WEB DRIVEN EXPERIMENTATION FOR TWO-PHASE FLOW

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Abstract

Two-phase flow introduces a very interesting field to several areas of engineering and science. The phenomenon brings about numerous applications and benefits, especially in the study of a cooling system for highly integrated electronic circuits used in computers, the problem of narrow-gap boiling in nuclear systems [9], and the design of highly efficient compact heat exchangers. These fields of study heavily depend on experimentations including data collection, where it is essential to design and develop two-phase flow experimental systems. This paper reports the design and development of an experimental system for two-phase flow that allows undergraduate and graduate students or other remote clients to easily run two-phase flow experiments, change control parameters and analyze the results via TCP/IP based network systems including the Internet and the Local Area Networks.

This computer-aided experiment uses LabVIEW software and data acquisition boards (DAQ). Control of the experiment is initiated from a web browser, and data are acquired and sent to the remote user as they are being measured in the laboratory. With the ability to control the experimental instruments remotely, equipment can be operated and the data acquired and analyzed via TCP/IP network.

Introduction

The recent developments in the Internet and the introduction of the World-Wide Web (WWW) have enabled the remote access opportunities to real world equipment with the availability and the capabilities of these new communication facilities, combined with the generalization of computer use for data acquisition, control of real processes and the incorporation of the two-phase flow web operable experiment, students can run the experiment from anywhere in the world anytime using TCP/IP Network and can interact with experiment instruments by changing input parameters and viewing the scene of the experiment. From the interaction with instruments, students can have hands on experiences and repeat an experiment without time pressure. There are many technical problems [2] associated with the web driven two-phase flow experiment and they have been solved in this paper. A successful web-operable experiment requires several characteristics. First, it should present the remote user a striking visual picture. Second, it should permit the operator to manipulate several key parameters and these parameters should have an immediate effect on the picture seen by the operator. The user controls are [4, 5] implemented to increase the dynamical performance of the equipment used for the experiment. The basic principle of such interaction is to take into account actual measurements in order to compute appropriate actuations that adjust the operational conditions to meet the given requirements.

Acquisition of measurements and modification of actuations is carried out by LabVIEW software. The use of LabVIEW provides numerous user controls, analysis tools, and built-in web server along with LabVIEW's graphical programming environment, which dramatically enhances development time and efforts than other tools using regular text based programming languages and compilers on a single Windows2000 based computer. Easy maintenance and adaptation is one of the most important and useful capabilities of LabVIEW. In our rapidly changing educational environment, LabVIEW's sole graphical programming technology [6, 8], G language, could be more useful. Professors and students can take advantage of easy implementation and modification of system by clicking and dragging a mouse pointer without changing text based programming codes like C, C++, Pascal, and even Assembly when it is needed to change sensors or apply the experiment system to different experiments minimizing modifications of the system.

The part of two-phase flow experiment involves concurrent flow of air and water in a transparent vertical tube (Fig 2). The tube is 1 meter long, 35 mm in diameter and can be mounted vertically, horizontally, or at an angle. At this moment, the operator in the lab can set up the angle of tubes in needs. The water is circulated with controlled by airflow intensity during rotameters and pressure level delivered by compressor installed in the lab. A web camera is focused on the tube, which enables the remote operator to view the flow patterns in the tube. The remote operators can set both the air and water flow rates remotely by using DAQ I/O system via network. The DAQ boards are connected to several sensors, which are used to measure the flow parameters in the flow tube and send back the measurement data to the DAQ boards for Digital Signal Processing (DSP) and analysis in LabVIEW, which sends back analyzed data such us Power Spectral Density (PSD), Cumulative Power Spectral Density (CPSD), Fast Fourier Transform (FFT), RMS value, AC and DC values vs. time, Histogram, and Cumulative Histogram to distant operators. [1, 2, 3]

Network System Description

The network environment for the remote experimentation is based on client server architecture as shown in Fig 1. There are two parts, which are necessary for a remote controlled experiment:

Remote Client: It is a computer equipped with the functionality necessary to observe and to act on the remote experiment. The client application is VI compile for the target platforms. This VI provides the user with a complete interface to the real process. It is used to generate excitation signals and to observe corresponding responses. The main purpose of such an interface is to provide a general view of the physical process evolutions and to allow full control of the operations.

Local Server: It is the computer located near the real process and equipped with hardware interface to the sensors and actuators. A web camera is also interfaced with the system to get the visual pictures of the flow tube and also other measurements. The server application receives the client commands and transmits them to the real process. It also returns the states of the physical process to the client including along with an image.

