Integration of *Teaching-by-Inquiry* Methods Into Undergraduate Classrooms

Jerry K. Keska, Ph.D.

Associate Professor, College of Engineering,
University of Louisiana at Lafayette,
P. O. Box-42972, Lafayette, Louisiana, USA 70506
E-mail: jkeska@louisiana.edu

Abstract

In the undergraduate teaching process, instructors and students alike often get bored solving simple, rather limited, classic textbook problems which require little if any imaginative thinking. To increase student interest and creative hands-on problem-solving skills, an innovative approach is needed that pushes students to their creative limits through the use of open-ended projects in which realistic, complex, challenging state-of-the-art problems are investigated. This new approach will increase student enthusiasm and provide closer alignment of classroom topics with today's standard industry practice.

This paper will deal with a unique application of the research/teaching method used at the undergraduate level, using a hands-on laboratory approach in conjunction with classroom lecture. The approach can be tailored to all levels from introductory freshman to senior-level classes. An open-ended project is utilized, requiring a creative approach for its solution. Faculty and students are both learners and investigators, formulating and solving challenging problems through the use of modern, up-to-date laboratory equipment. In this way, a full-cycle learning experience is realized, through development of an initial idea through the design and construction of a prototype and with the application of feasibility.

Introduction

One of the key issues, which significantly determines our tools and approach to any problem, is the determination of a process character, if it has a random or deterministic nature, or more realistic, the determination of the composition grade of both components and their significance in the phenomenon composition. Probably the following citation of Heinz Pagel, gives us an important clarification "The randomness at the foundation of the material world does not mean that knowledge is impossible or that physics has failed. To the contrary, the discovery of the indeterminate universe is a triumph of modern physics and opens a new vision of nature." In this matter one may argue successfully about a factual basis of a hypothesis that such general classification of processes for random or deterministic or predictable or unpredictable are rather a matter of perception, level of analytical depth, adequacy of the model applied, accuracy and completeness of observations used, the level of involved errors and verification process and/or other subjective correlation between dependant and independent variables or a combination of all the above mentioned components, rather than the character of the process itself. In other words, a purely random process, classified as a black box phenomenon from ones perception, could be fully deterministic from the perception of another person who may already know a deterministic model and is fully predictable, based on the known correlations. In addition to this controversy, this fact requires development of a list of challenging problems that need to be solved. In this sense a challenging problem is defined as a problem that is not yet solved satisfactorily and results could not be predicted with required accuracy (e.g. not ready-off-shelf instrument/system/solution is available and a solution is not known not only to the students but also to the professor).

One example of such a problem is the process of flow pattern recognition in two-phase flow, which currently is consider widely as a random (unpredictable) process and has continuously challenged the academic community since the 1940s. This problem is generating a group of especially challenging subjects for open-ended projects for both graduate and undergraduate courses. In this case, as in any experimental approach, the weight of such concepts such as uncertainty, error analysis, and data verification and identification, can never be underestimated[10].

Due to the complexity of "real-world" problems as illustrated by the above examples, there is broad agreement in the academic and industrial research communities that the learning process in these areas is a lifelong perpetual procedure wherein subjects (technical focus) and tools are changing constantly. The importance of exposing students to all possible scenarios in approaching deterministic or random processes, especially where the complexity of the problem involves superposition of both deterministic and random procedures, is therefore paramount. Successful students must have the knowledge and confidence of how to approach such complex problems, to dissect, analyze and then synthesize the problem, and to intelligently interpret and validate the results obtained.

Teaching by Inquires

In an attempt to increase student interest and ability in creative hands-on problem solving skills, an application of research and teaching by inquiry approach is introduced in the undergraduate level classes. In these classes, an open-ended project vehicle is used in which problems to be solved are intended to be realistic and complex, state-of-the-art and challenging, to generate and intensify the enthusiasm of the students and to more substantially prepare them for the "outside" world. It is crucial that the students need to understand their participation in the discovery process where they need to be active participants, not only passive receivers. In such processes, faculty members and students are simultaneously learners and investigators, whose communications support a more effective learning process and generate benefits for both.

One of the preliminary requirements for successful implementation of these processes is to make appropriate choices of references used to access such resources as patents, refereed papers and reports, and electronic databases via the library or the Internet. In the selection of resources, two key issues are (1) the use of objective and accurate references, and (2) access to state-of-the-art information. Two of the most important sources of information in this case are refereed journal papers and patents. Limited subject knowledge on the part of the student, and a plethora of relatively easy-to-access scientific (and pseudoscientific) information on the Internet, create a situation requiring the need for intense involvement of process knowledgeable faculty in the teaching process. This includes defining rigorous criteria for evaluation of quality resources before use in a learning and application process. Due to the broad spectrum of materials available on the net and their ready accessibility, there is also the ever-present danger of plagiarism. This therefore requires that the instructor explain to students the ethical and judicial repercussions, which hopefully will guide students to self-policing[10] .

The *teaching-by-inquiry* method involves defining the subject and scope of an open-ended project, in conformance with the following objectives:

1. An introduction to the creative thinking process by finding a solution to a challenging problem which involves a full cycle of activities beginning with brainstorming to create alternative solutions, through design and construction of the first prototype, including a feasibility study, prototype evaluation and redesign, and finally an engineering report documenting the design, development, test and evaluation of the end product;
2. Background search for the closest related solutions (from web sources, refereed journals, patents, and library materials), which provide comparisons to the approach, implemented in the process.
3. Introduction and application of uncertainty and error analysis including an error reduction process;
4. Use of a computer-aided experimentation and research process using tools such as Matlab, CADAS, the Internet, Lab VIEW, spreadsheets, graphics software, and other electronic data basis);
5. Prediction of the results from theory, and application of the phenomenological approach coupled with physical experimentation to verify the theory and assumptions used;
6. Application of data analysis and verification techniques (bias and precision errors, literature comparisons, concomitancy and redundancy).
7. Computer-aided communication and dissemination of results (class and conference presentations, reports and publications).

A challenging problem, in this context, is defined as a problem, which has not been solved satisfactorily on the industrial level, i.e., a ready-off-the-shelf solution is not available to students or professor. Such a problem will normally lend itself to the application of a phenomenological approach requiring a literature search, computer usage and application, utilization of random and/or deterministic analysis techniques, and compatibility for a full-cycle solution from the initial idea, through design and prototype development, feasibility/proof-of- concept, and final report with a formal presentation, followed by prototype improvement (see appendix).

