Available online at www.sciencedirect.com

SCIENCE DIRECT®

Journal of Food Engineering 67 (2005) 129–133

JOURNAL OF FOOD ENGINEERING

www.elsevier.com/locate/jfoodeng

Remote experiments for food engineering

E. Palou [a,*], J. Welti-Chanes [a], R.P. Singh [b], A. López-Malo [a], L.G. Guerrero [c], J. Carrillo [c], J.M. Ramírez [c], K. Athmaram [b]

[a] Departamento de Ingeniería Química y Alimentos, Universidad de las Américas, Puebla Cholula, Puebla 72820, Mexico
[b] Biological and Agricultural Engineering, University of California, Davis 2042 Bainer Hall Davis, CA 95616, USA
[c] Departamento de Ingeniería Electrónica, Universidad de las Américas, Puebla Cholula, Puebla 72820, Mexico

Received 10 October 2003; accepted 1 May 2004

Abstract

A set of seven laboratory exercises that contain remotely conducted experiments assisted by the Internet were created for teaching food engineering courses at the University of California, Davis (USA) and Universidad de las Américas, Puebla (Mexico). To illustrate how a remote-controlled experiment is structured, one experiment (*Dynamic Response of Sensors*) is described. The positive feedback received from students indicates that the exercises are useful in laboratory classes to develop a self-paced understanding. In lecture-only classes, students noted that these experiences enhanced their learning of concepts that were difficult to understand from textbooks. Exercises have been most advantageous in engaging students in an interactive Internet activity prior to conducting a more comprehensive laboratory experiment. A complete set of instructions including software on how remotely conducted laboratory experiments may be set up, is available to motivate other instructors to create additional Internet-assisted exercises.

Keywords: Internet-assisted exercises; Remote experiments; Food engineering laboratory

1. Introduction

A paradigm shift is taking place in education. Teaching success in today's world requires new instructional approaches. Universities are increasingly using the Internet to improve undergraduate learning, since as noted by Rudenstine (1997), the Internet offers several advantages in education: it provides access to essentially unlimited sources of information not conveniently obtainable through other means, it allows for the creation of unusually rich course materials, it is potentially an exceptionally fine tool for creating densely woven, unusually engaging and highly demanding new course materials, it can enhance the vital process of "conversational" learning, including extended office hours and discussion groups unbounded by time or place, it can reinforce the conception of students as active agents in the process of learning, not as passive recipients of knowledge from teachers and authoritative texts, it calls upon the student to be active and engaged—following leads, distinguishing the substantial from the trivial, synthesizing insights drawn from different sources, formulating new questions (Singh, 1996, 2002).

Because hands-on experience is of paramount importance in learning, educational curricula in every field emphasize inclusion of laboratory or field experiments to supplement lectures. This is of particular importance in food science and engineering related areas and thus often sought. However, the investment necessary to create adequate laboratory space with accompanying resources tends to limit the amount of experience available to a student. At the same time, the number

* Corresponding author. Fax: +52 222 229 2258.
E-mail address: enrique.palou@udlap.mx (E. Palou).

0260-8774/$ - see front matter
doi:10.1016/j.jfoodeng.2004.05.071

of students seeking higher education has continued to increase, while a large majority of universities continue to face ever-dwindling financial resources. Furthermore, many food industries located in developing countries or rural areas of developed countries are often at a disadvantage in obtaining high-quality educational materials for their staff. The Internet-assisted instructional materials being developed will be readily available to practicing professionals in the food industry who may want to update their technical skills. Lifelong learning outside of an academic setting must form an integral part of educational endeavors, as noted by NAS (1997). Distinction between learning inside of school and outside of school will blur. The food engineering discipline is quintessential to value-added processing of foods, because transport phenomena involving momentum and heat and mass transfer are the basis of many food processes commonly employed in the food industry. Internet-assisted remote laboratory experiments, complemented with multimedia tools, are aimed at increasing the effectiveness of food engineering instruction (Singh, 1999).