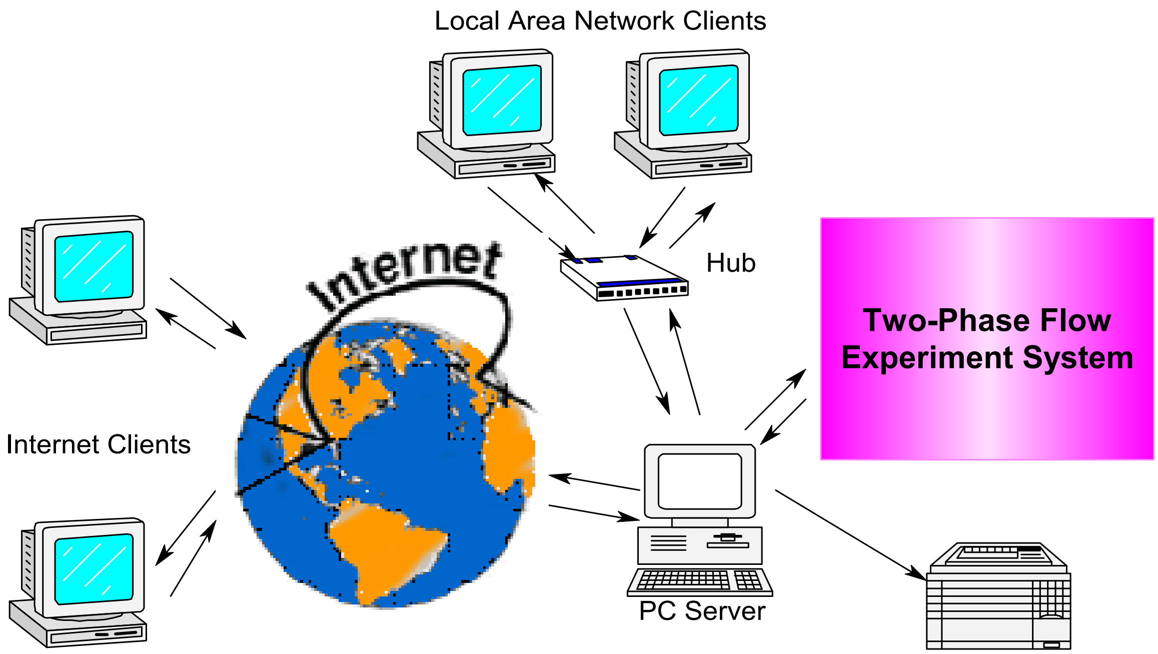

Fig 1: Web Driven Experiment Network Set-Up

Three modules are necessary to build a client and server application: the GUI module, the RT module and the COM module [6]. The application used locally can be split into two modules: the real time controller (RT) and the graphical user interface (GUI). The client and server application can be designed by adding a communication module to the existing modules. The client application is made up of the GUI and the communication modules. The server application is made up of the controller and the communication module. The communication module allows the client and server applications to exchange information with other computers distributed in different geographical locations. This module also takes care of security issues regarding network management like preventing the unauthorized access and it also schedules logins to avoid conflicts. In remote experimentation mode, video feedback information in addition to the information should be given to the remote computer through the graphical user interface. Fast system responsiveness is a key goal of remote experimentation, so adopting fast Internet connections like DSL, Cable or LAN should minimize response times. Different kinds of information streams are exchanged between the server and the clients as follows:

- The data stream representing the measurements made on the physical system.
- The video stream acquired by the camera.
- The parameter stream that reflects the user actions on the client side.
- The administrative stream which deals with login/logout issues.

National Instruments provides a fully featured built-in web server written in G language. When running this server, the front panel (FP) of running VIs can be transmitted to a web browser and updated at regular intervals using the server-push/client-pop technique. The server also supports CGIs written in LabVIEW such as image map. The combination of different VIs can provide the client with a view of the remote setup. Nacimiento software propose applet view a tool kit which provides users with a complete development environment for creating Java applets as front end instrument panels that communicate with a LabVIEW server.

Two-Phase Flow Experiment Description

The schematic representation of the experimental system used in this study is shown in Fig. 2 and a more detailed description of experimental part and data analysis could be found in [1,2]. The experimental apparatus consisted of a vertical glass tube of diameter 35mm. A web camera is focused on the flow tube to make available the real time images of the flow patterns in the tube. A mixing chamber positioned at the bottom of the vertical channel generates the two-phase flow and it provided the operator control of measured mixture components. The sensors from the capacitive, resistive, pressure and optical systems were positioned in the same space, which insured that each sensor would be affected by the same flow phenomenon, for example, same space and time. The signals from each sensor were conditioned to a proportional voltage signal, which is then converted to a digital input to a data acquisition system.

The signals from each system were interfaced to the computer and collected simultaneously and are conditioned by LabVIEW with DSP VIs. The airflow rate to the flow tube ranged from 0 to 0.15 [m^3/min]. After mixing with the water the two component mixture flowed to the top of the column were the air was released to the atmosphere and the water is returned to the system. The capacitive system used to measure in situ spatial concentration consisted of two electrodes opposing one another on either side of the flow channel, which measured the capacitance of the capacitive sensor. This signal is transferred to the voltage signal, which is collected in the computer through the data acquisition.

