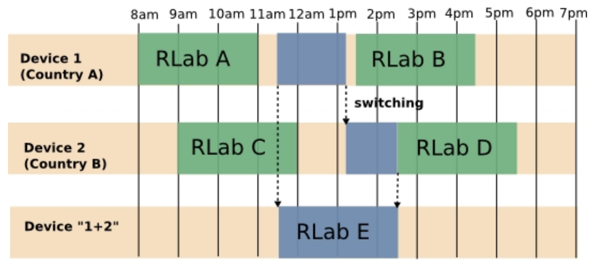


Figure 5. Switching from a device to another for availability on failure

Such a paradigm can be easily implemented by using logging. In order to illustrate this thought, an example of one of our remote laboratories presenting logging for late incomers in a collaborative session is available online[6] (a late incomer must replay the actions he missed in the current session, just like a device switching would need the device to replay the action made by the previous operated one).

C. Computer Supported Collaborative Learning applied to remote laboratories.

1) Make remote laboratories catch up with today's learning theories.

A widespread learning theory today is constructivism, which emerged from cognitive science. Constructivism is usually opposed to behaviorism [31]. Behaviorism focuses on passive transfer of knowledge between teachers and learners. It also tries to interpret knowledge acquisition as a settlement of a permanent change in learner's behavior, face to a given problem. On the opposite, constructivism try to make students learn from their own observations, using discussions with the teacher but also with their peers (sometimes referred as social-constructivism).

This way of teaching[7] belongs to Computer Supported Collaborative Learning (henceforth CSCL). The widely accepted definition of CSCL is:

”CSCL is a field of study centrally concerned with meaning and the practices of meaning-making in the context of joint activity, and the ways in which these practices are mediated through designed artifacts.” [34].

Such a definition had already been extended in order to stress out that CSCL is bound to learning theories:

”In their penultimate sentence, Hakkarainen, Lipponen, and Järvelä correctly point out that CSCL researchers have a complex challenge because the educational use of new information/communication technologies is inextricably bound up with new pedagogical and cognitive practices of learning and instruction.” [43]

We definitely think that this reflexion should not be limited to lectures or exercises, but extended to remote laboratories. When designing a remote laboratory, universities or engineering schools aim at bringing hands-on approaches right at the door of the students. A drawback remains in the social isolation caused by such an approach. Students appreciate to break that barrier by

6 http://diom.istase.fr/satin/einst/einst_demo.avi
7 shall we say “way of learning” ?

taking advantage of communication tools. Actually, social networks favor their learning process [37].

The key observation is the following: whereas modern learning theories promote collaboration among students, why existing remote laboratory only propose a single access to the remote laboratory at the same time ?

The idea of marrying computer supported collaborative learning and remote laboratories can be situated in academic researches at the crossroad of several domains (figure 6).

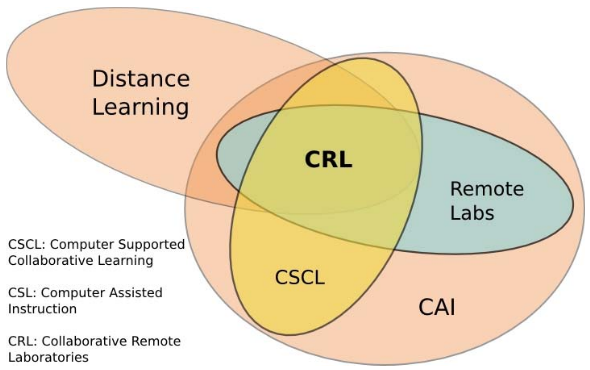
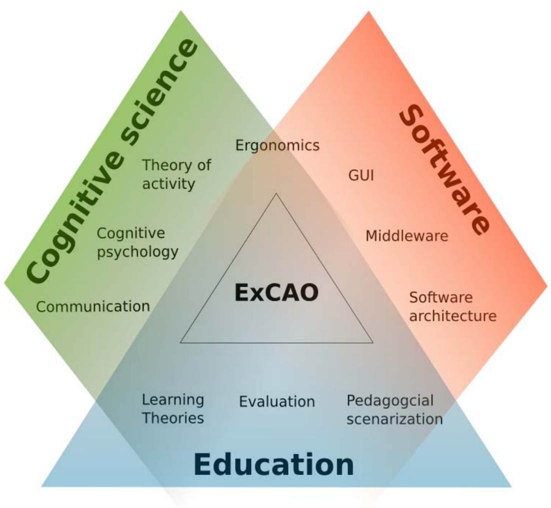


