

# From online experiments to smart devices

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**Abstract**—Online experiments have been available for more than a decade. The integration of online experiments to collaborative environments is more recent. The wealth of client application/environments, the versatility of possible interaction protocols/technologies and the needs for more autonomous actions impels the evolution of online experiments to the smart device concept. This paper reviews the evolution of an electrical drive experiment and presented the requirement for turning online experiment into smart devices.

**Index Terms**—Agent, collaborative environment, online experiment, smart device.

## I. INTRODUCTION

Online experiments are typically used by brokers to provide remote experimentation to distant users. For example, the access to an online experiment during a live demonstration in classroom. Online experiments are often used in control, robotic and mechatronic education for illustrating theoretical principles and deployment methodologies. As example, the different control design and implementation steps taught to students in control courses (system identification, controller design, real-time control, performance validation, etc.) can be efficiently carried out remotely on mechatronic systems as they exhibit visually observable dynamical behaviors.

Remote experimentation solutions are based on a client-server approach where the server is connected to the physical equipment and the client application is connect to the server via the Internet. The user interface can be of various forms but it is generally proposed through a web browser. The objective of a remote experimentation solution is to make the student interaction with the distant system as close as possible as the actual work on the real equipment. Collaborative environments are proposed to support the distant user learning process. These environments integrate various services to streamline the user experience and to help the user environment appropriation. To provide a tight integration of remote equipments within collaborative environments specific cares are to be taken for the interface, the functions and the communication. This customization leads to a very specific solution that is difficult or impossible to integrate in another collaborative environment. The concepts of smart devices are used to expend the online experiment scheme such that the proposed solution is adaptive, autonomous, as envisioned in the Internet of Things realm.

This paper is organized as follow: the physical equipment locally controlled is first presented. Then in section III, a communication component is added to permit remote access. The integration of online experiments into collaborative environments is presented in Section IV. Section V presents the smart device concept applied to online experiments and its requirement.

## II. PHYSICAL EQUIPMENT AND LOCAL ACCESS

The physical equipments remotely controlled are often mechatronic devices with moving parts as they exhibit visually observable dynamical behaviors. For example the laboratory-scale electrical drive (Fig. 1) is used in many textbooks and courses to illustrate automatic control theory. This setup consists of a DC motor equipped with a digital encoder. This motor drives a brass disk acting as the load. The angular position is measured with the help of a digital encoder connected to the motor axle. Along the same axle, an enlarged rotating disk permits an easy visualization of the motion. This enlarged disk and the rotating load motion are captured by a video camera. The whole hardware has been designed such as it is fully controllable from a connected computer. Similarly, the hardware state can be diagnosed from the connected computer. For example, beside the standard motor control, the main power can be switched *on* and *off* from the connected computer. Likewise, in addition to the required disk position and speed measurements, diagnostic signals informing about the power status can be read from the connected computer.

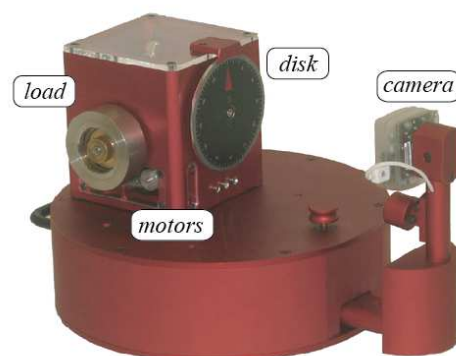


Figure 1. Laboratory-scale electrical drive.

Physical equipments are generally controlled by an external computer connected via data acquisition board

(DAQ). Depending on its complexity and computational resource requirement, the control of the equipment can also be performed via an on-board micro-controller. This later solution offers less flexibility than the former one.

The considered physical equipment is used by students to apply control theory and learn controller design. For example, the experimentation protocol consists in choosing the right set of parameters to position the load or to impose a rotating speed according to some specifications. The PID controller is implemented as a real-time task that communicate with both the physical equipment and the graphical user interface (GUI) [1].

