UPGRADING AN EDUCATIVE HYDRAULIC TEST STAND INTO A DIGITAL MEDIA

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ABSTRACT

For the author, it has been a teaching concern how to encourage engineering students to grasp and improve their understanding of technical concepts such as parallel-series hydraulic pumping. The interest that students have in the Internet provides windows of opportunities to link such interest with our teaching concern through a new technology. A fully developed concept is presented herein on how to convert the ordinary twentieth-century hydraulic test stand into a modern digital media source, taking into account the cognition, metacognition and motivation aspects that are requisites for an effective learning process. Minimal hardware modifications, software development as well as the several paths used by the students to access the interactive content design, using the Internet, have turned the hydraulic centrifugal pump stand into an educational tool. A first pilot test made with fifty-three students indicated a high percent level of positive acceptance.

Keywords: cognition, education, hydraulics, remote laboratory, virtual laboratory

TRANSFORMACIÓN DE UN BANCO DE PRUEBA HIDRÁULICA EN UN MEDIO DIGITAL EDUCATIVO

RESUMEN

Es de preocupación en la enseñanza el cómo animar a los estudiantes de ingeniería a comprender y profundizar sus conceptos técnicos, tales como bombeo hidráulico con máquinas centrífugas en serie y paralelo. El interés que los estudiantes tienen en Internet, ofrece una ventana de oportunidades para canalizar una solución a dicho problema con una herramienta tecnológica actual. En este documento se muestra el procedimiento para transformar un banco de pruebas hidráulico del siglo XX en un moderno sistema de medios digitales, teniendo en cuenta los aspectos de cognición, meta-cognición y motivación que son requisitos para un proceso de aprendizaje efectivo. Las modificaciones mínimas de hardware, el desarrollo de software y los diversos caminos que utilizan los estudiantes para acceder al contenido interactivo a través de Internet, han convertido al banco de pruebas en una herramienta educativa accesible a un número ilimitado de estudiantes. Se realizó una primera prueba piloto con cincuenta y tres estudiantes, obteniendo un nivel de aceptación positiva elevado.

INTRODUCTION

A Conversion Energy Laboratory at a Venezuelan public university has more than seven operating hydraulic and positive displacement test stands to educate and develop research on hydro-electrical generation with Pelton, Kaplan and Francis turbines, as well as multiphase pumping for the petroleum industry and mechanical power generation with internal combustion engines.

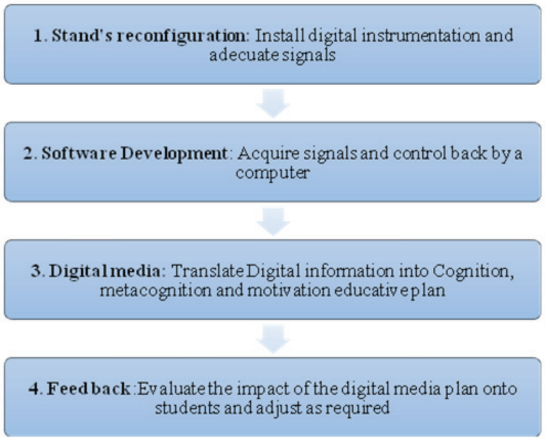
Traditionally, the optimum number of students to have adequate interaction with any stand was around ten students but, in the last few years, the classroom capacities were increased to a number above fifty students. This resulted in a poorly attended and ninteresting laboratory.

On the other hand, todays students interact virtually and regularly with partners and with their communities through the Internet. They even prefer to study and think in front of a computer. Thus, the laboratory staff will adapt and develop new options for accessing and exploring the technical information using digital media over the Internet, for the growing undergraduate student groups.

Now, by having this type of digital tools in an institution where education has been traditionally face-to-face, the design and testing of methods of evaluation that provide adequate feedback on the upgrade herein developed are out of the scope of the present work.

PLANNING

Currently, these stands are manually controlled and instrumented with analogical sensors. To convert the information of the analogical sensors into a digital media source, it was necessary to develop a four-stage strategic plan (SP) as shown in Figure 1.



