A Remote Access Laboratory for Fluids Education in Mechanical Engineering

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1 Introduction

The Mechanical Engineering program at Washington State University (WSU) has grown substantially in the last five years. Class size has increased markedly at the home campus in Pullman, WA and in addition, two new satellite campuses at Bremerton, WA and Everett, WA are the home to Washington State University students who receive instruction from onsite instructors and from WSU faculty through distance education. One of the major difficulties for the satellite campuses is providing appropriate laboratory experiences for students. There are several lab classes in the junior and senior years which require specialized equipment. The initial focus of delivering lab education to satellite campuses is the junior thermal fluids lab on measurement techniques.

There are three styles of laboratory experiments throughout engineering education: hands-on, simulation, and remote (or virtual) labs.[1-7] Hands-on experiments allow student to physically manipulate components and gather data. Simulations use computer software to emulate the results gathered in a real laboratory setting. Simulations can be successfully used to explain and reinforce physical concepts, but limit the capability for true experimentation. Remote labs use the positive features of both hands-on and simulation type lab environments. Simulation based labs cannot provide a “feel” for real things. Students need to use real devices and execute commands on real tools to gain necessary practical skills. Remote labs are similar to simulation techniques in the sense that they require minimal space and users can rapidly configure them over the internet. Unlike simulations, remote labs provide real data in which the user can adjust the input parameters. Although currently all of the experiments in the junior thermal fluids lab are of the hands-on type, the remote lab approach was judged to be the best solution for delivery of distance lab education to satellite campuses.

This paper describes the development, implementation, and testing of a remote laboratory for a thermal fluids lab on flow through a venturi and flow measurement. There are two intended users of the laboratory: students at satellite campuses will operate the lab remotely as part of their laboratory course and instructors will operate the lab from their classrooms to bring demonstrations and active learning components to lecture courses. This paper provides an initial assessment of effectiveness of remote labs for two applications, 1) in class demonstration for lecture classes 2) remotely operated instrumentation lab experiments.

2 Approach

The development of the lab involved putting together hardware for the actual flow circuit, adding automated controls for valves, installing a web based data acquisition system, and integrating a web camera with controls.

2.1 Hardware and Plumbing

A schematic of the lab is shown in Figure 1. The on/off valve permits air to flow through the system. The flow control valve regulates this air flow. The air follows the piping through the

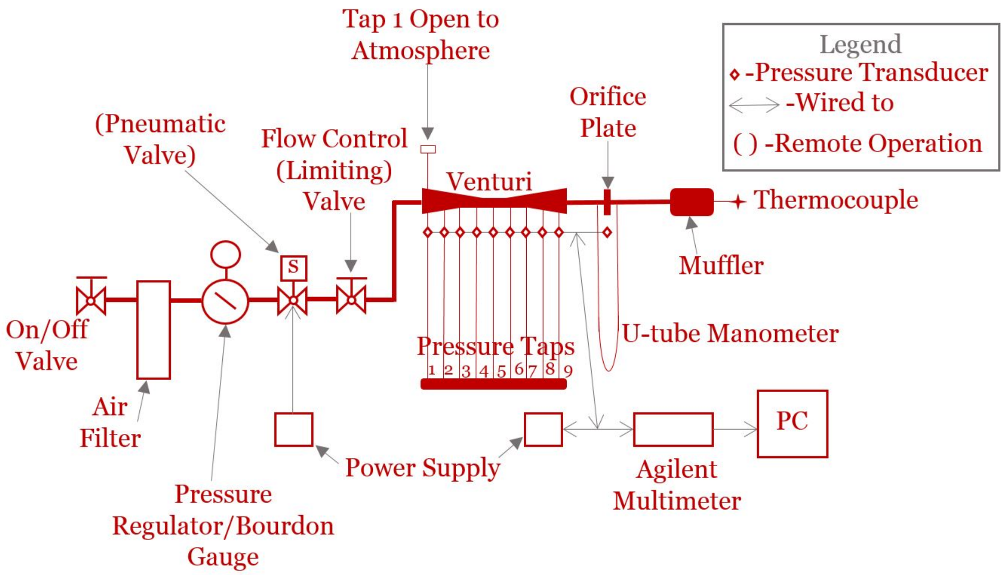

Figure 1: Venturi Flow Experiment Schematic

filter, pressure regulator, and flow control valve (when open) and into the venturi to the orifice plate and out of the muffler. There are nine pressure taps along the venturi and one at the orifice plate as well as a thermocouple attached to the end of the muffler. All of these components are wired to an Agilent 34972A digital multimeter and power supply. The computer receives data from the web connected multimeter in the form of voltage readings from each transducer. The orifice plate, used to determine the volumetric flowrate of air through the system, has a u-tube manometer attached to it. The u-tube manometer visually displays the pressure drop across the orifice. The muffler at the end of the flow circuit stifles the sound of compressed air through the system to a low hum while the thermocouple records the temperature of the air. A web-enabled surveillance camera (not shown in the figure) was also installed to allow users to view the experiment over the internet.