With the help of the graphical user interface, the users can experience the effect of the various controller parameters and see their effects on the physical equipment. Figure 2 shows the user interface of the application that locally controls the laboratory-scale electrical drive. It is written in LabVIEW [2]. The upper part displays the acquired measurement in a scope area. The bottom part let the user modify the controller parameters and the reference signal.

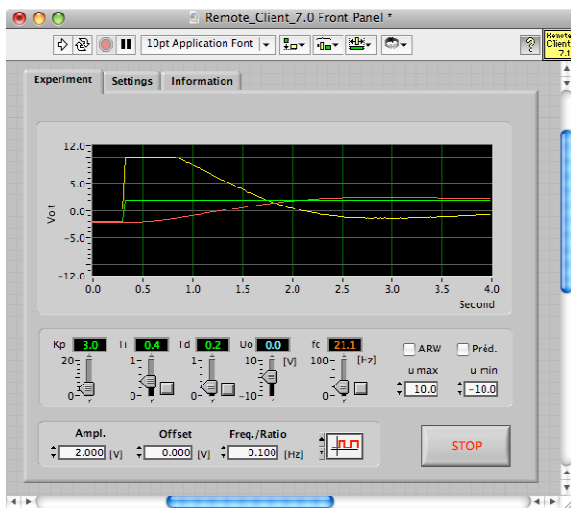


Figure 2. Local control of the electrical drive

### III. FROM LOCAL TO REMOTE ACCESS

Providing remote access to physical equipments controlled locally by a dedicated computer is fairly straightforward assuming that the computer is connected to the Internet. Depending on the required degree of interaction between the distant user and the physical equipment both turnkey and customized solutions can be envisioned.

#### A. Turnkey Solutions

Nowadays many turnkey solutions are proposed by commercial applications. The quickest solution is the use application that enable the sharing a distant computer screen (VNC, Remote Desktop, Timbuktu, etc.). While

easy to implement this solution generally suffers a high bandwidth usage. Another drawback is that the user cannot see the physical equipment. Visualizing the controlled equipment is considered a key feature to differentiate simulation from real experimentation. Also directly accessing the remote server may grant too much right to the distant user permitting to act on aspect he/she not supposed to.

Another kind of turnkey solution relies on specific applications that are able to generate a remote view of the local GUI, this view is generally displayed in a web browser. The server application can either generates a dynamic web page or required specific client applications (LabVIEW remote panel). Both solutions can be enabled with only a few mouse clicks but suffer the same visualization drawback as the screen sharing solution. While a video stream coming from an IP camera may be embedded to the web page containing the deported local view, the information synchronization between the sources of information is added to the potential bandwidth problem.

#### B. Custom solutions

Custom solutions permit a finer control of all the aspects involved in remote experimentation, this at the cost of additional developments to create the client application and to add the network communication layer to the local [3].

Various technologies can be used to implement the client application. Web based technologies (Java, Flash, Silverlight, QuickTime, ActiveX) are the most widely used since they are ubiquitous and often pre-installed within the web browser.

Depending on the client application requirements, the chosen technology should provide the following features:

- display GUI elements, (button, etc)
- ability to get user actions/events (mouse click)
- support communication protocol (TCP,UDP)
- timing synchronization (threads, timers)

As of today Java is the most versatile option that permits the finest control of the client application. A solution that only uses standard web technologies (CSS, Ajax) without the help of plug-ins is possible provided that the web transmission protocol (HTTP/TCP) does not constrains the envisioned communication. Java provides the full control over the above features necessary to implement an advanced remote experimentation client. It especially permits to implement alternate transmission protocol (UDP) and allows a tight synchronization between the various flow of information (video, data).

Figure 3 presents a java applet that enable to control the distant laboratory-scale electrical drive. The provided interface permits the user to change the various parameters of the PID controller and see its effects in real-time via the oscilloscope area and the video feedback.