Examples of challenging open-ended problems well suited to the teaching by inquiry method are [1, 2, 3, 4, 10]:

(a) Spatial and temporal distribution of concentration;
(b) Flow pattern recognition;
(c) On-line viscometer;

(d) Multi-phase flow measurement systems;
(e) Wear in machinery; and
(f) MEMS (Micro-Electro-Mechanical Systems) including fluidics, two-phase flow, and micro heat exchangers.

The *teaching-by-inquiry* process is started by introducing students, in the shortest possible way with hands-on experience, to the following subjects:

1. How to find quality resources on the net and in the library? (including patents, refereed journals and reports).
2. How to approach, design and build a unique system in full cycle?
3. Experiments and experimentations, including data collection and analysis, data validation using concomitant measurements and redundancy, error and uncertainty analysis and reduction, data analysis and presentation.
4. Web and computer applications.
5. Demonstration of a complex open-ended project including experiment, report, paper and presentation.
6. Students are conducting a complex experiment with all of those elements including background search and presentation of results.
7. Report writing and presentation process. Evaluation criteria, which are included in the appendix.

In the next step, a request for proposal is issued and collected for which an example is included in the appendix. After teams and proposals are accepted, teams consisting of one to three students begin to work on the topic, doing a background literature search and analyses. Based on the search and analysis, teams designed their first prototype with a feasibility study program, and definition and measure the final product success. This is the subject of the first part of each team's report submission. If the report is accepted, it is graded and returned to students with feedback. If a report is not accepted it is also returned to students with listed deficiencies, which need to be addressed. The final step is to build a first prototype, conduct feasibility study, analyze data, write a final report, and make a presentation. The following results were generated in open-ended projects [10]:

Two-Phase Flow

To illustrate the process using state-of-the-art tools, the combination of first, second and fourth problem with the application of computer-aided and web driven experimentation in the above list are selected for discussion. In a two-phase flow system, the flow depends on dynamic parameters such as concentration, velocity, and film thickness. Different patterns result for changes, even imperceptible ones, in these parameters. If such a flow is passed through a vertical round tube, a bubbly flow regime is created at low gas-fraction rates, and as the gas fraction increases, the flow coalesces into "slug" flow, "churn" flow and other regimes, until annular flow finally appears. These individual flow patterns require different and often sophisticated observation techniques for full understanding of the mixture components in time and space, the combination of which constitute the whole of the complex flow pattern.

Flow patterns observed by different researchers employing various methods consistently produce different results for the same flow conditions. This is caused not only by differences in the method used, but also by varying calibration procedures' validation criteria, which makes it extremely difficult for investigators to analyze and compare the results. A typical experimental apparatus consists of a vertical transparent column with a cluster of four flow-pattern-measurement systems [Fig. 1]. The apparatus accommodates closed-loop water and open-loop airflow. A mixing chamber positioned at the bottom of the vertical channel allows the mixture to enter the column. Sensors from each of the four measurement systems are positioned in a cluster [1, 3, 4].

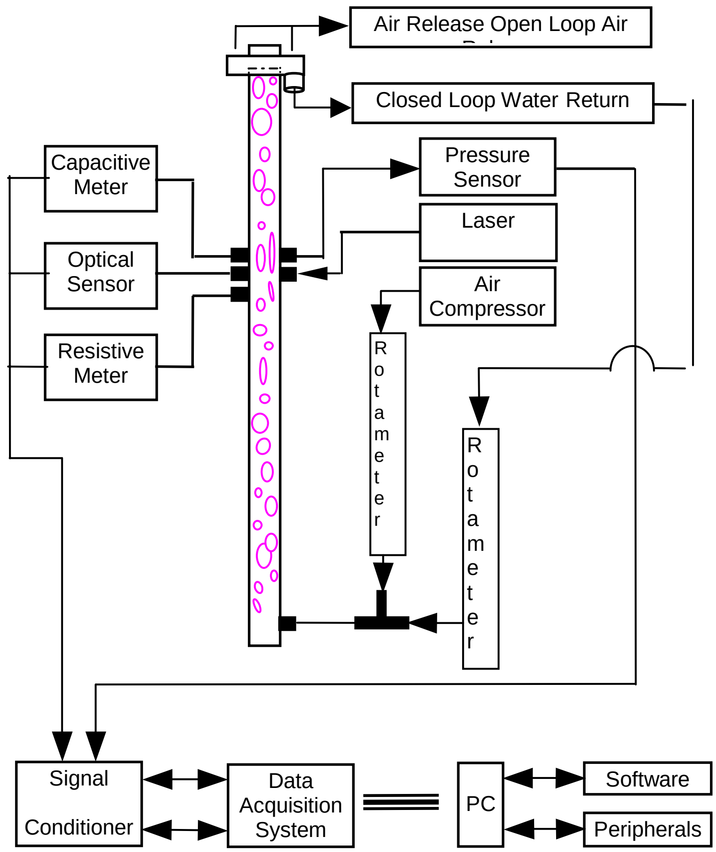

Figure 1. Experimental apparatus for a vertical closed-loop adiabatic two-phase flow system

This experimental system allows the measurement of in-situ signals concurrently in the same space and at the same time. Signals from each sensor are conditioned to a proportional voltage signal, which is converted to a digital input to a computer-aided data acquisition system. A multichannel interface allows signal storage from each measurement device concurrently. This concurrent collection of signals from each system, arranged in a cluster, insures that all devices will be compared based on signals collected during the same flow conditions. This cluster arrangement and simultaneous data acquisition permits a direct comparison of each method's ability to distinguish between a spectrum of flow patterns even without a definite determination of the precise flow pattern and flow parameters.

Four measurement devices are employed in this system. A capacitive system measures in-situ spatial concentration and consists of two non-intrusive opposing electrodes placed inside the flow channel. This capacitance signal is then transformed into a proportional voltage signal, which is then interfaced with the signals of the other three devices into a computer-aided data acquisition system, which allows simultaneous data collection with a sampling frequency of 1 kHz. The calibration method consists of a correlation between the capacitance and the in-situ spatial concentration, as described in the literature [1, 3].

The optical device consists of a laser, optical resistor, and resistance meter. The laser is positioned 180 degrees from the optical sensor on the outer surface of the transparent channel. The light beam is directed onto the receiving surface of the optical resistor, where the output voltage of the resistance meter is dependent upon the intensity of the light on the surface of the optical resistor. This intensity varies due to light scattering at the curved interfacial surfaces present in two-phase flow [1]. The maximum voltage output from this system corresponds to the highest achievable light intensity acting on the surface of the optical sensor. Due to total light scattering, the minimum voltage output of this system corresponds to the condition when only the ambient light is acting on the optical sensor. The static pressure system consists of a pressure sensor, which measures the static gauge pressure in the channel. The static pressure fluctuates because of physical conditions inside the channel.