2.2 Web Components

An Agilent 34972A data logger was used for data acquisition and control. This data logger can be controlled by a web based graphical user interface. This allows students to use their personal computers to control the experiment and log data. The pressure transducers, thermocouple, and power supplies for the venturi experiment were wired to a 20 channel multiplexer module. The solenoid valve was wired to the multifunction module of the Agilent multimeter which allowed for remote control of the valve through the web interface. The solenoid valve, an Enfield Technologies M2D Pneumatic valve, was selected for its high speed switching capacity and flowrate range. It is installed in a basic open-looped proportional control configuration. A TRENDnet Wireless PTZ Network Camera (TV-IP612WN) was installed to provide visual access to the experiment. This camera has 10x optical zoom and 16x digital zoom with autofocus technology. The camera pans 330 degrees left to right and 115 degrees up and down. Users control the Pan-Tilt-Zoom functions remotely via a web interface.

2.3 Running the Experiment

Users may view the experimental set up by accessing the camera via a provided link. From the camera home screen students may zoom, pan, or tilt the camera to adjust their view. The display always has the date, time, and camera name stamped on it. After becoming familiar with the flow circuit students may begin experimentation. Users access the multimeter through a website with a link provided in the lab write up. From the home page they start by applying a voltage to the solenoid valve which opens the valve and permits flow through the system. Colored water rises in the manometers connected to the pressure taps along the venturi and provides a visual. The multimeter is then configured to collect the voltage reading corresponding to the pressure transducers along the venturi and across the orifice plate. The user may then vary the voltage to the solenoid valve to change the flowrate and collect the corresponding data. The collected data may then be exported to an excel spreadsheet for further manipulation.

3 Results

The remotely operated experiment was implemented in two settings. In the first setting an instructor used the remote lab in a lecture class on Fluid Mechanics to enhance student learning of concepts associated with flow through a venturi, Bernoulli's equation and the energy equation. In the second setting a pilot group of students enrolled in the junior lab at Pullman and the satellite campus were asked to run the lab remotely and provide feedback and assessment of the experiment.

3.1 Integration into a lecture classroom

The remote lab was used in an active learning segment in the junior introductory fluid mechanics course. In this activity students collaborated on a worksheet designed specifically for the experiment. Students took a pre and post assessment quiz used to evaluate understanding of flow through a venturi before and after the exercise. The goal was to strengthen both procedural skills and conceptual understanding.

The lecture on venturi flow in the context of Bernoulli's equation was given the day before the exercise took place. Students completed an online quiz following the lecture which tested their understanding of the relationship between velocity and pressure in a venturi.

In the following class students were given the link so that they could view the experiment live on their laptops. The instructor controlled the experiment and projected the image. Students could observe the change in pressure along the venturi from the height of the colored fluid in the manometer tubes. They were then asked to perform calculations based on the experiment. The worksheet included a diagram of the venturi used in the remote lab, calculation questions, and conceptual questions. Students were given the flowrate and dimensions of the venturi section at the location of each pressure tap from which they calculated the corresponding velocity. They then completed a table using the experimental pressure data and the calculated velocites which provided a clear illustration of the relation between cross-sectional area, pressure and velocity of flow through a venturi. They also calculated the expected pressure along the venturi based on Bernoulli's equation and compared these pressures to the experimental pressures.

The assessment quizzes each had conceptual questions on flow through a venturi and Bernoulli's Equation. Although the questions on the two tests were similar, they were not identical nor were they ordered in the same way. The questions addressed the relationship between velocity and pressure, the points of lowest and highest pressure in a venturi, the points of lowest and highest velocity in a venturi, and when the application of Bernoulli's equation is valid.