The static pressure system consisted of a pressure sensor that measured the static gage pressure in the flow tube. The resistive system measures the in situ concentration based on the difference in resistivity of the two-component mixture. The resistance meter measures the resistance of the sensor and translates it into a voltage signal that is interfaced to computer aided Data acquisition system. The transition from the slug flow region to the churn flow region, which is a function of air and water flows, can be clearly seen by the remote operator. The control software piloting the real process locally is a virtual instrument (VI) using LabVIEW. The VI provides a complete interface between the user and the real process. It is used to generate excitation signals and observe corresponding responses. The main concept of such an interface is to provide a general view of the real process evolutions and facilitate full control of the operations. More detailed description of the system components are listed below in the system specification.

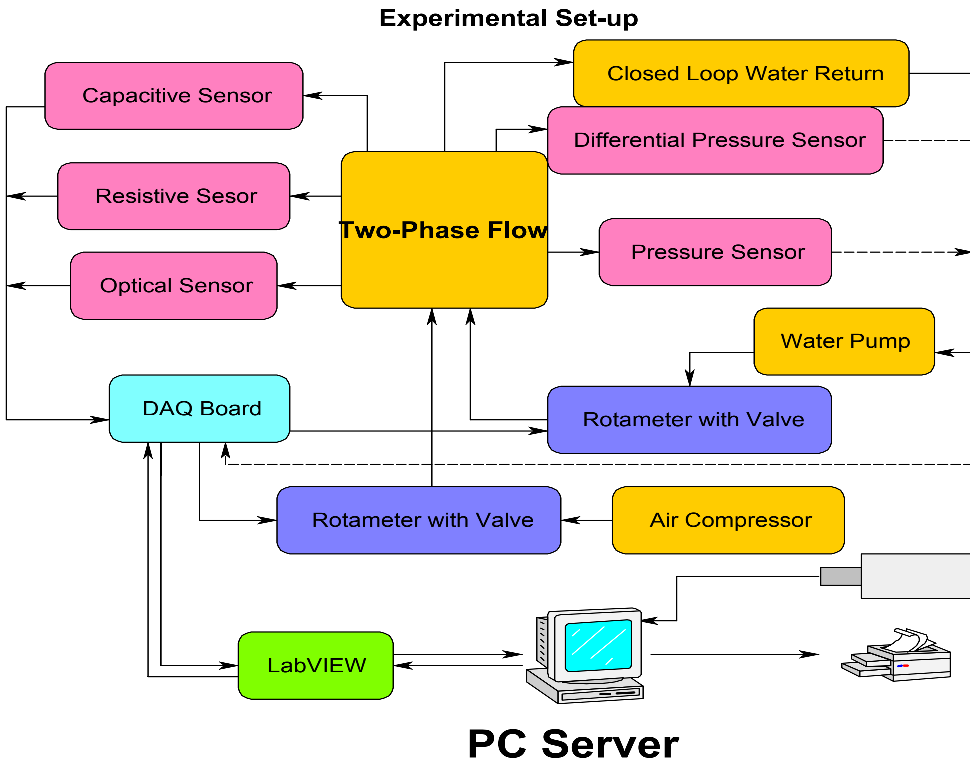

Fig 2a: Experimental System for Web Driven Experimentation on Two Phase Flow

System Specifications

A. System Hardware

1) DAQ Board: PCI-1200 manufactured by National Instruments.

   Analog Inputs: eight single-ended, eight pseudo differential or four differential, software selectable channels, and resolution is 12 bits, 1 in 4,096. The maximum sampling rate is 100 kS/s.
   Analog Outputs: Two voltage output channels with 12 bits resolution, and update rate is 20 S/s – 1kS/s (System dependent)
   Digital Input and Outputs: TTL Compatible 24 I/Os with three 8-bit ports).

2) Pressure Sensor: In-house develop based on Sensym pressure sensors. The sensor has the ability to measure differential and gage pressure with 1 kHz sampling rate.

3) Optical Sensor: An in house developed optical sensor with Wheatstone bridge circuit and output voltage 0V to 5V.

4) Capacitive Sensor: This sensor developed in house consists of two copper electrodes facing each other (8 x 10 mm).

5) Resistive Sensor: This sensor developed in house consists of two copper electrodes (8 x 10 mm).

6) Host: A Windows 2000 based PC with Pentium III .

7) Air compressor: A lab-installed air compressor with pressure and flow rate controls.

8) Power Supply for Transducers: The system uses DC-5V generated from DAQ boards.

9) Web Camera: This camera, which has USB interface was manufactured by Vimicro. The camera is used for transmitting experiment images to distant operators.

10) Two-phase flow channel for air-water mixture with measurement and control systems. In house developed.

B. System Software

1) LabVIEW: LabVIEW 6.1 Professional Development version. LabVIEW is the heart of the experimental system, which has built-in web server and numerous analysis virtual instrument libraries.