The resistive system measures the in-situ concentration based on the difference in resistivities of the mixture components, while the resistance meter measures the resistance of the sensor and transforms it into a voltage signal, which is directly proportional to the void fraction. These signals are then evaluated using statistical analysis tools, which include characteristics in time, amplitude, and frequency domains, such parameters as (root mean square) RMS, (probability distribution function) PDF, (cumulative probability distribution function) CPDF, and (power spectral density) PSD values[1, 3, 4].

In Fig. 2 are shown the experimental data collected at flow numbers 1, 4, and 8. For each of the figures, shown are the time traces in row ***A*** for each measurement and three of the eight flow patterns are chosen. Flow 1 was bubble flow, 4 was slug flow, and 8 was churn flow. The name of the pattern is chosen on visual observation of the naked eye and only to be used as a rough approximation. In row ***B***, the data collected from each system at flows 1, 4, and 8 are shown in the amplitude domain as a function of the frequency of occurrences. In row ***B*** of these figures the shape and range of distribution of the frequency of occurrences is important in the evaluation process. Differences in the range of distribution of a method's signal from one flow pattern to another can help to distinguish between flow patterns and generate differences in the CPDF from flow to flow, which are also important in the discrimination process. Row ***C*** is the plot of the PSD for each system at each of the flows, which is used to analyze the frequency structure of the primary signal

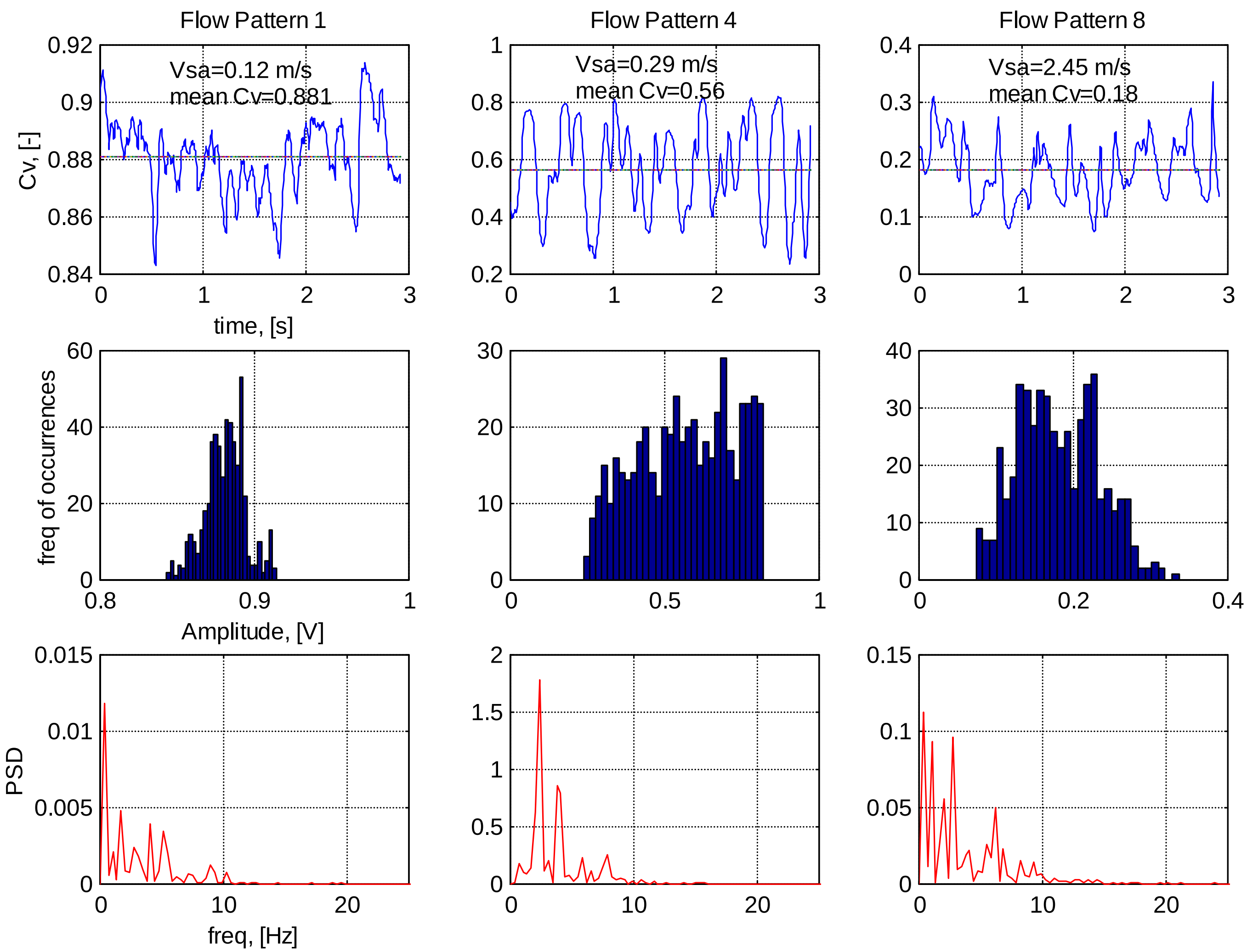

Figure 2. Concentration Signals for Capacitive Method; Time Domain (A: top row), Amplitude Domain (B: middle row), and Frequency Domain (C:bottom row).

The results of RMS values vs. in-situ spatial concentration for all four implemented systems at each flow condition (1-8) are shown in figure 3, in which the RMS values are plotted against the average concentration for each respective flow condition. For an overall view of each method's RMS characteristics with respect to average concentration, a "best fit" curve has been drawn in to represent the most likely characteristics. One possible approach to compare the ability of each method is by using criteria that determines the sensitivity of each method. This sensitivity can be directly related to the absolute value of the RMS and the slope of the curve over a particular range.

