Abstract—This paper presents the conceptual design of a remote experimentation laboratory - a Weblab - for a thermal process plant, based on a systematic model for its planning and development. The adopted approach comprises three layers (physical system, hardware and software), being prescribed the following steps: definition of requirements; system technical specification; conceptual synthesis; analysis, simulation and dimensioning; detailing and documentation; integration and start up. The conceptual solution includes the thermal process plant remote configuration to allow the variation of the experimental setup parameters, offering three variants of control engineering exercises. The presented results provide the basis for the next stage of the Weblab development.

Index Terms — Weblab, Conceptual Design, Thermal Process Plant.

I. INTRODUCTION

The recent evolution of information and communication technologies made real the possibility of development of new educational processes, with remarkable benefits for students in terms of the distance learning modality. Weblab, or remotely operated laboratory through the Internet, is a system concept that makes possible the use of laboratories in long distance education and, as well, in research cooperation. The use of such systems permits the extension of the use of laboratories located in developed centers to places where the essential infrastructure is not found. Moreover, Weblabs can assist in collaborative research activities, in the execution of real time experiments, interactively and safely, by the proper addition of complimentary devices, hardware, software and networking resources. As references, [1], [2] and [3] can be cited as elaborated projects of Weblabs.

The development of Weblab projects, as is the case of most technical systems, is a better conducted process if systematized through a design methodology. A very applicable methodological proposal includes the steps: task definition, conceptual design, preliminary design and detailed design, as proposed by [4]. Other authors from the engineering design academy have included further steps aiming the inclusion of more aspects related to product development processes, planning also the production, the market, the maintenance and obsolescence [5].

A methodology proposal specifically directed to the Weblab development process was presented by [6] as a tool to plan and implement Weblabs. The model is adapted from the concepts of [4], and considers the multidisciplinary aspects typically existent in this kind of system. This proposal was used in the present case study.

The conceptual stage of the present Weblab design case included the description of the system through a functional structure, with the definition of a global function and a sub-functions tree. The functional structure is helpful in the synthesis of alternative solutions, which are then compared in the process of selecting the most suitable one.

Therefore, the objective of this work was to develop the Weblab conceptual design for a didactic temperature process plant located at the Systems and Automation Laboratory of the Control and Automation Engineering Department of the Pontifical Catholic University of Parana (Brazil). The model 3504 LabVOLT Temperature Process Station, as shown in Fig. 1, is equipped with, an electric oven whose operation range varies between 20 and 200ºC.

This station contains an oven which can be manually operated as an on-off process, through a 24Vdc relay, or proportionally, through a 4 to 20mA input signal. The plant includes a compressed air input, used in the variation of the process dynamic characteristics, being the air release done by a manual valve. An adjustable damper located by the oven is also used to generate variable disturbances. The process instrumentation comprises a temperature transmitter based on a RTD sensor, a capilar bulb thermal switch and a J-type thermocouple. The plant configuration, equipment connections and signal control links will depend on the activity to be carried out and is performed using the proper connectors located on main control panel. Additional disturbances are introduced through the damper positioning.

The didactic activities (experiments) defined for the present Weblab project were: ON-OFF control; PID (proportional, integral, derivative) control; dynamic model identification of the thermal process. These activities include the following user actions: control signal variation; set-point adjustment; setting of the PID controller parameters; definition of the operation mode (open or closed loop).

Each configuration that must be set up for the remote operation of the didactic activities requires actions on the
real system of the temperature plant, which are carried out by specific actuators specially designed for these purposes.

2. DESIGN METHODOLOGY

The development of a Weblab is tightly connected to the context of the didactical experiments to be executed. Its complexity may vary from simple to sophisticated systems, according to the characteristics and requirements took into account in its implementation. The adopted systematic model, shown in Fig. 2, is composed by six phases, where the first two deal with the project planning. The following phases consider three distinct layers denominated physical system, hardware and software, characterizing an integrated engineering process.

![Figure 2. Stage of the Development Process. Mendes et al. (2010)](image)

In the reference model, several high level functions to be considered in Weblabs projects are pointed out. The following list is a subset of those functions which are pertinent in the present project:

- Positioning of sensors/actuators and interactive devices
- Supply energy
- Protect system components from potential hazards
- Condition and transmit input sensors signals
- Output and amplify actuation signals
- Position the visual take of the physical system
- Live reproduce and capture audio / video
- Exhibit system state locally and remotely
- Computational capacity to execute the local (server-side) software applications
- Initialize and configure WebLab systems
- Manage I/O signals with hardware components and interfaced instruments
- Run experiment(s) algorithm(s)
- Manage experiment data exhibition, storage and remote retrieval
- Process acquired data into meaningful information
- Manage local network and web data transfers
- Ensure safe operation