2) Microsoft Visual C++ 6.0: For compiling web camera library using Microsoft's Video For Windows (VFW) interface.

3) Macromedia Dreamweaver 4.0: This software is used for generating a webpage for students and modifying the webpage.

4) LabVIEW 6.1 Runtime Library, which the distant operators must install on their own computers in order to see and manipulate the experiment. It can be downloaded from National Instruments' webpage for free.

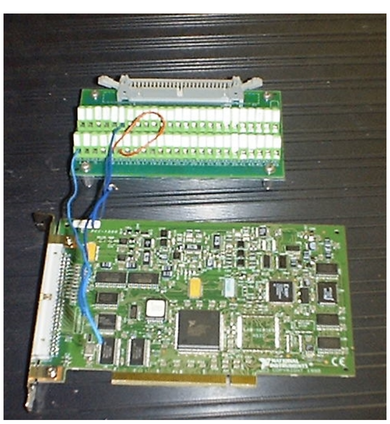

Fig. 2b. PCI-1200 DAQ Board

Fig. 2c. Two-phase Flow System

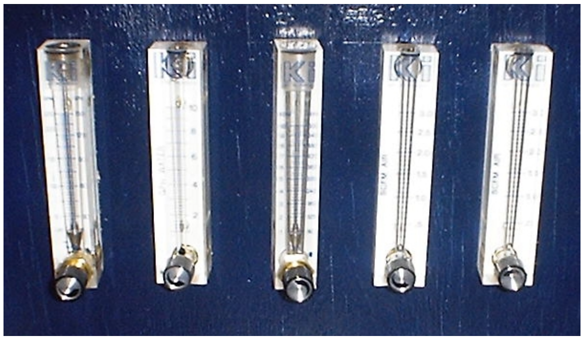 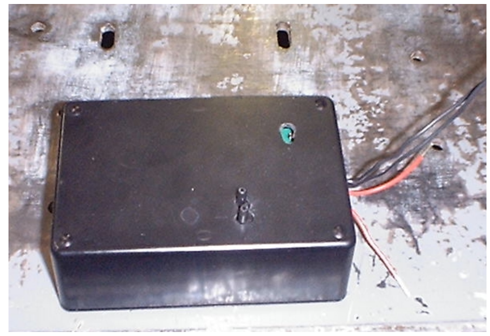

Fig. 2 d. Flow Meter Panel Fig. 2e. Pressure Transducer

Signal Conditioning and Processing in LabVIEW

In this experiment, LabVIEW performs five basic functions, which are signal conditioning and processing, data analysis, instrument control, and communications with distant operators. In the stage of signal conditioning, LabVIEW separates noises or fluctuations from input signal generated by sensors and electromagnetic fields. It is essential to equip digital filters to separate unwanted fluctuations. The filters are low pass, high pass, band pass, and band stop filers, and windowing technique is also applied to the system due to its processing capability of frequency domain signals. Fig 3 shows an example of Hanning window applied for sine and square wave signals in LabVIEW

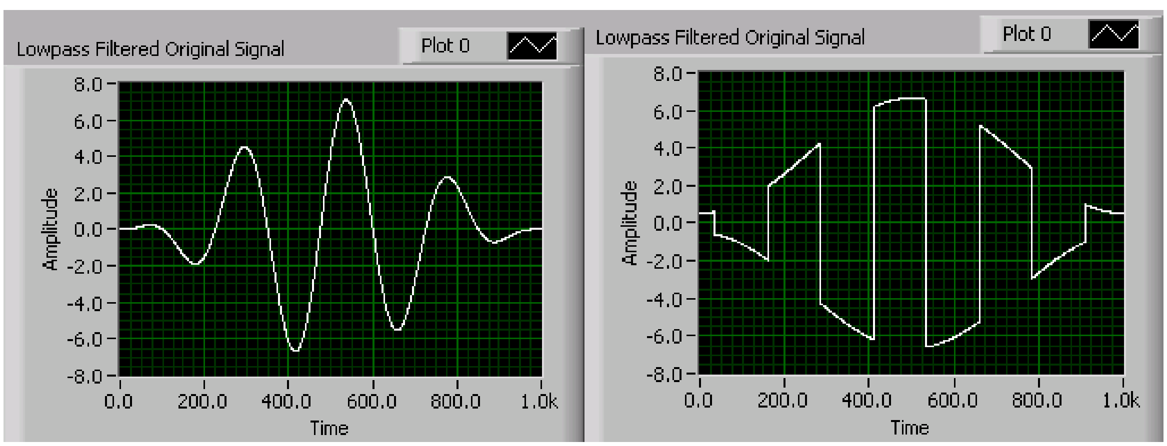

Fig 3. Hanning Window Applied in Sine and Square Waves

Filters are essential for the analog circuits or sensors to remove noises in the signal. There are five different filters implemented in the system, which are Butterworth, Chebyshev, Inverse Chebyshev, and Elliptic. Each filter has also four types of behaviors, which are low-pass, high-pass, band-pass, and band-stop. Fig. 4 shows an example of low-pass filtered signal. A signal bearing uniform white noise comes into the low-pass filter VI and is processed. In front panel, operators can see only filtered signals, but they can see original signals also by changing the order of the filter and the cut-off frequency. This operation is useful to operators for understanding signal processing and the concept and the characteristic of each filter.