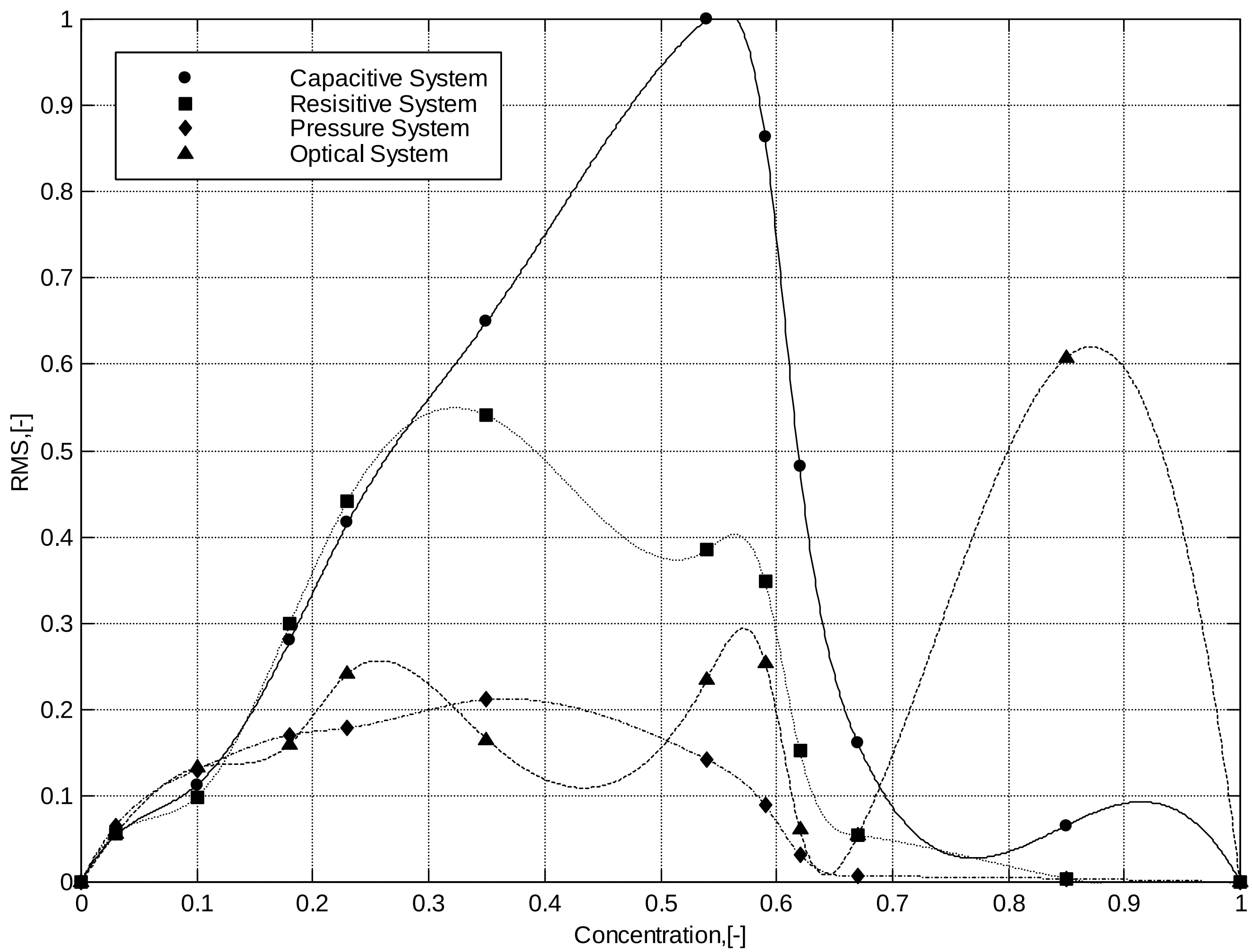

Figure 3. Comparison of RMS values of each signal obtained from four systems (capacitive, resistive, pressure, optical arranged in the cluster) vs. in-situ spatial concentration of two-phase flow.

Due to the fact that distance-learning process requires use of remote experimentation, the system is modified to allow remote students to easily run experiments, change control parameters and analyze the results remotely. This modified web-based experiment (Fig.4) is designed to use the Internet as the primary means to control the devices and equipment used in the two-phase flow experiment.