The main adjunctions to the distant application that locally control the physical equipment (Fig 2) are the video acquisition and transmission layer that allows remote clients to communicate with the online experiment. With these additions the local application becomes a server application. Additional requirements and best practices are presented in [4].



Figure 3. the client application implemented as a java applet

#### IV. WEB 2.0 SOCIAL SOFTWARE FOR COLLABORATIVE LEARNING AND INTERACTION WITH ONLINE EXPERIMENTS

The additional flexibility provided by remote experimentations is highly appreciate and permits distant users to manage the remote experimentation sessions at their own pace and from their own location [5]. One drawback is that the learning modalities often found on campus should be emulated. Collaborative learning support should be provided, as well as some forms of tutoring and assistance. Collaborative environments such as *emersion* [6] and [7] support the activities with online experiments by providing additional services such as shared spaces for saving measurements, discussion forums, live support, etc. The online experiments need to be specifically adapted to maximize the benefits offered by collaborative environments. Not only the client applications needs to be adapted, but also the server application. For example authentication is often required by collaborative environments, thus the client and/or the server applications must be adapted to support authentication. Similarly, saving data in a shared space required specific protocols that may not be presents initially. When possible, some or all the required adaptations could be implemented by a proxy application that bridges both worlds. This translation is often done at the cost of performances. This proxy application bridging mechanism can be generalized to concept of *agent* that works on the behalf of users or in the presented case on the behalf of the online experiment server [8].

Figure 4 shows the remote experimentation agent working on the behalf of both the user *Chris* and the

equipment *RT-201* within the *elogbook* {ref]} collaborative environment. The measurements acquired with the help of the agent (center of Fig. 4) are directly saved within the shared space (right column of Fig. 4) and are be visible by the members (left column of Fig. 4) of the given activity (top of Fig. 4). The agent has been granted the right to directly save measurements in the shared space after it authenticated using the provided *elogbook* mechanism.



Figure 4. Remote experimentation agent in *elogbook*

The original online experiment does not know about the *elogbook* it is only aware of the *elogbook* agent. Using the agent concepts, the online experiment could be interfaced by various collaborative environments but would require a dedicated agent for each new environment. To alleviate this restriction and to permit “any” clients to access the online experiment, *all* the agents should be hosted at the server side. While this is not directly feasible since *all agents* are not known before hand, the structure to support multiple types of connections, protocols, modes of operation and interfaces in an autonomous and self-contained way should be implemented in the server. A server connected to physical equipment with the above capabilities and the ability to interact autonomously with other machines is called a smart device.

#### V. SMART DEVICES

Smart devices can be described as devices that have some autonomy to perform actions. Theses devices often have sensors and/or actuators and support communication with other devices. The interconnection of smart devices and other intelligent objects sketches the Internet of Things.

The Internet of Things is a metaphor that envision the connection of all existing objects for the universality of communication processes, for the integration of any kind of digital data and content, for the unique identification of real or virtual objects and for architectures that provide the communicative glue among these components [9].

Thomson suggested that smart devices needs some or all of the following capabilities: *i*) communications, *ii*) sensing and actuating, *iii*) reasoning and learning, *iv*) identity and kind, *v*) memory and status tracking [10].

### A. Requirements for turning online equipment into smart devices

Physically, the considered smart device is made of the adjunction of the controlling computer -the server-connected, on one side to the physical equipment and, on the other side to the Internet. The capabilities required for smart devices controlling physical equipment are twofold.

The first set of requirements is related to the physical equipment. The physical equipment should be *identifiable* to define what kind of equipment is connected. Also the equipment should be fully *controllable* and *diagnosticable* by the controlling computer. The full controllability of the physical equipment may not be exposed to the outside world due to security reasons. Controllability also implies that it is always possible to place the equipment in a known state. Other requirements such as *reliability* and *maintainability* should also be considered.