The main qualitative and technical / quantitative requirements for this project were brought from a previous work [7], which included the use of House of Quality matrix from the QFD (Quality Function Deployment) method. The QFD method, according to [8], seeks to guarantee the quality in all phases of the project development capturing the clients’ desires and needs (user requirements), transforming them into measurable technical requirements and then working out their priority order. Ten main user’s requirements to be considered along the system development were compiled, as shown in Table I.

| User’s Requirements                                    |
|-------------------------------------------------------|
| 1- Number (variety) of access devices                  |
| 2- Access from different operating system              |
| 3- User interaction with the equipment                 |
| 4- User immersion (reality perception)                 |
| 5- Monitor commands execution                          |
| 6- Easy to use and operate                            |
| 7- User management                                     |
| 8- Allow experimental data analysis                    |
| 9- User’s procedures orientation                       |
| 10- Safety standards                                   |

The functional synthesis method is used to map essential functions of a product, device or system under development, during its design problem solution approach. This process focuses in establishing the desired functionalities in a new project, and not in how to implement them [9].

Once defined the functional structure, one can build a morphological chart as a systematical research method to decide for the best solution approach. In the chart, through the combination of solutions for the partial functions, one can assemble global (or total) solutions for the entire system. Through this procedure, a bird-eye view of the solutions domain is achieved, making the creative process of synthesis more rational.

According to Cross [9], the method can be summarized in the application of the following steps: list the characteristics or essential functions to the product; list the ways by which the desired characteristics or functions can be reached; elaborate a table containing the possible solutions; identify the possible combinations of the partial solutions as to arrange global (total)conceptual solutions.

From the global conceptual alternatives assembled, one is to be elected for implementation. An evaluation of performances is carried out using an alternatives comparison and selection method, such as Pugh’s, which consists in an evaluation matrix used to rank the candidate solutions with weighted criteria. This ranking method assigns a performance score for each alternative solution being compared, to every criteria defined by the user. The score of each solution is stated by the project development team. The criteria set and their importance weights can be arbitrated or, conveniently, the user requirements and their already stated importances from the QFD step can be used, as in [10] and [11]. In this sense, the solution choice is indirectly driven by the project client’s opinions.

3. RESULTS

In order to better organize information, the functional structure was divided into three categories: User, Lab Server and Experiment.

From the initial global function stated as “Remotely operate the thermal process plant”, partial functions were
derived and classified in accordance with the belonging layer (hardware, software or physical system). The applicable solution principles to each partial function were organized in the morphological chart, as shown in Table II.

### TABLE II.
INTEGRATED FUNCTIONAL ANALYSIS AND MORPHOLOGICAL CHART

| Categories | Layer | Functions | 1 | 2 | 3 |
|------------|-------|-----------|---|---|---|
| User       | Hardware | I/O interface | Computer | CLP | Reviewer |
|            | Software | Application | Microcontroller | LabVIEW | LabVIEW |
|            |         | Experiment | Java | Java | Java |
| Lab server | Hardware | LabVIEW WebServer | PLC | PLC | PLC |
|            | Software | LabVIEW | LabVIEW | LabVIEW | LabVIEW |
|            |         | Supervision | PLC | PLC | PLC |
|            | Physical | Physical | PLC | PLC | PLC |
| Experiment | Hardware | Physical | PLC | PLC | PLC |
|            |         | Protective | PLC | PLC | PLC |
|            |         | Electrical | PLC | PLC | PLC |
|            |         | Device | PLC | PLC | PLC |
|            |         | Network | PLC | PLC | PLC |
|            |         | Experiment | PLC | PLC | PLC |

The collection of solution principles reflects the team experience and research, and may include elements and concepts extracted from the experience of existent Weblabs.

The synthesized solutions are indicated by lines drawn on the morphologic chart, and were designated solutions S1 (red continuous line) and S2 (blue dashed line) respectively. Through Pugh’s method, Table III, they have been compared. The adopted criteria were the user requirements from the QFD method. The scale used to attribute performance indexes to the alternative solutions was the 1-3-9, being 1 (lowest performance), 3 (average performance) and 9 (highest performance).