The objectives of this collaborative project between the University of California, Davis (UC Davis) and Universidad de las Américas, Puebla (UDLA) were: (i) create a set of instructional laboratory exercises, mainly in the area of food engineering that contain remotely conducted experiments assisted by the Internet, (ii) develop a complete set of instructions including software on how remotely conducted laboratories may be set up by an instructor, and (iii) evaluate the role of remotely conducted experiments in the effectiveness of teaching food engineering in undergraduate education.

2. Experiments

Internet-assisted laboratory experiments were created to complement undergraduate engineering courses and offered for worldwide use on the Web. The experiments are: dsynamic response of sensors, psychrometric properties of air, convective heat transfer coefficient of air, thermal conductivity of foods and biomaterials, image processing to determine shape characteristics of food and biomaterials, heat and mass balance across an air dryer, and monitoring of electrical parameters of either a DC or an AC motor. Each of these experiments has different components of complexity, from static measurement to dynamic movement of a selected piece of hardware. Thus, the experiments provide useful information to instructors who may want to develop new Internet mediated exercises. A complete set of instructions including software on how remotely conducted laboratories may be set up, are available to motivate other instructors to create additional Internet-assisted laboratory experiments.

The seven experiments developed in this project have been extensively used in teaching food engineering courses at UC Davis and UDLA. Students in different lecture and laboratory classes have been assigned these experiments. Students had access to these remote-controlled laboratory exercises, and were able to conduct "hands-on" experiments at a computer. "Hands-on" implies that a student carries out various tasks, while the manipulated (live mode) apparatus, may be located in another country. We envision that the use of remote-conducted experiments will be in several modes, including the following three that were already tested: *Pre-Experiment Exercise*. Students will be asked to conduct a given experiment prior to coming to the laboratory. Having conducted an Internet-assisted hands-on experiment, the student will be better prepared to discuss related topics with the instructor and peers. Follow-up experiments may then be conducted with related food process equipment if available. The advantage of this approach is that every student participates in a hands-on experience despite the class size. It is not uncommon in laboratory classes with large enrollments for only a few students in a group to actively participate in every given task; several remain passive observers. By requiring each student to conduct an Internet-assisted experiment prior to attending a laboratory, every student will be better prepared to later work in a group and conduct additional measurements to enhance his or her learning experience. The server keeps a record of names of students who successfully complete an assigned experiment. *Stand-Alone Exercise*. Students may be able to conduct experiments when the required facilities at their respective institutions are not available. *Lecture-Only Classes*. Typically, in lecture-only classes, homework assignments are given that are created with hypothetical data. By incorporating Internet-assisted experiments in those assignments, students will obtain real data for use in problem solving, gaining further insights.

The seven laboratory exercises are now Internet-available (for a fixed-time duration) to interested students and teachers worldwide. At selected international conferences, remote control of laboratory experiments across continents has been demonstrated. Demonstrations have provided new opportunities to conduct joint experiments with some foreign institutions.

3. Remote experiment

To illustrate how a remote-controlled experiment is structured, the experiment *Dynamic Response of Sensors* is briefly described: Sensors are used to sense the change in the property of the environment in which they are employed and thus control the environment according to the need. The time constants of the sensors like resistance temperature detectors (RTD), thermocouple, and thermistor reveal valuable information about their operation, behavior and capability for use in different applications. A property of the environment, for example temperature is sensed by measuring a change in the voltage as in a thermocouple or by the change in the resistance as in the case of thermistor and RTD. A time constant of a temperature sensor such as a thermocouple is a measure of how rapidly the sensor responds to the change in the environmental temperature. The principle of operation of a sensor depends on the different types of sensor designs. In case of a thermocouple, the thermoelectric voltage generated when the junction of two dissimilar metals is heated, is interpreted to give the temperature of the junction. A resistance temperature detector (RTD) operates on the principle of the change in electrical resistance in wire as a function of temperature. A thermistor is similar to an RTD operating on changes in electrical resistance with changes in temperature. Resistance values are correlated to give the temperature. Time constants are calculated on the basis of the sensors reaching 63.2% of the final value to a step change in the temperature.