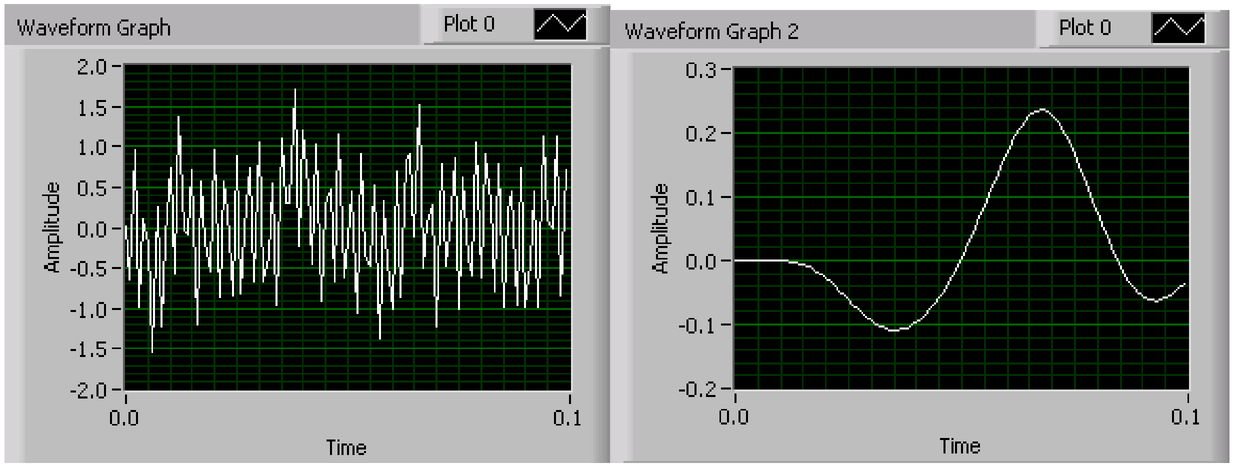

Fig. 4 An Example of a Low-Pass Filtered Signal

The system can generate eight different analyzed signals, which are: Power Spectral (PSD), Cumulative Power Spectral Density (CPSD), Fast Fourier Transform (FFT), RMS value, AC and DC values, Histogram, and Cumulative Histogram. By showing these eight different analyzed signals to remote operators, they could have a chance to understand and analyze signals in time, amplitude and frequency domains. In Fig. 5, two different analyzed signals are shown as an example.

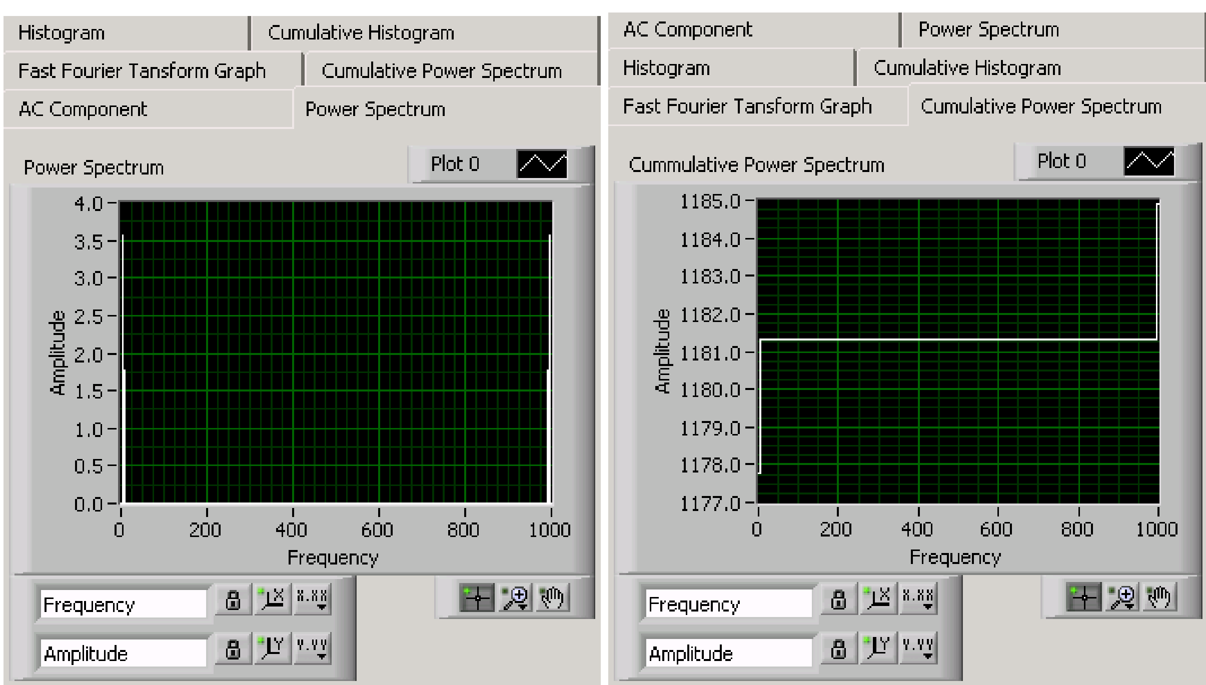

Fig. 5 Analyzed Signals (Power Spectrum and Cumulative Power Spectrum)