Figure 6. Collaborative Remote Laboratories

Because Collaborative Remote Laboratories lie at the intersection of several scopes, it is highly a multidisciplinary subject that is debated within that scientific community. Building a collaborative remote laboratory requires knowledge in:

- cognitive science in order to make remote environment catch up with modern learning theories,
- education for the integration of remote laboratories activities in the students learning process,
- software engineering so that the imagined model can be implemented.

This multidisciplinary face of CRL is illustrated at figure 7.



Collaborative Remote Laboratories

Of course, injecting cooperation, or even collaboration[8], into remote laboratories is not easy. There is still a long way to go to reach real synchronous collaborative learning within remote laboratories[9],[10] .

2) Communication in our litterature review

Base on the same set of papers (see II.B), only 12 papers deals with CRL on different levels. Figure 8 shows the various tools used for communicating.

It is interesting to notice that instant messaging is not the most used media, but voice over IP. Other media are spread among white boards and video conferencing systems.

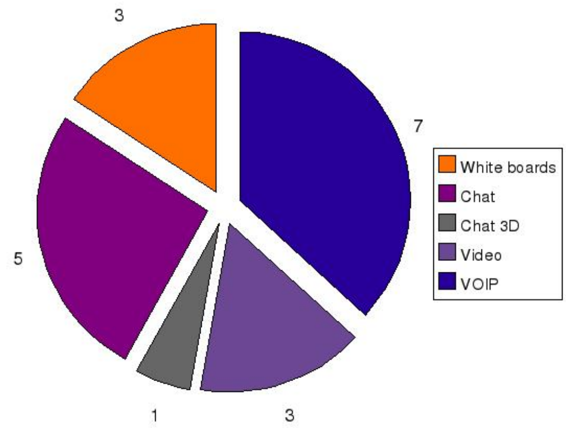


Figure 7. Communication tools in the review

D. Convergence with Learning Management Systems

Distance learning is not a new matter of interest. Researches are under progress for a long time in order to deliver:

- the best learning content exposition to the students,
- the best learning content reusability and production facilities to the teachers.

The first issue lead to the creation of Learning Management Systems (LMS) and the second to the creation of Learning Content Management Systems (LCMS). LMS are hence web sites held responsible for exposing pedagogical electronic materials to the students. As a complement, LCMS are mostly authorizing tools back ends used by teachers in order to create and reuse those pedagogical contents.

Nonetheless, as for now, the pedagogical material ranges from lectures, online exercises and also homeworks. Whereas LMS track actions made by every single student in order to dress the evolution of the learner (so that he could be granted the more suitable help and advises), it has never been coupled with remote laboratories. Because of that, no track can be kept of the

[8] difference in cooperation and collaboration regarding Dillenbourg's classification: "In cooperation, partners split the work, solve sub-tasks individually and then assemble the partial results into the final output. In collaboration, partners do the work "together"" [17].

[9] http://ra.fernuni-hagen.de/CRL2007/

[10] http://diom.istase.fr/satin/einst/collaborativeness.html

experiences conducted by the students. As a consequence, there are no follow-up of learners' evolutions by the teacher, neither evaluations of their online activities. The gap between remote laboratories and LMS has to be closed for a better tutoring of the students [24].

IV. CONCLUSION

In this paper, we provided a number of clues in order to dress a figure of future generation of remote laboratories.

From our literature review and our own experience in that scientific domain, we expose four major issues for the leverage of remote laboratories. These are reusability, interoperability, collaborativeness and convergence with Learning Management Systems. Those functionalities are pieces of a large picture, but they can be handled independently. Some already present the beginning of an answer, which is provided here through our bibliography, others are a brand new topics.

Future research directions are merely called to address some of these issues. We see in each of these paths a serious possibility to blow away a lot of problems of remote laboratories, thereby providing a richer learning experience to the students, but also to the teachers.

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