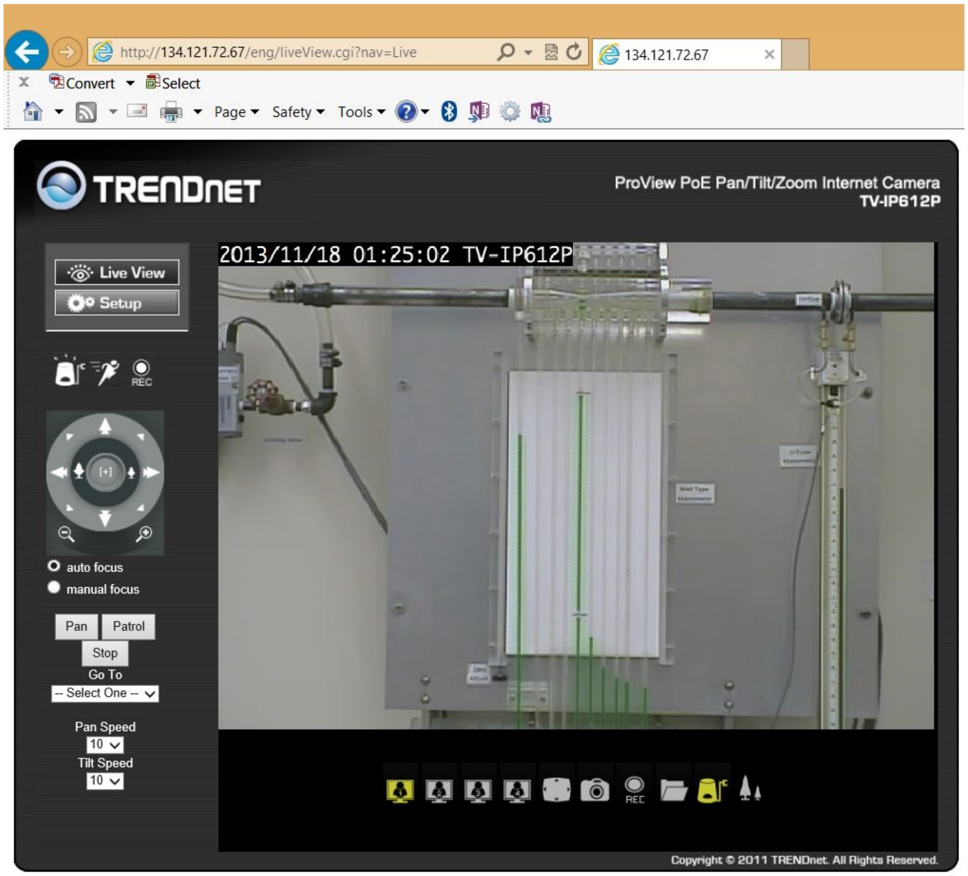

Figure 2: Home screen: Student view.

Students had fifteen minutes to complete the pre-assessment quiz at the beginning of the class. After completing the worksheet and demonstration, students completed the post-assessment quiz. On the questions addressing characteristics of velocity with location 79% answered correctly on the pre quiz and 98% on the post quiz. On questions addressing the characteristics of pressure with location 37% answered correctly on the pre quiz and 81% on the post quiz. Sixty nine students took the pre quiz and 63 took the post quiz.

3.2 Integration into a virtual laboratory

The venturi experiment was run in the Pullman campus junior lab in the Spring of 2014. The majority of students performed the lab as a hands-on lab. A small group of eight students were selected to operate the lab remotely in a pilot study. Students performed the lab from somewhere else on campus or from home.

Students were given a task list specific to the remote lab that first guided them into the web camera user interface, and familiarized them with the pan-tilt-zoom functions of the camera. Students then use the camera to explore the different components of the experiment. A sample of the camera screen is shown in Fig. 2.

Next students accessed the Agilent multimeter through its web interface where they were guided through gathering data beginning with how to send a voltage to the solenoid valve to adjust the air flowrate. A window pops up where the user inputs a voltage between zero and ten volts depending on the desired valve opening.