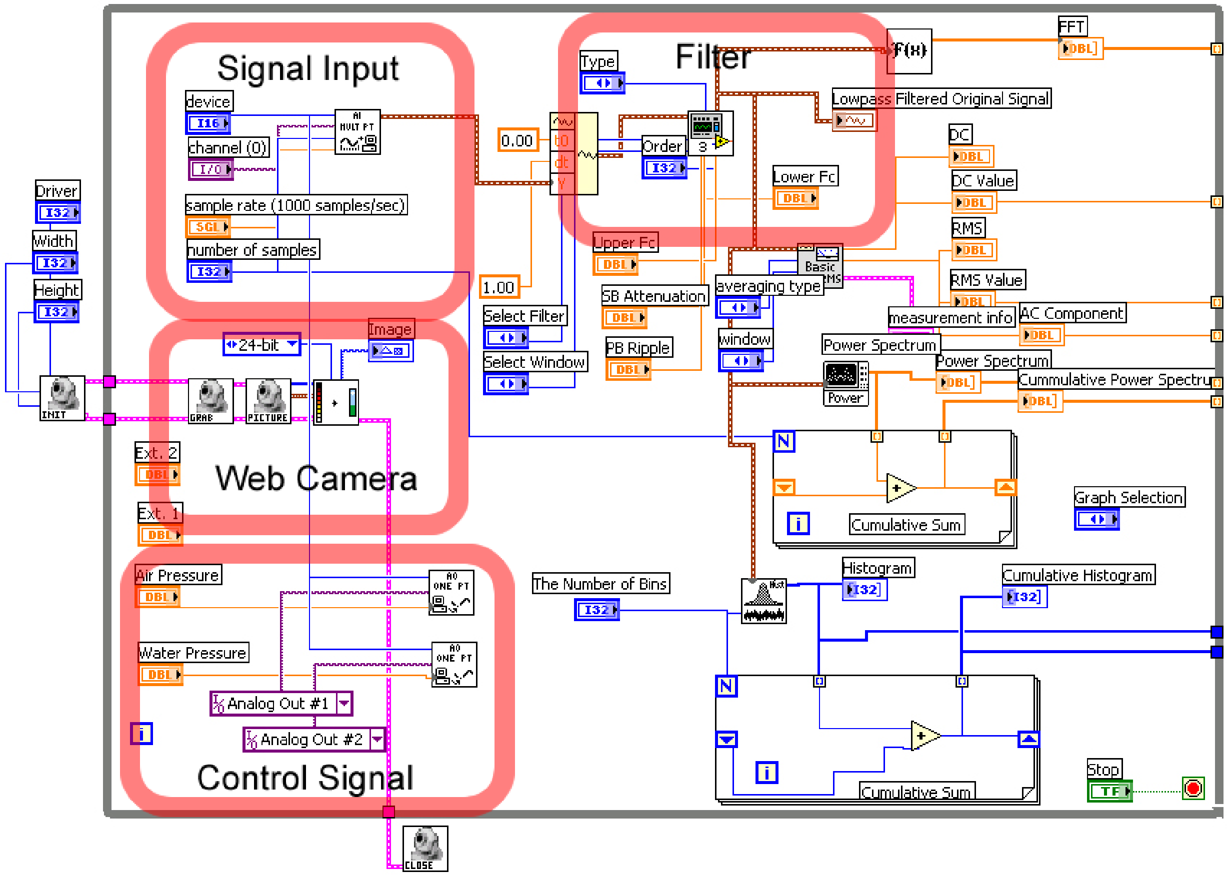

Fig. 6 Actual LabVIEW Language Implementation (Sub VIs' diagrams not shown)

The system VIs consist of a data acquisition, a filter, a DC/RMS separation, an image acquisition, and analysis VIs including: Power Spectral (PSD), Cumulative Power Spectral Density (CPSD), Fast Fourier Transform (FFT), RMS value, AC and DC values, Histogram, and Cumulative Histogram.