1. Stand's reconfiguration: Install digital instrumentation and adecuate signals

2. Software Development: Acquire signals and control back by a computer

3. Digital media: Translate Digital information into Cognition, metacognition and motivation educative plan

4. Feedback: Evaluate the impact of the digital media plan onto students and adjust as required

Figure 1. *Four-stage strategic plan. Adapt analog and manually controlled stands into a digital media source*

A centrifugal dual-pump stand was selected for transformation according to the SP (see Figure 2). The main educational objective of the stand was to understand the hydraulic performances of the pumps when working in parallel or in series, so pressure and flow rate were the key variables to be measured and monitored. For a student's first contact with gauges of different scales, valves and flow meters, the real challenge was centered on making multiple, consecutive and successful readings of all sensors. The immediate result was a total deviation from the objective, and as a consequence, an incorrect prediction of the performance curves of the pumps.

Hardware Modification

A low-cost technology (National Instruments data acquisition hardware USB Data Acquisition System – DAQ- 6009 configured with LabVIEW 2013 software) was selected to convert the basic analog hydraulic parallel-series pumping test stand (see **Figure 2**) into a digital instrumented source (see **Figure 3**).

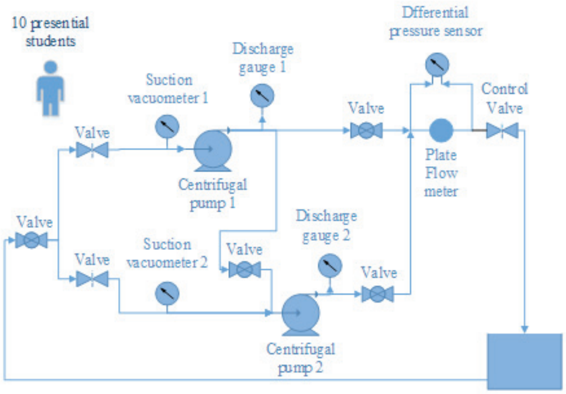


Figure 2*. Original test stand configuration*

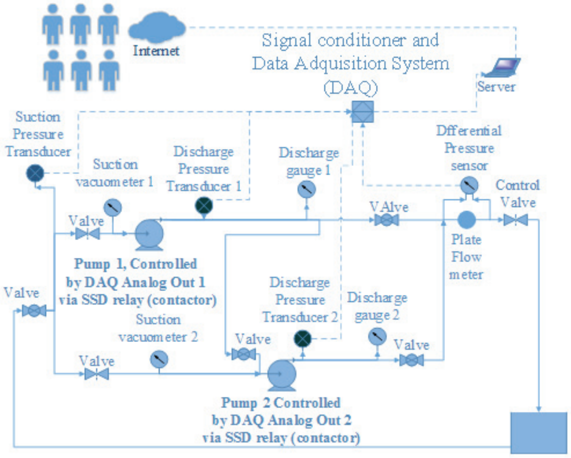


Figure 3. *Converted test stand configuration*

This USB DAQ system is a multiplexer data acquisition device that provides eight single-ended analog input channels (±10 V with an absolute accuracy of ±14.7 mV @ 25 ºC), two analog output channels (0 to +5 V, 5 mA current drive), 12 digital input/output channels and 32-bit counter with a full speed USB interface (National Instruments, 2008). The maximum analog input sample rate is 48 kS/s. As can be seen in **Figure 3**, there were only four single-ended analog input channels and two analog output channels available for this work. We could have used digital channels instead of analog outputs, but this would have required additional components to drive the solid state 0-5 DCV contactors to control de pumps that were available at the laboratory.

Industrial pressure transducers were available and added to convert the pressure variables into electrical signals for subsequent digitalization. Because the transducers were built to a 4-20 mA industrial standard, a previous work was necessary (Zuleta, 2013) to provide hardware solution to convert it into a 0-5 V signal, suitable for capture by a DAQ system (see **Figure 4**).

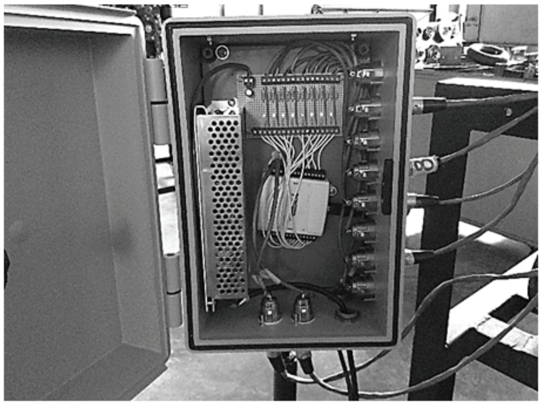


***Figure 4.** Internal view of Signal conditioning Hardware 4-20 mA to 0-5 V and NI DAQ system USB 6009*

The 0-5 V electrical signal originating from sensors were digitally processed for calibration against standard pressure and according to the flow capacity equipment within the test stand operational range, as shown in **Figure 5** and **Figure 6**. The accuracy and repeatability of the transducers and DAQ were good enough to reflect the readings of the standard equipment, without appreciable deviation.