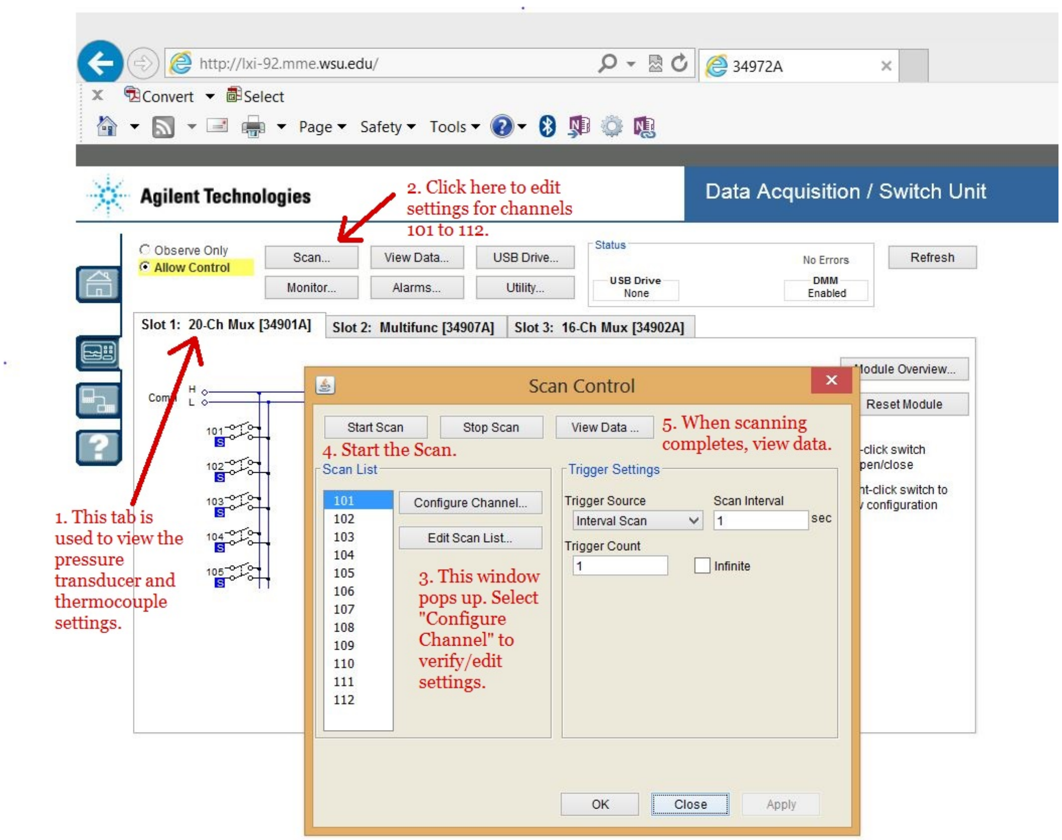

Figure 3: Configuring the Multimeter

Students then set up each channel of the multimeter, set a flow condition, and gather data at each flowrate. To set up the digital multimeter to read channels 101 to 112 (the pressure transducers and thermocouple) the user clicks on the appropriate tab in the web browser configuration window. They then select the “scan” button at the top of the browser, followed by the “Configure Channel” button to collect a set of data. Figure 3 shows a sample of the window the student sees in this process.

The control group of students who ran the experiment remotely helped to pinpoint “holes” in the instructions and gave many helpful suggestions. Most of this feedback came through emails while they ran the lab. The rest came from the online survey they completed. The survey included the following questions: How would you rate the overall ease of operation? Were the screenshots showing how to operate the camera helpful? Was the camera image good enough to gather all the required data? Were the screenshots showing how to operate the multimeter helpful? And were the tasks listed in the handout easy to follow? The student survey indicated that only minor operational changes were needed for students to successfully operate the web-based lab.

Students at the satellite campus ran the virtual lab in the fall of 2014 as part of their junior instrumentation course. Thirteen students performed the lab at the satellite campus. The lab reports of the students at the satellite campus were compared to the lab reports of students who performed the experiments with the hands-on equipment at Pullman. There was no significant difference between the quality of data obtained and plotted by students using the virtual lab compared to those performing the experiment in the laboratory. In the lab write up students are asked questions concerning the relationship between velocity and pressure, the points of lowest and highest pressure in a venturi, the points of lowest and highest velocity in a venturi, and when the application of Bernoulli's equation is valid. The majority of students were able to correctly discuss how velocity and pressure vary in a venturi tube based on their observations and calculations. There was no discernable difference between the two groups of students on these questions. However, students who performed the virtual lab consistently failed to identify friction as a reason for the difference between measured and ideal pressure downstream of the venturi throat. Students at both the home and satellite campuses receive instruction in fluids fundamentals from the same instructors so this is not likely the source of this discrepancy. However further more rigorous assessment will be required to pin down the reason.

4 Summary

An experiment with web based control of and data acquisition from a venturi tube was developed and implemented into junior level engineering classes. Assessment performed by administering pre and post tests indicated that students showed significant improvement in conceptual understanding after exposure to the web-based lab in the junior fluid mechanics course. Students at a satellite campus performed the virtual lab as part of their junior instrumentation lab. Comparison of lab reports produced by students who performed the virtual lab to those produced by students performing the experiment physically in the lab showed few discernable differences.

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