Sensors used in this experiment are a thermocouple, an RTD and a thermistor. A heater is used to heat the air, and a fan is used to blow the heated air at equilibrium temperature past the sensors, past the sensors. Reference temperature of the heater is measured by a thermocouple previously calibrated with a certified glass thermometer (Miller and Weber Inc., Ridgewood, NY). And a gate is used to give a step change in the temperature by forcing the heated air into the inner pipe where the sensors are kept. The parameters for the experiment include the gate control, and a heater unit. For the gate control, a motor is used which when excited produces a sliding motion used to open the gate. When the motor is not excited, the gate closes the entrance of air to the inner pipe. To measure the reference temperature of the heater unit, a thermocouple is used close to a steel mesh, in line with the sensor positions, in the inner pipe. Since there is a gradient in the temperature of the airflow, the alignment of the reference thermocouple and the three sensors inside the pipe must be properly taken care of to prevent the ambiguity in the measurements. The gate has a digital control (On—when motor is excited and Off—when motor is not excited). While the heater has an analog control (varied from 0% to 100% = 400 W).

Experimental setup consists of two pipes of different diameters such that one slides through the other (Fig. 1). The inner pipe, on one of its end, has the motor control for the gate, which is fixed to the end. Holes for the sensors are drilled across a point in the inner pipe in a way that alignment does not hinder the airflow. At one end of the outer pipe a fan unit is kept and two bulbs, each rated at 200 W, are installed for analog control of the heater unit. A steel mesh is kept next to the bulbs to facilitate the heat distribution and prevent radiation. A hole for a reference thermocouple is also drilled (Fig. 2). A drawing of the experimental set-up is available in Courtois and Singh (2002). The procedure to remotely conduct the experiment *Dynamic Response of Sensors* is as follows: The apache web server is started and *labserverd*, the server program for the sensor dynamics experiment, is executed so that the server is ready to accept host connections. Apache server broadcasts the default static homepage on the server's address (http://foodlab.engr.ucdavis.edu or http://mexus.udlap.mx) as shown in Fig. 3. The server greets the host with its resources. When the host clicks the link for the sensor dynamics experiment, the *labserverd* gets started. First it asks for the host's username and password. If those are not correct, the host is a passive observer and is only allowed to view the experimental setup. Upon proper authentication of the host, a live setup of the experiment with a link taking to controls is displayed (Fig. 4). On clicking the link and authenticating again, the host is taken to the controls, where the heater values (from the scale of 0 to 100) as well as the gate condition (either open or closed) can be controlled. Meantime the user is shown the live image shot by the web cam and the val-

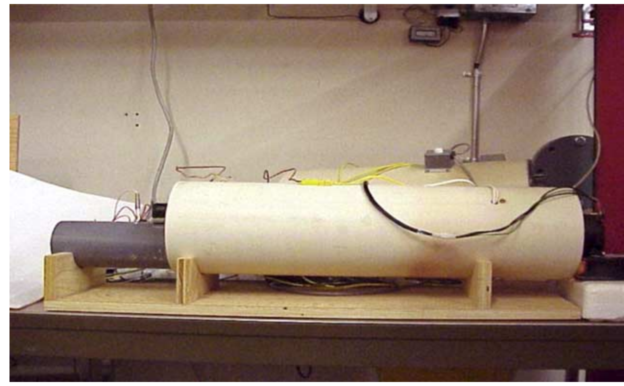

Fig. 1. Experimental setup for the sensor dynamics experiment.

Fig. 2. Cross section of the inner pipe showing the sensors, gauge and bulb.