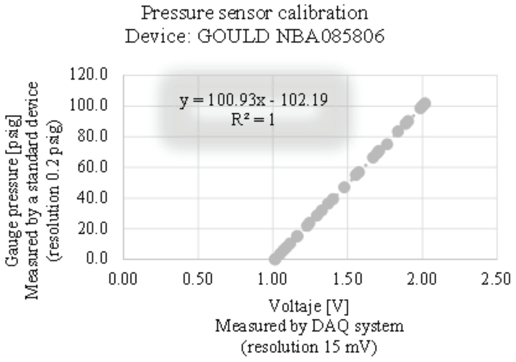


***Figure 5**. Calibration curve gauge pressure transmitter*

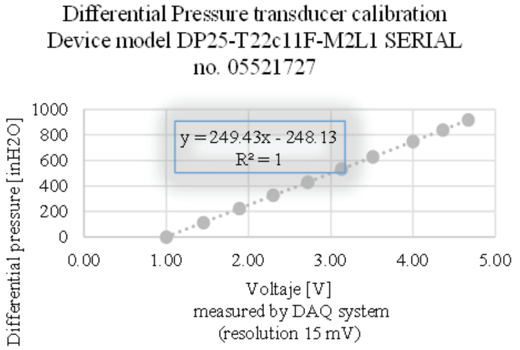


***Figure 6.** Calibration curve for a differential pressure transmitter*

The pumps' electric power consumption was measured within their full operational range using portable equipment and recording the data for further post-process use. This technology will allow the addition of more sensors for future studies and for teaching other topics. The original hydraulic scheme remains the same. It was designed for four different pumping configurations: pump 1 or pump 2 working singly, pumps one and two working in series and pumps one and two working in parallel. For any of these cases, the control valve (CV) can manually set the flow rate of the pumps to a desired value.

SOFTWARE DEVELOPMENT

The software was compiled on a PC, connected to the DAQ system and Internet service. The architecture consisted in a queue messages consumer-producer algorithm combined with a state machine to acquire and process real time data and to interact with users locally or via Internet (**Figure 7**; National Instruments®, 2009). This application constitutes this Remote and Virtual Laboratory (Hidalgo, 2014).

The application processes the incoming signals from sensors and statistically calculates their root-mean-square values (National Instruments®, 2013). The data is stored in a .csv database file. The user is able to decide when to start or to stop a pump from the computer or from the web browser, locally or via a web browser interface as shown in the software architecture **Figure 7** (National Instruments®, 2011).

Because calibration curves are linear, they can be represented with two coefficients (see **Figure 8**): the slope and the intersection with Y-axis when X=0. The application stores the coefficients and loads them when the program starts, but the user can then modify them at runtime. **Figure 8** is a cropped image of these coefficients in the user interface.

There is a secondary calibration curve that relates the differential pressure produced by the orifice plate to the flow rate throughput. This calibration, shown in **Figure 9**, was previously made using a standard flow meter. The numbers 36.41 and 0.4743 are coefficients related with the orifice shape. The 27.68 is a factor to convert inches of water into psi.

Flow rate, pump head and hydraulic power, are calculated and will be available to the user in accordance with their connection profile

All sensor readings can be recorded simultaneously for a specific pumping configuration and CV opening, for a specific user system state or “point”. The user can decide whether to record a single state (instantaneous flow rate and hydraulic head) by just pressing a “point” button. Another button can send by e-mail all recorded states as a .csv file to a user-defined account.