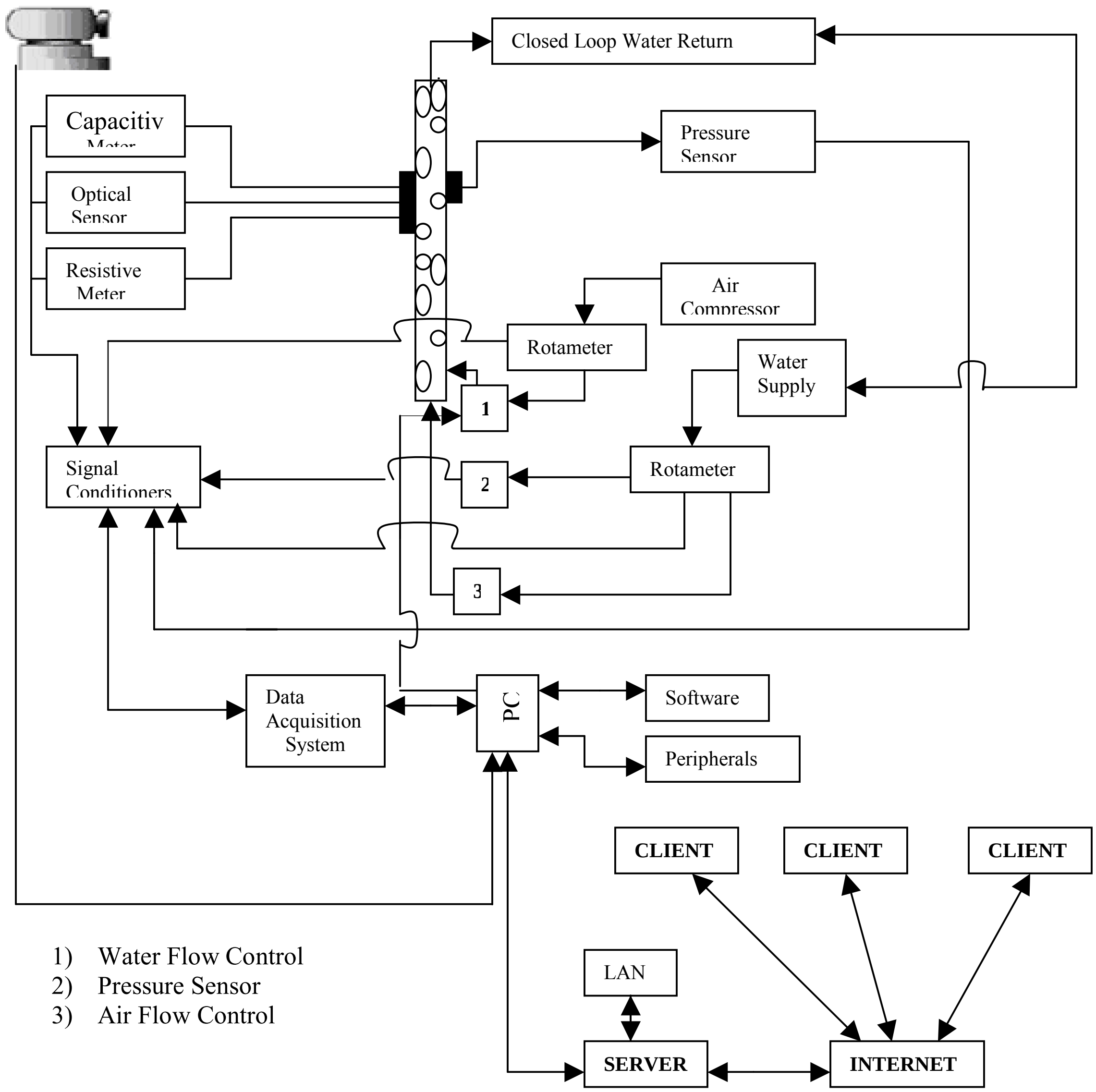

Fig 4: System for Web Driven Experimentation on Two Phase Flow

The experiment involved concurrent flow of air and water in a transparent vertical tube. A web camera is focused on the tube, which enables the remote operator to view the flow patterns in the tube. The operator can set both the air and water flow rates remotely by using I/O system. Sensors are used to measure the flow parameters in the flow tube. The remote operator can get the data files at any instant of time, to analyze the results. The student can typically connect from a remote client to the lab server, choose the experiment, change some parameters and run the experiment. Through the use of Web-based methodologies, the laboratory learning environment is extended to the "anytime, anywhere" remote user by making this experiment available for on-campus students as well as off-site locations throughout the world. This experiment uses a standard Pentium PC with Windows2000 operating system along with National Instrument's Lab VIEW software, data acquisition hardware, and Web-server. Control of the experiment is initiated from a standard 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 apparatus remotely, equipment can be operated and the data acquired and analyzed from anywhere.

The control software piloting the real process locally is a virtual instrument (VI) using LabVIEW. An in-house real time kernel extends LabVIEW capability and guarantees high speed and accurate pace. 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 purpose of such an interface is to provide a general view of the real process evolutions and facilitate full control of the operations. (Fig5)

Experimentation and Results

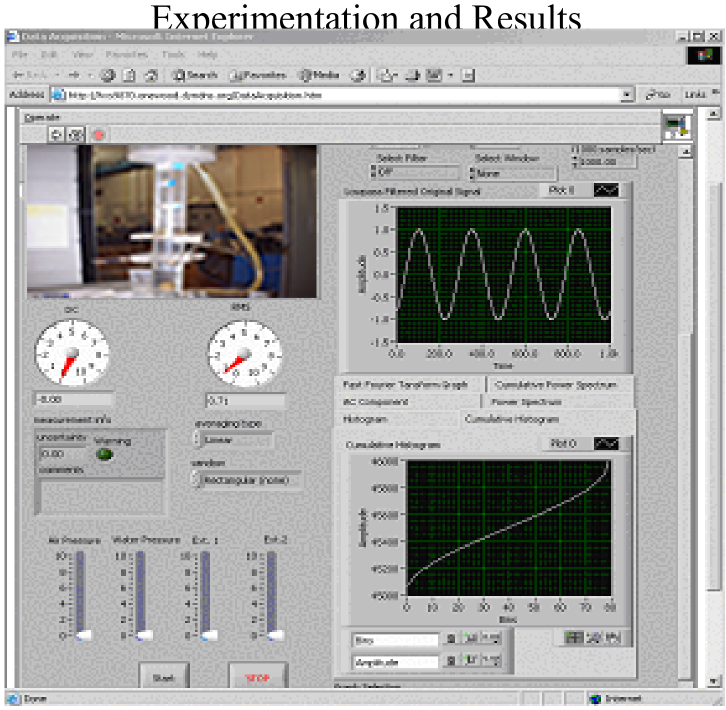

Fig 5: An example of Front Panel of a client VI

In the signal analysis of two-phase flow, the parameters are measured using conductive and capacitive sensors, which are interfaced to the DAQ with a signal conditioner, generating signals proportional to the in-situ concentration[1, 3, 4]. A CCD camera is generating real images of the two-phase flow in the system and is interfaced to the CAS.

The random fluctuations of the two-phase flow air-water mixture is converted into digital signal and then interfaced to the PC employing a DAQ board, which is interfaced through the LabVIEW virtual instrument and displayed in the front panel (Fig.6). Then using LabVIEW VI the signal's various properties are determined. The properties considered for the random signal generated by the two-phase flow are RMS value, PSD, and PDF prominently, which are normalized and calibrated (N&C) and displayed in the front panel of labVIEW. Simultaneously the output signal is also normalized, scaled, displayed and sent to actuators to control the two-phase flow process.