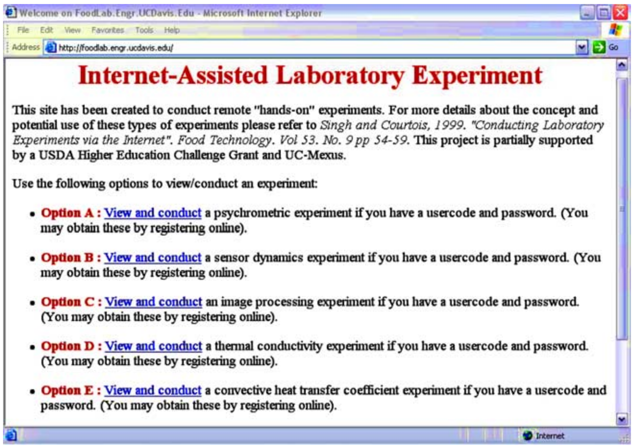

Fig. 3. Remote experiments home page.

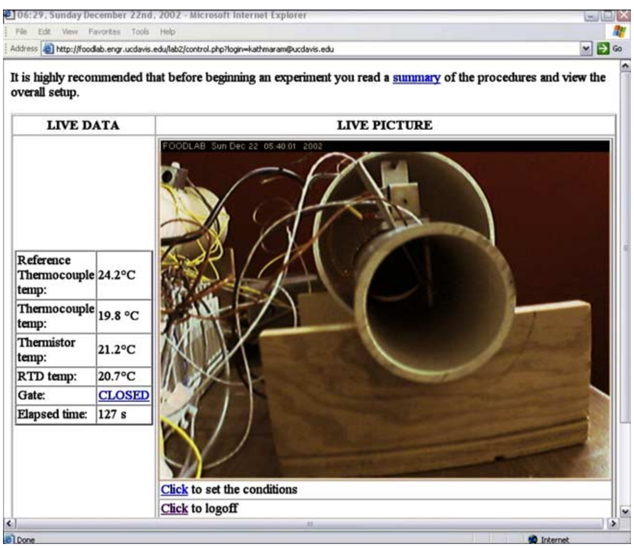

Fig. 4. Live image of the experimental apparatus and preliminary data.

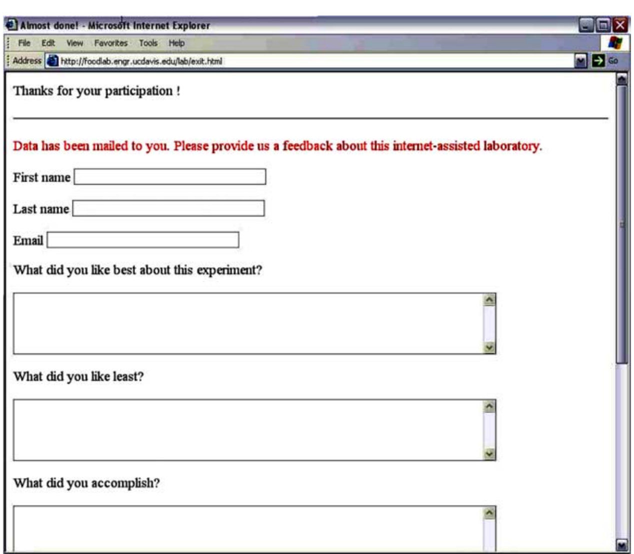

Fig. 5. Session end screen with a feedback form.

Table 1
Time constants of sensors

Trial	Time Constant (s)		
	Thermocouple	RTD[a]	Thermistor
1	19.29	88.50	46.59
2	17.29	87.27	38.10
3	19.83	86.52	35.97
4	19.10	84.03	34.31
5	18.62	83.43	42.47
Average	18.83	85.95	39.49
Standard deviation	0.96	2.16	5.01

[a] Resistance temperature detector.