Experimentation and Results

A web camera is focused on the flow tube as shown in Fig 2a., and shows the flow pattern at about 3 frames per second. The remote operator can view the experiment including the flow tube and the other equipment used in the experiment using a standard browser. The operator using a browser can set the air and water flow rates remotely. The remote operator can also observe the panel meter that displays the air and water flow rates through the rotameter readings, concentration of the air water flow mixture, pressure readings, film thickness and flow pattern via web camera output. He can also the trigger the collection of data files from both optical and pressure sensors. The files can then be downloaded to the user's computer for plotting, and analysis by program or by spreadsheet. The main concept in turning the locally controlled setup into a remotely controlled one consists of moving the user interface away from the experiment.

In this web driven experiment setup there are two components: the remote client and the local server with lab experiment. The remote client is a computer equipped with the user interface functions. The client software, with which the users can observe and act on the remote experiment, is an executable application compiled for the target platforms. The local server is the computer located in the laboratory and equipped with the hardware interface to the sensors and actuators of the two-phase flow experiment. The server software receives the client commands and transmits them to the real process. It also returns the current state of real process to the client. These two parts are linked through a communication layer built on LabVIEW Distributed Computing tools. I have introduced an approach to call a sub VI in LabVIEW, referred to as a call-by-reference. [5] Using this new mechanism, we can call a sub VI on a local or remote machine using TCP/IP transparently. The remote machine, acting as a server, needs to be correctly configured. Prior to calling the sub VI, the user needs to establish a connection with the server. On termination the connection needs to be closed. On the server side the user can specify the access by allowing or denying given address or domains. The user can also restrict access to the VIs called. To implement the remote experimentation we used four call-by-reference VIs. The first one transmits the controller parameters from the client to server, the second sends the measured values from server to the client and the last two implement watchdogs to detect if the client or server are still available. The user interface of the control software consists of an oscilloscope for signal visualization, a signal generator providing the reference and parameter settings for the controller. An additional window provides the visual representation of the results and the LabVIEW picture tool kit is used for this purpose. The image and sound of the physical setup are transmitted to the video with video conferencing software. The audio/video server runs parallel to and independently of LabVIEW on the computer connected to the real process (server).