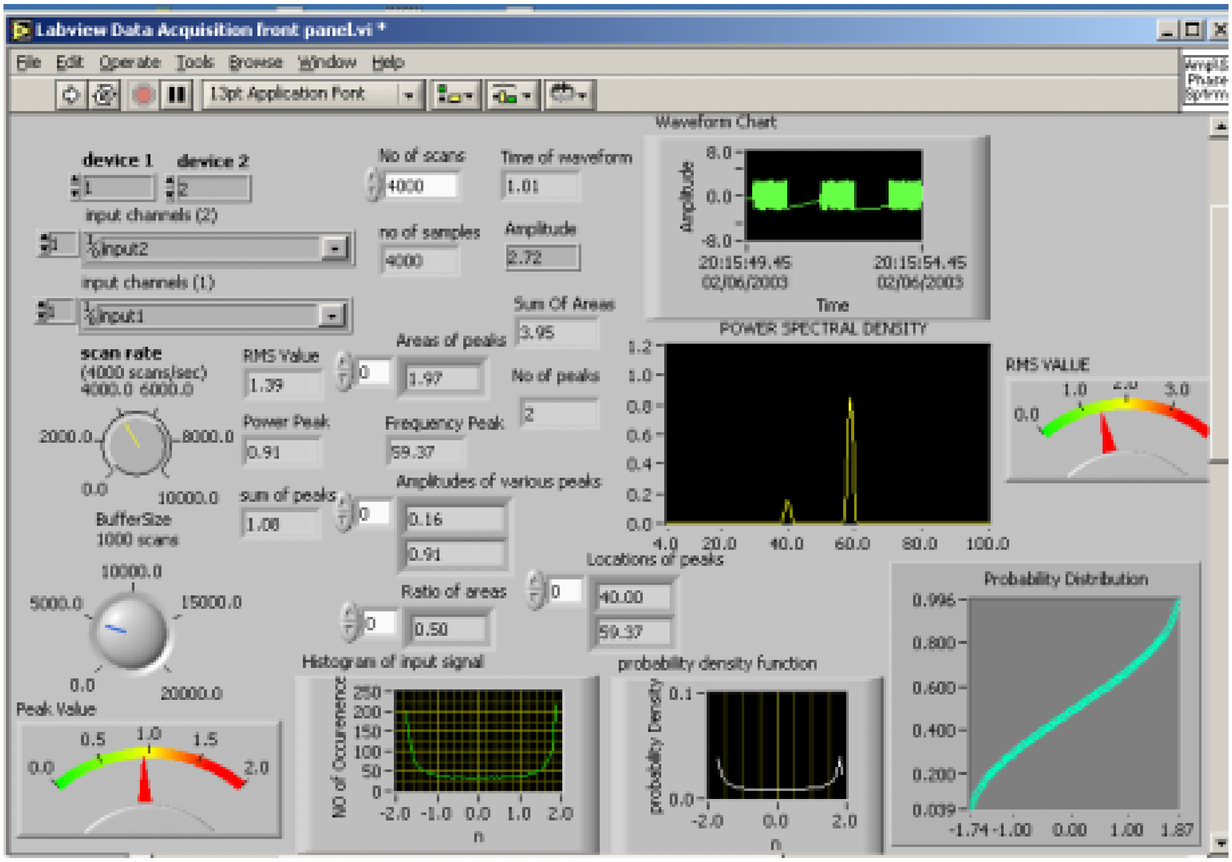

Figure 6. LabVIEW Virtual Instrument Front-Panel Interface

LabVIEW Virtual Instrument Front-Panel Interface provides accurate and interactive control and display of measured and analyzed parameters such as RMSvalues of the signal, probability distribution function, PDF, histogram, peak detection, number of peaks its frequencies and amplitudes, and PSD. The measured and calculated parameters are displayed graphically, along with their values, and limits wherever appropriate. The control of all functions and data acquisition settings is conveniently provided through the virtual instrument's "front panel" interface.

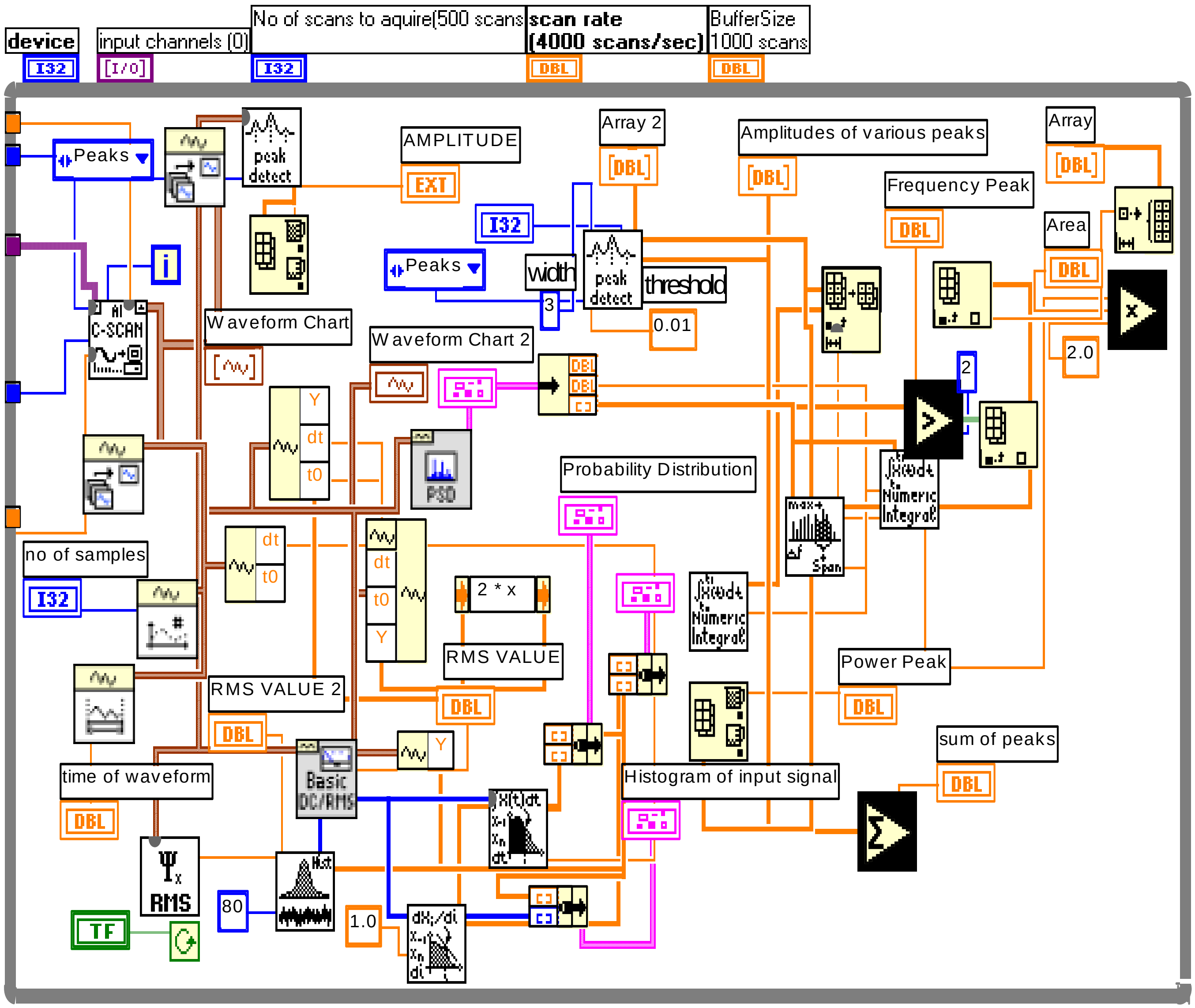

Figure 5. Block diagram of computer-based data acquisition system for VI.