The second set of requirements is related to the interaction of the controlling computer and the outside world. This interaction implies that first the computer is *connected* to the Internet and capable of *understanding* incoming *requests* and to reply to them. It should also be capable of some *autonomy* to report for example alarms or its status. *Security* and *authentication* must also be provided. It should not be possible to temper with the physical equipment from the outside world. This is also true for the hosting computer and the engaged communications. In the considered case, the server may propose a graphical user interface to interact with the server.

The communication requirements suggest that the server is able to talk any low level protocols such as TCP or UDP to get the requests and send replies, but also high level protocols or technologies such as HTTP, XML, REST, FTP, XML-RPC, WSDL, POP, MAIL, RSS, etc. to understand the requests. It is definitely not possible to implement all possible protocols, but the structure to handle new protocols should be in place to minimize the development effort. The next section presents the chosen set of protocols to be implemented and the rationale behind these choices.

### B. Smart device example

The proposed smart device is an extension of the online experimentation server described in section II. Initially, the sole task of the server was to control the physical equipment locally. Then a communication component was added to send measurements and to receive parameters from a home-built application using the UDP protocol. The access from a web browser required the writing of a Java applet and the associated server modifications. The integration of remote experimentations in collaborative environment implies the adjunction of new functionalities and new protocols and the use of the agent concepts. The global management of the available resources was also required

to dynamically spread the load among the available online equipments leading to additional modifications at the server side.

The current server is a smart device with an evolving structure that guaranty compatibilities with existing solutions while streamline the addition of new ones. On the physical equipment side, the server only expose a limited set of actions that are validated prior to its application on the physical device. Similarly the server only provides aggregated information regarding the physical equipment to the outside world.

The former client applications can interact with the smart device by sending UDP packets that contains parameters for the implemented controller. As a reply, client applications receive two UDP streams, one for the video feed and the other one for the measurements feed.

The current collaborative environments (*emersion* and *elogbook*) do not have specific interface to the smart device. This interface is provided by the smart device in the form of a Java applet. The smart device is also able to handle the user credential to directly interact with the collaborative environment. This interface can also be used independently by web browsers without link to collaborative environment. The interface functionalities will be adapted accordingly, for example user would only be able to save measurements on the user desktop and not in the collaborative environment shared space.

In addition, the sever features awareness information to the outside world. These information cover, among other information, the sever status, connections statistics and usage statistic. Client applications can get the above awareness information through various channels. For example by opening a raw TCP connection to the server. Alternatively the client application can use a provided web service using the XML-RPC protocol. An RSS feed with the above information is also provided. Last but not least, it is possible to send an email to the server to get the above information. Interfacing programs via email is not new but has been forgotten over the years. However email support provides a simple and unobtrusive interface that is generally ubiquitously available [11].

The mechanism implement for the awareness information is also available for the other streams of information (parameters, measurements and video).

The above information exchange relies on a request-answer mechanism. The smart device is also able to pull information to given recipients. In case of self-diagnosed malfunctions the server can send an email and an SMS. A typical malfunction is the physical equipment main switch set to OFF. The power status of the equipment is regularly checked and appropriate actions are taken once discovered.

The collaborative environment may deal with many devices. An auxiliary application dynamically redirects the collaborative environment agents to available devices. The smart device informs this auxiliary application about its status. If the auxiliary application is unavailable and if the smart device already in use, the smart device is able to re-route the agent requests to neighbor equipments .

## VI. CONCLUSIONS

This paper presents the evolution of an electrical drive that is initially controller locally by a computer. Various components are added to permit a remote access. The online experiment is then integrated to collaborative environment. The concept of agents is used to permit the online experiment to work on the behalf of the user within the collaborative environment. The performed actions can be controlled when the user decided to save measurements at a given time or autonomous when sending an alarm. If the agent performing autonomous task is part of the server, the resulting tandem can be called a smart device. The requirements for turning online equipment into smart device are then presented. An emphasis is placed on the communication side that should accommodate to many technologies and protocols. Finally an example depicts the interaction between a smart device and various client applications.

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