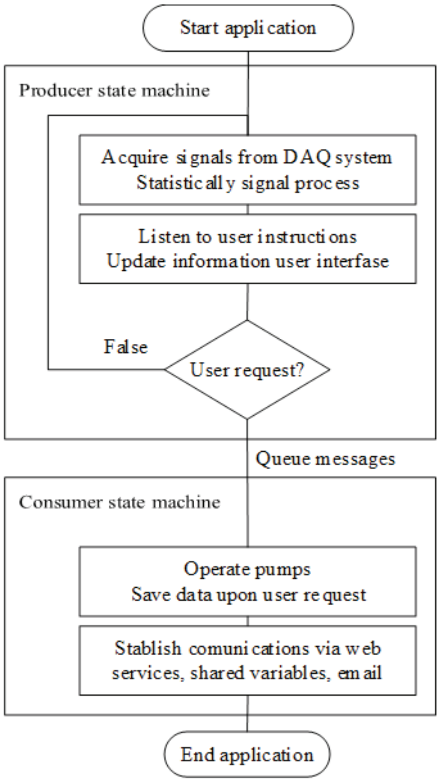


Figure 7. *Software acquisition and control Architecture*


PO
m 249.43 [inH2O/V]
p -249.13 [inH2O]
C1 36 [l/min]
C2 0.4743 [1]
umbral zero 1 [V]
MD1
m 100.44 [psig/V]
p -102.5 [psig]
MD2
m 100.44 [psig/V]
p -103.8 [psig]
MS
m 100.44 [psig/V]
p -101.5 [psig]

Figure 8. *Sensors calibrations coefficients user’s interface*

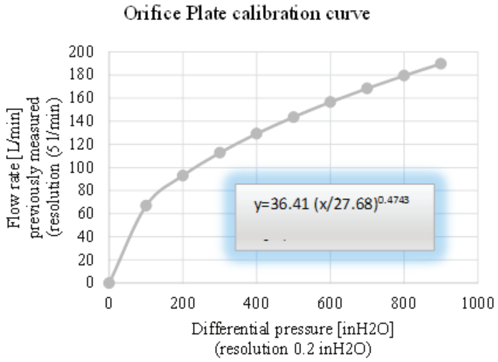


Figure 9. *Calibration curve for orifice plate*

Once the recorded database includes a full range system states, a simulation of a hydraulic stand can be made by just calling back any operative point, making available a virtual laboratory of the stand without turning on the pumps. This results can be online 24 hours a day with no human supervision as a virtualized software.

Besides, the hydraulic practice is completely remote-controlled and virtualized, so new experiments such as instrument calibration, industrial control or motor vibration analysis can be performed to expand the laboratory services to other students with just a few new sensors and minimal software reconfigurations.

The complete solution presented in this work is constituted by four independent software. Their navigation map can be seen in **Figure 10**. The first and second are the completely remote-controlled software and virtualized software.

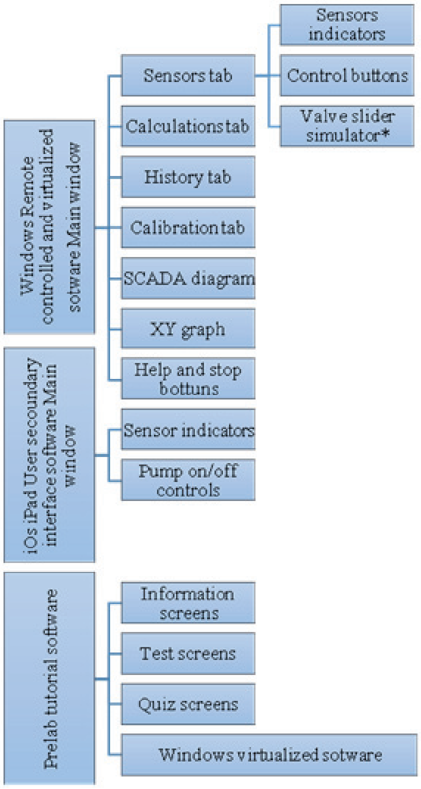


Figure 10. *Software’s Navigation map*

A main window shows always to the user a SCADA type process diagram. With specific changes in colors, it is described the valves position (on/off), the pumps state (on/off) and pipes flooded with water. A XY graph (flowrate vs. hydraulic head) shows a plot of one of the 4 user-selected pumping configuration: pump 1, pump 2, pumps 1 and 2 in series or parallel, and a dot over the plot indicates the actual system state point (**Figure 14**). A tab control with four pages, allows the user to navigate anytime from real-time acquired data ("Sensores" page) to real-time calculations: hydraulic head and power ("Calculos" page), historic changes of acquired data ("Historico" page) to the coefficients control for the calibration curves, email settings, and selected pumping configuration, buttons to save a point, and send an email with all states previously saved (**Figure 13**, **Figure 14** and **Figure 15**).

The windows remote virtualized software is almost the same as the completely remote-controlled but fully detached from real-time acquire and control signals. A control slider simulates the opening of the real CV. When it is changed by the user, the software has access to the virtualized practices and recall the flowrate and hydraulic head depending on pumping configuration selector and pumps start/stop buttons.