The other example of use of the World Wide Web for remotely controlled experiments that have opened new-excited opportunities for students and customers, is the participation in on-line physical experimentations on heat transfer and heat losses in buildings. In the analysis of thermal energy losses for a building, three components of thermal energy transfer need to be considered. These components are thermal energy conduction, convection, and radiation. The conduction component is influenced by; gradient of temperature in the exterior surfaces; the thermal conductivity; the effective area of exterior surface; and differences in air humidity between internal and external environment. The radiation component is in function of the temperature difference

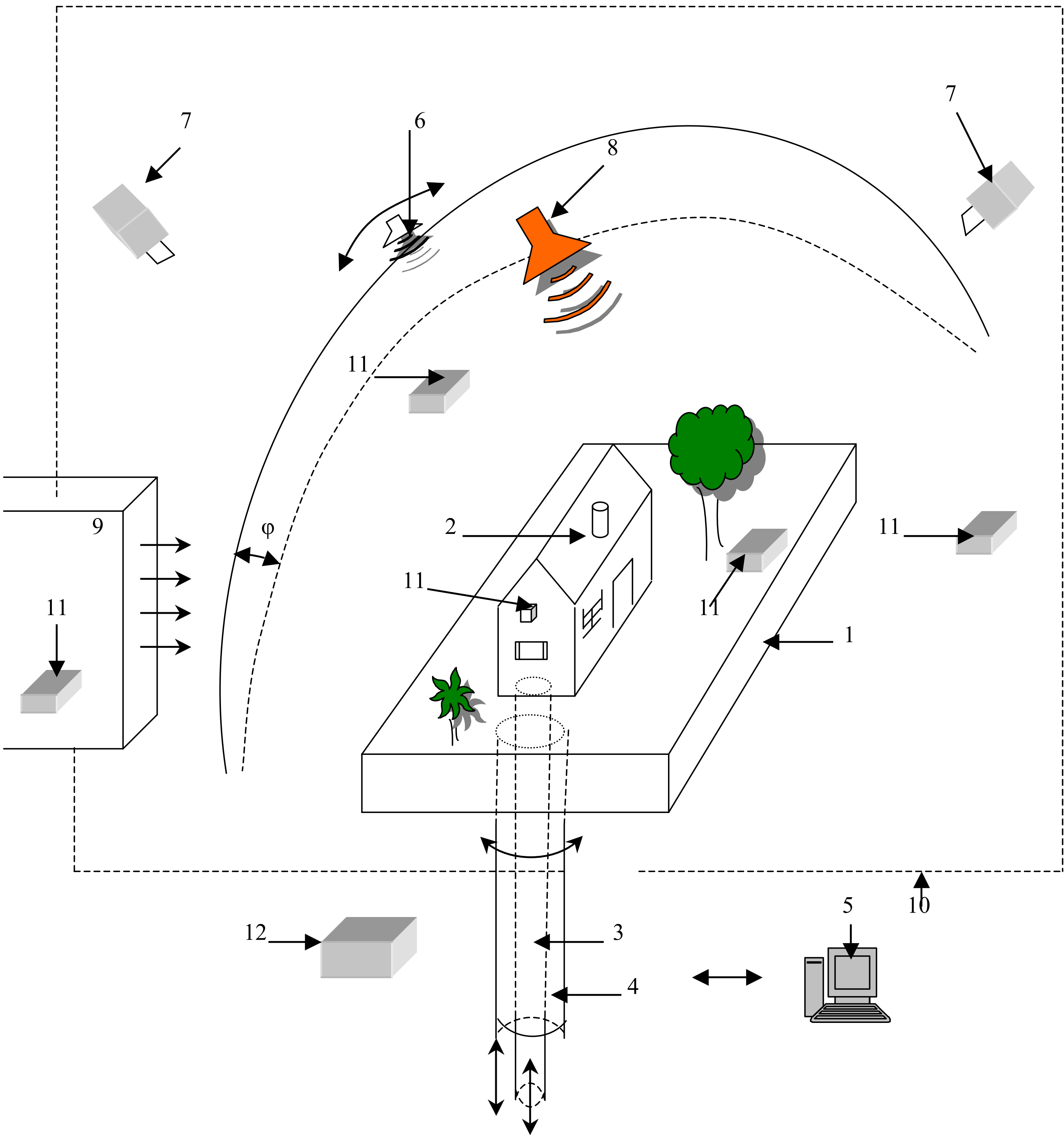

Fig.6. The Internet-controlled experiments for heat losses in buildings.

Heat Losses In Buildings. The Internet-Controlled Experiments (Description of Fig.6).

1 – Down scaled physical model of the building's surrounding (scale 1:15).
2 - Down scaled physical model of the building (scale 1:15).
3 – Input/output pipeline for independent parameter controls and measurements inside the building.
4 - Input/output pipeline for independent parameter controls and measurements of the building base.
5 – Computer/server systems.
6 – Computer controlled system of the sun radiation.
7 – Infrared and visible light cameras.
8 - Computer controlled system of raining.
9 - Computer controlled system of air parameters and motion.
10 – Physical systems located in the ULL laboratory.
11 – Measurement and control systems for each subsystem.
12 – Highest priority system's control console.

between inside and outside environments. Thermal energy losses due to the conduction and radiation components depend on temperature difference, the geometry and area of the building, and the thermal characteristics of the material used for the building. However, both conduction and radiation require different calculations for thermal energy losses for each construction component of the building (floor, roof, walls, etc.).

In determination of the total thermal energy transfer from or to a building, not only extreme but also average conditions are of concern. Partially thermal energy transfer is due the value of a temperature gradient of a building/environment system. Also thermal energy transfer is generated due to the air infiltration and other fluid flows in and out of the building. The magnitude of thermal energy transfer by fluids in both directions is determined by examining the flow rate of fluids, temperature of fluids, and inside/outside environments, and the thermal properties of fluids, which enter or leave the building. Also it is important to notice that the magnitude of the air exchange rate changes proportionally to the outside temperature.

Thermal energy that is emitted to the sky from the exterior surface is considered to be radiative component. Since radiation is a surface phenomenon, both the surface area and the surface property (emissivity) of the exterior wall material must be obtained for each exterior component of the building. After radiative heat energy losses of all components are found, they are summarized to receive the total thermal energy loss for radiation in the building.

Thermal energy conduction is the transmission of heat energy through a solid of specific characteristics. In a building analysis that solid may be a floor, roof, wall or window. Thus, each of these components will be a composite of many different materials. All materials could be characterized by a resistance (R) value, which is in function of the thickness of the material, and the easiness by which heat passes through it. R-values are determined experimentally. Conductive heat energy transfer is inversely related to R-value. Since the higher the insulating values of the material, the higher the R-value, the lower heat energy is transmitted through the material. For heat conduction, interior and exterior temperatures and distance produce the temperature gradient. When energy heat losses of conduction, convection, and radiation are derived and summed up they give the total thermal energy loss of the evaluated building. The calculated total thermal energy loss may be used to optimize this building construction process or components such as AC or heating system. Using a concept of a web-driven experimentation system (Fig. 6) for the total thermal energy losses of the building, an offering of experiment-oriented problem solutions can be obtained in real time for requested design accessing from any locations to eliminate barriers of space and time.