### TABLE III.
SOLUTIONS OBTAINED BY THE PUGH’S METHOD.

| Order | Criteria | Importances | S1 | S2 |
|-------|----------|-------------|----|----|
| 1     | Number of access devices | 11,5 | 9 | 3 |
| 2     | Access from different operating system | 11,5 | 9 | 3 |
| 3     | User interaction with the equipment | 11,5 | 9 | 9 |
| 4     | User immersion (reality perception) | 11,5 | 9 | 9 |
| 5     | Monitor the commands execution | 11,5 | 9 | 9 |
| 6     | Easy to use and operate | 11,5 | 9 | 3 |
| 7     | User management | 4,0 | 3 | 3 |
| 8     | Allow experimental data analysis | 11,5 | 3 | 1 |
| 9     | User’s procedures orientation | 4,0 | 3 | 1 |
| 10    | Safety standards | 11,5 | 9 | 3 |
| Total |          | 100,0 | 784.7 | 477.0 |

In general terms, both solutions S1 and S2 would be eligible for the Weblab project. The application of Pugh’s method demonstrated that solution S1 (784.7 points) presents a higher degree of accomplishment of the criteria than solution S2 (477.0 points). Considering just the question of the remote computational equipment for the Weblab access, in the elected solution S1, the access to the Weblab was defined to be through a personal computer (desktop or notebook), making use of the versatility and higher processing capacity of these equipments. On the other hand, solution S2 was mobility-focused: with the rising availability of the new 3G and 4G networks, portable devices will offer a growing application potential. A limiting factor by the moment, however, is their yet relative processing and data storage capacities. Another relevant factor in the definitions of the solutions S1 and S2 involve the hardware and the software used to manage and to process the user and the experiment data. The selection of CLPs suggests the use of supervisory software, while the integration of multifunctional I/O is easier with a versatile platform such as LabVIEW™ [12].

Naturally, the elected solution implementation requires adaptations to be made in the existent temperature plant, in order to enable it to operate either locally or remotely whilst reliably and safely. The main additional systems to be integrated to the existent plant are:

- A shared server containing:
  - I/O multifunctional board with analog and digital inputs / outputs;
  - LabVIEW WebServer;
  - Firewall and Antivirus;
  - Video conference resources;

- In the temperature plant:
  - Residual protective device (DR);
  - Locking device (Kirk switch / relays);
  - Temperature indicator (TI);
  - Damper electrical actuator;
  - Air flow electrical proportional valve.

At the user side, the resources needed for the remote access and operation, parameters configuration, exhibition, data storage, execution and live visualization of the experiments are:

- Computer with multimedia devices (audio / video) and Internet access;
- Java resources availability;
- Internet explorer browser;
- LabVIEW™ plug-in.

A scheme of the system architecture is shown in Fig. 3. The integrated concept, as a diagram of the complete elected conceptual solution, is shown in Fig. 4.

### 3.1 SOLUTION DISCUSSION

The user will access the Weblab from a remote PC connected to the Internet. The access to the page of the experiment is realized through the Internet Explorer browser, being necessary the installation of a LabVIEW plug-in. As a security measure, users are required to fill a form and define personal login information. Once connected, the user has access to the parameters of the selected experiment, as well as to the live audio and video.
of the plant via webcam and microphone located in the laboratory.

Figure 3. Weblab architecture for the thermal process plant.

The web server hosts the page and plays the following roles: to guarantee secure access to the experiment; to store the temporary data as well as the user information; to manage a user’s agenda; to manage the operation of the temperature plant through the acquisition and transmission of control signals to the actuators, proportional valve, relays and the power TRIAC.

Figure 4. Technical diagram of the selected solution concept, with indication of the solutions for the system functions.

The acquisition and transmission of the input and output signals is performed by I/O boards interfaced to the local computer, which contains analog and digital inputs and outputs. The proportional valve replaces the manual valve (in the air line) in order to allow the user to vary the characteristics of the process loading.

In order to produce disturbances, an electrical actuator is connected to the damper. Two temperature indicators (TI) were used, locally and remotely (via webcam) visible. The LabVIEW and the Java platforms were the software solutions used in the development of the web interface, as well as for data processing and storage. The applications and software are based on Microsoft operational systems. Firewall and antivirus on the server provide web security solution.

To guarantee that local and remote operations will not occur simultaneously, a Kirk locking device has been added to the acrylic front door adapted on the plant panel. This device will block the access to the panel connectors, avoiding unauthorized changes while an experiment is running in remote mode. If the Kirk switch is unlocked, the system is automatically switched to local mode. In emergency cases, the electrical power can be switched off by a local switch or by the residual protective device (DR).

IV. CONCLUSION

The adoption of a systematic model based on a functional analysis, followed by alternative solutions assembly using a morphological chart and then the selection of the most suitable through Pugh’s method, significantly improved the structuration of the activities in the conceptual phase.

The solution to the global function took advantage of the available pre-existent resources in the lab and in the thermal process plant, aiming the minimization of implementation costs. Standard software and hardware solutions available were prioritized. Furthermore, existent Weblabs architectures studied inspired several options for the fulfillment of the morphological chart.

The obtained results will support the next phase of the systematic model (preliminary design), where the concept general dimensioning and the definition of the final Weblab layout will be accomplished.

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