The third and fourth applications corresponds to the iOS IPad user secondary interface, and prelab tutorial sections that are explained in the next sections of this paper.

EXPLORING SEVERAL WAYS OF REMOTE COMUNICATIONS OVER THE INTERNET

LabVIEW® has several ways of remote communication for an application. One of them is a web server method that publishes html webpages (web publishing tool) to remote users over the Internet (National Instruments®, 2014). This method requires a host computer to run the lab application as a server and the remote user can be a viewer-only or a control-user. The second option will require the user to install a runtime application in the remote computer.

Any remote user over the Internet with any browser can connect with this html page as a viewer-only using a URL address like http://IP_address/name1.html. This address continuously refreshes a front panel image. The default connecting port is 80, but it can be configured for any other port. If another port is selected, the firewall security setting on server and LAN/Internet routers must be changed to allow TCP and UDP communication through a non-80 port. For most cases the IP address is dynamically assigned by a web master or the Internet service company, this means that the IP address will change unexpectedly, resulting in an obsolete one. A dynamic DNS service (free or paid) could be a solution for an automatic hostname update within each new assigned address. When using a dynamic DNS service, the URL address will be like http://hostname/name1.html.
A second html page will be available http://hostname/name2.html. If the remote user installs a National Instruments runtime engine software in the remote computer, then, he will be able to request its control by a right click over an Internet Explorer web browser (**Figure 11**). By default, this page will admit multiple and simultaneous users (viewers) but only one user will have control over the server. If two or more users request the control, the application will queue these users and will sequentially transfer the control from one user to another, once the first one ends his connection or releases the control. A local user with server access can regain the application control at any time and reassign the control to the next user.

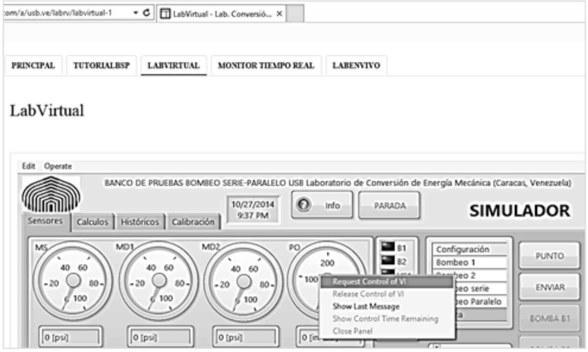


Figure 11. *Server control request by a remote user via web browser*

The third way of communication, a set of network published shared variables (NI Publish and subscribe protocol "NI-PSP") were configured to transmit system state and control of the pumps over the local network or Internet (National Instruments®, 2012). This communication source must be allowed to cross the operating system firewall, including that of the server computer. A modification of network ports and settings should follow as described in National Instruments® (2013). Thus, the application will be able to connect devices such as tablets and cellular phones with Android or iOS. There we used a free complementary National Instrument software (Dashboard) available for mobile platforms, to configure a user interface (**Figure 12**).

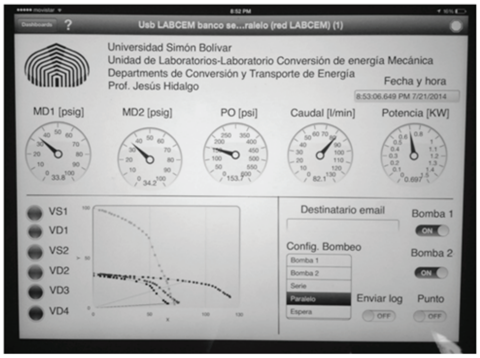


Figure 12. *Developed User interface on iPad (iOS National Instruments Dashboard app)*

Finally, any of these methods requires a good Internet connection for all users to see changes in real time. The Internet connection available to us during this development was approximately 1Mbps, so it was necessary to compile a distributable application to be downloadable at slow speed. An additional functionality was added to transmit the remote user interaction resume as a plain txt e-mail message.

DIGITAL MEDIA METHODOLOGY

Medina (2013) stated three main elements that are decisive in a student's self-regulation profile. Self-regulation is defined as the skills required for understanding and controlling their learning environment, selecting goals, strategies, and monitoring their progress (Schunk, 1996). Thus, the student's self-regulation skills are encouraged with an easier learning process.