Conclusion

The "teaching-by-inquiry" method details measurable objectives for accomplishing the process goals, including activities by means of which the objectives will be achieved. Examples of typical problems and projects are discussed to illustrate the use of the *teaching-by*-inquiry method, which will hopefully give the reader a feel for the tools, efforts and equipment required for the implementation of such a process.

References

1. Keska, J. K., M.D. Smith, and B. E. Williams, "Comparison Study of a Cluster of Four Dynamic Flow Pattern Detection Techniques," Flow Measurement and Instrumentation, Vol. 10, pp. 65-77, 1999.
2. Kolar, Madhusudan and Jerry K Keska, "Preliminary Experimental Research on Flow Pattern Recognition," *Proceedings of the 2002 ASEE Gulf-Southwest Annual Conference,* IVA4, The University of Louisiana at Lafayette, March 20 – 22, 2002.
3. Keska, J. K. and B. E. Williams, "Experimental Comparison of Flow Pattern Detection Techniques for an Air-Water Mixture Flow, "International Journal of Experimental Heat Transfer, Thermodynamics, and Fluid Mechanics, Vol. 19, pp. 1-12, 1999.
4. Keska, J. K., M.D. Smith, and B. E. Williams, "Comparison Study of a Cluster of Four Dynamic Flow Pattern Detection Techniques," Flow Measurement and Instrumentation, Vol. 10, pp. 65-77, 1999.
5. Ch.Saltzmann "Introduction to Real Time Control Using LabVIEW with an Application to distance learning", IJEE 1123*, International Journal of Engineering Education vol. 16, No. 2*, Great Britain.
6. Ch.Saltzman "Requirements for real-time experimentation over the internet, International Conference of Engineering Education", *Proceedings of 1998 International Conference of Engineering Education, paper 222*,Rio De Janeiro, Brazil (1998)
7. Jefrey Y.Beyon, "LabVIEW Programming, Data Acquisition and Analysis", 2001, Prentice Hall, New Jersey.
8. www.uspto.gov
9. www.matweb.com.
10. www.ucs.louisiana.edu/~jkk9202/

JERRY K. KESKA

Dr. Keska, a mechanical engineer, currently serves as an Associate Professor of Fluid Power and Mechanical Systems in the College of Engineering at the University of Louisiana at Lafayette. His research interests are in the areas of Microelectromechanical Systems (MEMS) including microheatexchangers and microsensors, fluid dynamics of complex heterogeneous mixtures (multiphase, slurries), computer-aided measurement systems and instrumentation of turbulence and flow pattern phenomena in mixtures, and deterministic and random signal analysis including data validation process using web-based experimentation.

Appendix

EXAMPLE PROJECT

Requirements for

Design Project and Feasibility Study (Open-ended Project)

1. Submit a project proposal on the following subject:

Wear, defined as unwanted material removal, is a subject, which is known and experienced by all engineers. It strongly impacts the national economy as well as the life styles of most people. Very often wear is accepted as the natural consequence of use; that is, a certain level of wear is accepted as normal and no attempt is made to improve the situation. For some applications this judgment may be correct; however, for others there may be significant cost penalties. From a national point of view, wear is very costly to the economy. At a recent workshop by the Office of Technology Assessment, U.S. wear costs were documented in various equipment categories. Some examples (in 1975 dollars) were as follows: Naval aircraft, $243.87/flight hr; Navy aircraft tires, $1,853,200/year; Navy ships, $38.92/ship hr; cutting tool wear, $900 million/year. Automotive maintenance and repair costs were estimated to be $40 billion per year, a large portion of which could be attributed to wear. In a recent report by the National Institute for Standards and Technology (formerly the National Bureau of Standards), $70 billion was estimated for corrosion, and $20 billion for wear. Peterson estimates, using two examples (fighter aircraft and ships), that the cost of wear per year is approximately two-thirds the fuel cost. These figures indicated that the cost of wear is large and national efforts should be made to reduce it.

Wear is not only a failure mode but also a prime cause of secondary failures. Worn parts lead to increased vibration and fatigue, shock loading, and misalignment, all of which increase the probability of equipment failure. In addition, wear debris can cause seizure of spalling failures in other components. Even if failure does not occur, wear causes deterioration in performance. Energy is lost by the wear and loss of compression in internal combustion engines. Pumps and compressors become less efficient as wear occurs in the pumping elements and seals. This loss of efficient operation may well be the major cost of wear.

In design and operation of mechanical equipment, the engineer is faced with a number of problems, which relate to wear. Here the wear limit must be known, and is usually supplied by the manufacturer when critical. In addition, some means must be available to ascertain the present level of wear. The simplest approach is to disassemble the equipment and measure the wear. This may not always be possible and is usually an expensive process. For many applications (e.g. brakes), it is possible to install wear gages, which give a continuous measurement of the dimensional change. Very often indirect methods are used, such as oil analysis, ferrography, or changes in operating parameters such as pressure, temperature, motions, or noise. Where direct or indirect measurements cannot be used, then some predictive scheme must be used to estimate the dimensional change.

Learn more about this subject and devices as well as a method of wear measurement, direct or indirect (Literature study, professional discussion, etc.). Submit a short project proposal describing your idea of wear measurement, and failure prediction and detection.

GENERAL NOTE: You are encouraged to work in teams (up to three students) and submit a single formal report per team. For your open-ended project, submit a proposal describing your idea with time, references and realization plan for instructor approval. For report requirements and evaluation procedures see guidelines in the Laboratory Manual.

Design Project and Feasibility Study (Open-ended Project)

Group ( )
Individual ( )

FINAL EVALUATION

Date:

Project Team: ______________________________ Project Leader: ______________________________

Project Title: ____ Difficulty Factor ______

		Available Points	Received Points
1.	Meets proposal submission deadline and proposal quality of the FSP	10	
2.	Literature and patent search (documentation, discussion and analysis)	10	
3.	Deadlines (late penalty - minus 10 points per day)		
4.	Design process (group dynamics, progress during project, resources, experiment construction and development of the project, feasibility study, working prototype)	30	
5.	LAB WORK: Data base, test matrix, accuracy, procedures, documentation of experimental activities, and analysis and interpretation of data	30	
6.	REPORT	10	
	6.1. Procedures and quality		
	a. Graphs and curve fitting		
	b. Numerical results, data analysis		
	c. Valid principles and assumptions (discussion)		
	d. Interpretation of the results		
	6.2. Neatness, readability, typing and nomenclature		
	6.3 Contents		
	a. Report completeness (See substantial elements)		
	b. Error and uncertainty analysis		
	c. Comments, observations and conclusions		
	d. References (only used in the report)		
7.	Project presentation	10	
	TOTAL	100	