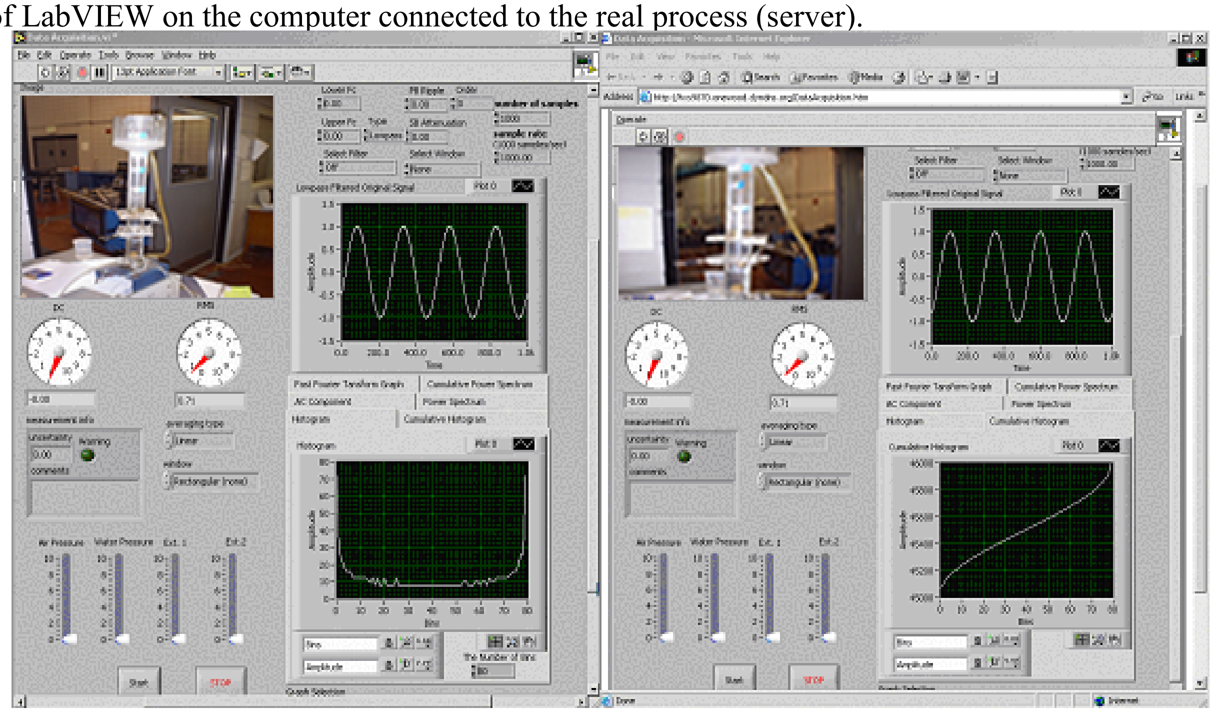

Fig 7. User Interfaces in LabVIEW and Web browser

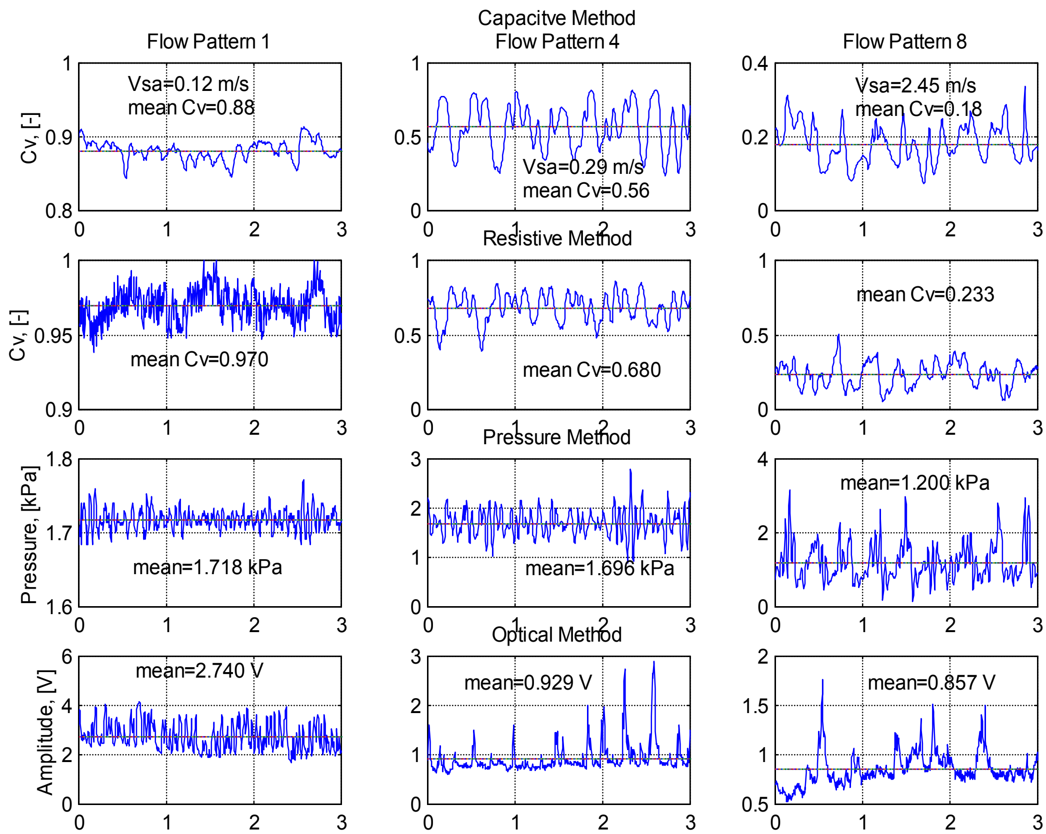

Fig. 8. Two-phase Flow Experiment Data for Four Sensors

For vertical flow there is transition from slug flow, which is discrete bubbles separated by minimally aerated water to churn flow, a chaotic mixture without clearly defined regions of air and water. The variations of flow pattern under different conditions are observed [2]. This transition can be seen on the video frames produced by the camera. The velocity of the air is changed keeping the velocity of the water constant. A graph is plotted with the voltage from the upper optical sensor as a function of sample index. In the plot the higher voltage corresponds to water and the troughs correspond to the passage of the bubbles [4]. For the low airflow rate water is present at the sensor about 70% of the timer. For high airflow rate the signal corresponds to relatively long bubbles separated by short slugs of water. Visual observations of the flow show smaller bubbles entering the bottom of the tube and coalescing as the flow moves up the tube with smaller trailing bubbles rapidly catching up and merging with larger bubbles.

The character of the sensor signal changes as the air velocity increases. At low velocities the signal is relatively periodic with a more random signal evident as the air velocity increases and churn flow appears. At high air flow rates (churn flow) the spectrum changes in two ways. First, the smoothened power is much more evenly distributed and extends to higher frequencies, approaching the spectrum of white noise. Second, the total power in the signal decreases as is also reflected in the standard deviation of the censored signal.

Conclusions

The developed web remotely operable experiment on two-phase flow consists of computer-aided experimental system connected with the Internet, web CCD camera, sensors of pressure and concentration, flow system with actuators for controlling flow of air and water mixture and software LabVIEW, which are located in the server near the experimental setup and remotely controlled by a user via the Internet. The flow rate changes impact the dependent variables, which characterized two-phase flow and generate a real time effect on the flow patterns and various other parameters related to the experiment such as average and fluctuating components of spatial concentration and pressure as well as a real image of the system and flow patterns.

Based on the data the system eight different products, which are: Power Spectral (PSD), Cumulative Power Spectral Density (CPSD), Fast Fourier Transform (FFT), RMS value, AC and DC values, Histogram, and Cumulative Histogram and send to distant operators giving them a chance to understand and analyze signals in time, amplitude and frequency domains.

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