Optimum learning using digital Media needs to cover three fundamental aspects:

1. Cognition: Problem-solving strategies, critical thinking. Visual, audio and kinesthesis stimulus using graphs, charts, summaries, mind maps, etc. Predict-observe-explain.
2. Metacognition: Knowledge and regulation of cognition. Self-recognition skills. Planning, monitoring and self-evaluation of the whole process.
3. Motivation: Self-effectiveness, epistemology. Degree to which an individual is self-confident to perform a task.

A. Cognition and metacognition strategies

The remote lab is used as a cognitive tool, presents virtual instruments, pipe sections full or empty of water, valve in open or closed position (**Figure 13** and **Figure 14**) and a real time graph that shows instantaneous pump discharge, hydraulic head and flow (**Figure 15**).

All these representations and subsequent calculations illustrate what is going on behind the pipe surfaces and the main hydraulic flow qualities of the pump system. For the future engineer it is crucial to recall these schematic representations of reality, in order to achieve proper decision-making in this kind of system.

Tools like Google Hangouts or LogmeIn® allow a live interactive audio & video broadcasting through a visualization of the user's interface available at the PC with the main application. In addition, the instructor can share the user's application interface, via web browser, to allow a remote control over the stand pumps.

To reinforce student's metacognition abilities, we have developed a pre-lab web browser tutorial to introduce the underlying technical information required to understand the basic principles of the remote lab (Figure 16).

A test with true/false questions will appear at the end of each section as a self-evaluative tool for the student (**Figure 17**).

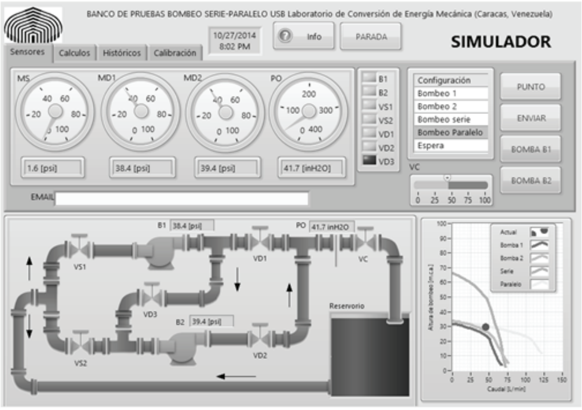

BANCO DE PRUEBAS BOMBEO SERIE-PARALELO USB Laboratorio de Conversión de Energía Mecánica (Caracas, Venezuela)
10/27/2014 8:02 PM
1.6 [psi]
38.4 [psi]
39.4 [psi]
41.7 [inH2O]
EMAIL

Figure 13. *User interface main view. Screen shot*

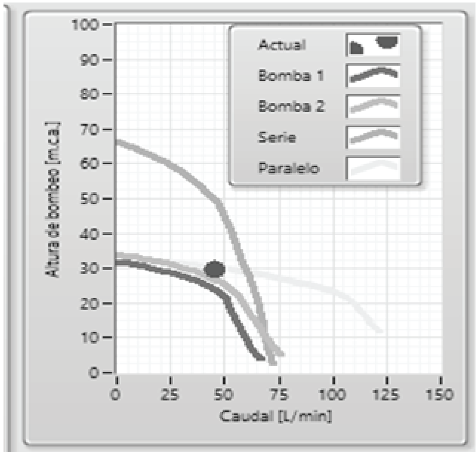


Figure 14. *User interface main view detail. Instantaneous pumps discharge hydraulic head and flow*

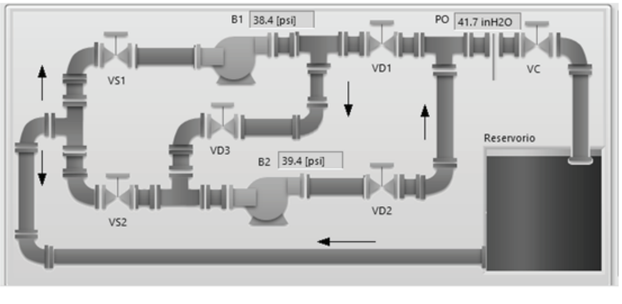


Figure 15. *User interface main view detail. Pipe sections*

BANCO DE PRUEBAS BOMBEO SERIE-PARALELO, Universidad Simón Bolívar,
Laboratorio de Conversión de Energía Mecánica, (Caracas, Venezuela Julio 2014)

Bienvenido Admin

Sartenejas, 8/22/2014
7:46 PM

Banco de pruebas bombas hidráulicas Serie-Paralelo

El banco de pruebas se encuentra ubicado en la sección de máquinas hidráulicas del Laboratorio de Conversión de Energía Mecánica de la Universidad Simón Bolívar y consta de:

1. Dos bombas centrífugas accionadas por motores eléctricos de corriente alterna llamadas (BC1) y (BC2).
2. Tablero de control principal (TCP).
3. Caja de adquisición y acondicionamiento de señales (CAA).
4. Un computador.
5. Sistema de tuberías y válvulas para operar el banco en diferentes modalidades.
6. Un medidor de flujo tipo placa orificio (PO).
7. Un tanque de almacenamiento (TAL).
8. Set de instrumentación (transductores de presión y manómetos tipo bourdon).

694.941

Figure 16. *Pre-lab tutorial screen shot*

BANCO DE PRUEBAS BOMBEO SERIE-PARALELO, Universidad Simón Bolívar,
Laboratorio de Conversión de Energía Mecánica, (Caracas, Venezuela Julio 2014)

Bienvenido Admin

Sartenejas, 8/23/2014
10:59 PM

Operación de múltiples bombas

Por razones técnicas y económicas es muy común encontrar múltiples bombas operando simultáneamente. Estas se disponen en configuraciones conocidas como arreglos en serie o arreglos en paralelo.

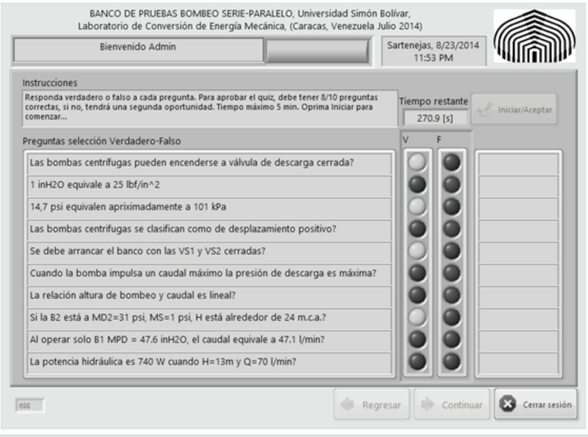
Bajo estas condiciones, y conociendo las curvas características de las cada equipo por separado, es necesario predecir el comportamiento de los arreglos en serie y/o paralelo, y de esta forma poder determinar el desempeño del conjunto en el sistema.

Las bombas son un invento de la humanidad del siglo XX?

688

Figure 17. *Pre-lab tutorial test screen shot*

A final time-restricted quiz will be the formal evaluation and the student will have an automatic instantaneous grade (**Figure 18**). Students will have the opportunity to review the tutorial, prior to the quiz, until they feel comfortable enough to be evaluated. This application has been coded so that the technical information such as photographs, test questions and quiz questions are updated as simple texts in a Microsoft excel spreadsheet and *.png files in a specific folder, so it can be easily changed and expanded. When the application is accessed to the server by an html, the maximum number of users that can connect simultaneously to the server has been restricted to one, to preserve the confidentiality of the quiz. Further program development will allow multiple users to have access in different instances of the same application.



BANCO DE PRUEBAS BOMBEO SERIE-PARALELO, Universidad Simón Bolívar,
Laboratorio de Conversión de Energía Mecánica, (Caracas, Venezuela Julio 2014)

Bienvenido Admin

Sartenejas, 8/23/2014
11:53 PM

Instrucciones

Responda verdadero o falso a cada pregunta. Para aprobar el quiz, debe tener 8/10 preguntas correctas, si no, tendrá una segunda oportunidad. Tiempo máximo 5 min. Oprima Iniciar para comenzar...

Tiempo restante
270.9 [s]

Preguntas selección Verdadero-Falso

Las bombas centrífugas pueden encenderse a válvula de descarga cerrada?
1 inH2O equivale a 25 lbf/in^2
14,7 psi equivalen apriximadamente a 101 kPa
Las bombas centrífugas se clasifican como de desplazamiento positivo?
Se debe arrancar el banco con las VS1 y VS2 cerradas?
Cuando la bomba impulsa un caudal máximo la presión de descarga es máxima?
La relación altura de bombeo y caudal es lineal?
Si la B2 está a MD2=31 psi, MS=1 psi, H está alrededor de 24 m.c.a.?
Al operar solo B1 MPD = 47.6 inH2O, el caudal equivale a 47.1 l/min?
La potencia hidráulica es 740 W cuando H=13m y Q=70 l/min?

698

Figure 18*. Pre-lab tutorial Quiz screen shot*

Because the Internet connection speed is unpredictable at some locations, a distributable executable program was uploaded to the cloud to allow downloading at slow-speed. For this version of the remote lab, an additional functionality allows the program to connect to the Internet at the end of the test to send the test results with an e-mail addressed to the professor. The MS Excel spreadsheet is access-locked so that a remote user cannot open it.

After all students finish the pre-lab, they must attend, simultaneously, to a scheduled remote laboratory session conducted by the professor. This session will rebuild the tutorial concepts and introduce a few new ones.

B. Motivation

It is important to motivate students to make an additional effort to work with the new digital media source. During the pilot sessions and the first implementation of the remote and virtual labs, there is a natural expectation in the students regarding this educational tool. Therefore, the encouragement and guidance from the professor is crucial. Certainly, the better marks achieved in the course's final exam will be the biggest incentive for next season's students.

1st PILOT TESTS RESULTS

During summer, a pilot test was made with fifty-three mechanical engineering students. The strategy for presenting the media tool to the students is seen at **Figure 19**, but its effectiveness is beyond scope of this work and long term studies with consecutives courses shall be needed.

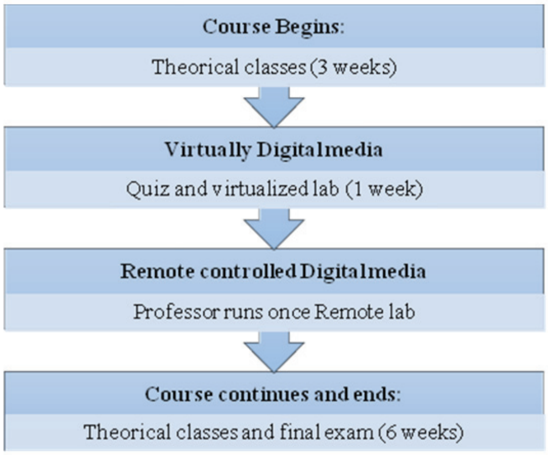


Figure 19. *Classroom implementation strategy*

After the pilot course runs for a couple of weeks of ordinary classes, the student can access to the virtual software: perform the quiz and play the virtual pre-lab. All the remote laboratory ways of communication were available, but all students decided to download the software to their own computers and install the distributable application. This behavior is expected in a country which has an overall obsolete Internet platform. At the end, the student should answer a poll focused on questions concerning the application, including photo quality, font size, ease of understanding, quiz duration and general observations.

100% of the attendees pass the quiz and only 6% needed to perform it twice. Ninety-one percent of the responders' general observations were explicitly satisfied with the digital media tool. For example, we read comments such as: "Excellent program, very good pilot test, it will revolutionize laboratory practices as we know them today". Nine percent of the opinions were neutral, neither in favor nor opposed to the digital media tool. The students made observations about font size that happened to be difficult to read in some small laptops. They also reported installation and communications bugs as well as some pre-lab phrases that they did not fully understand. There were a couple of opinions centered on the application instead of on the pre-lab. They suggested that it is important to allow the students to make mistakes (and to warn them about it) when turning on/off the pumps and valves. In other words, they were interested in the importance of making the virtual laboratory a closer reflection of the real stand.

Then, the professor performed a remote controlled lab at the classroom in front of the students, repeating the virtual lab experience but with a question-answer dialog to reinforce the student memory and solve doubts about technical information. Classes and a second final evaluation continued in an ordinary way with a 13% improvement in classroom overall final grade.

The further evaluation of the digital media tool presented at this work and its incoming improvements needs to be guided by methodological study. The reliability and validity of the evaluation instruments is essential to conduct changes as efficient as possible (Schleyer TK, 2003), but the right selection of the evaluative method is not an easy matter, and will be an interesting subject for a later publication.

CONCLUSIONS

For teaching engineering, it is a major step to switch from a traditional twentieth-century stand to a modern digital media source, considering that the hardware changes were minimal and the scalability of this new version is open for future advances.

The software developed not only includes an application to manage the existing hardware but in addition, it transforms the electronic and digital information into an educational tool, as effective as those proposed by experts and researchers in the field of digital media education.

Fifty-three students of mechanical engineering participated in the pilot test. Ninety-one percent of them expressed positive opinions on the new tool and methodology. Furthermore, some students were motivated enough to identify several bugs and to suggest ideas that would significantly improve the tool. A couple of students even suggested to evolve the software application into a more realistic stand by allowing the user to make mistakes and be warned of the impending results.

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