ues of the sensors like temperature of the ambient thermocouple and sensor thermocouple, RTD temperature and thermistor temperature are displayed continuously with respect to the acquisition rate. The server tracks the user's time and once it gets expired or equals the time allotted for the session, the host is logged out (Fig. 5), and the last screen thanks the student on having successfully completed the experiment, and a set of five questions are asked for immediate feedback regarding the experiment. The student may repeat the experiment for other settings or close the browser and use a spreadsheet application for further data analysis. The data from every experiment are sent to the user's mailbox, copied and saved in a Microsoft Excel™ format with the extension *.xls*. The user opens the file through the Excel program and delimits accordingly to obtain the file in a specified format. The data could then be analyzed. The columns of the data collected in a particular experiment are as follows: time, reference temperature, thermistor, RTD, thermocouple, heater value and the status of the gate control. The time after the gate opens is taken as the reference time, i.e., time is taken as 0 s when the gate opens. The reference temperature is taken as the ambient temperature, T_a, and the initial temperature of the sensors, T_i, when the gate opens. T is the temperature sensed by the sensors with time. Natural logarithm of $(T_a - T)/(T_a - T_i)$ is calculated and plotted versus time. A trend line is fitted for the data plotted and the equation gives the slope of the line. The inverse of the slope gives the time constants of the sensors as presented in Table 1 from actual data obtained by an UDLA student. The average time constant of these particular five replicates for thermocouple is 18.83 s with a standard deviation of 0.96 s. As expected, thermocouple responds fastest to a step change in the environmental temperature, whereas RTD is the slowest of the tested sensors.

4. Evaluation of experiments

We evaluated project effectiveness based on selected questions at the end of each experiment to assess student understanding of the tasks just completed. Furthermore, at the end of a course feedback was obtained through written evaluations as well as from student and instructor reflections. Results demonstrate that this innovative approach of using the Internet has considerable merit in enhancing learning (Courtois & Singh, 2002; Palou et al., 2003). 93% of the students believed the use of remote experiments enhanced their learning and viewed them as valuable and enjoyable experiences. Internet-assisted experiments helped shift students' emphasis toward quality laboratory work, encouraged use of their evaluative and creative skills, and allowed them to take control of their own learning. However, for only a few students the Internet-assisted process was uncomfortable and required additional instructor support.

The positive feedback received from students indicates that these exercises are useful in laboratory classes to develop a self-paced understanding of a concept. In lecture-only classes, students noted that this experience enhanced their learning of concepts that were difficult to understand from reading textbooks. The Internet mediated laboratories have been most advantageous in engaging students in an interactive Internet activity prior to conducting a more comprehensive laboratory experiment. With the pre-exposure to the topic at hand, students are better prepared to discuss issues relevant to a given exercise.

5. Future plans

The opportunities for student interaction across borders and different continents offer new paradigms to enhance learning and collaboration. While we know that our experiments change the teaching and learning experience, we do not have hard, consistent evidence documenting that they enhance academic achievement and learning outcomes in order to be sure that we have transformed the laboratory experiments, instructional activities of the faculty and/or the learning experiences of most students. Therefore our future plans, are to develop, for every experiment, new forms of assessment that focus on establishing what students have learned, the knowledge and skills they have achieved, their potential for further independent learning (Angelo & Cross, 1993; Brakke & Brown, 2002; Speck, 2002) as well as the usability (Mehlenbacher, 2002) of the remote experiments while engaging students from UDLA with those from UC Davis in bi-national teams to conduct experiments on a remote basis and prepare joint laboratory reports (Nicolay, 2002). This will allow students to collaborate on the Internet by collecting and analyzing real-time data. Depending on the outcomes assessment of our attempt, we will seek similar joint opportunities with other institutions in Mexico, United States and abroad.

Acknowledgment

Authors acknowledge financial support from an UC MEXUS-CONACYT Advanced Network Services Applications Collaborative Grant.

References

Angelo, T. A., & Cross, K. P. (1993). *Classroom assessment techniques: A handbook for college teachers* (2nd ed.). San Francisco: Jossey-Bass.

Brakke, D. F., & Brown, D. T. (2002). Assessment to improve student learning. *New Directions for Higher Education, 119*, 119–122.

Courtois, F., & Singh, R. P. (2002). A low-cost, versatile laboratory experiment in food engineering using the internet. In J. Welti-Chanes, G. V. Barbosa-Canovas, & J. M. Aguilera (Eds.), *Engineering and food for the 21st century* (pp. 1035–1041). Boca Raton, Florida: CRC Press.

Mehlenbacher, B. (2002). Assessing the usability of on-line instructional materials. *New Directions for Teaching and Learning, 91*, 91–98.

NAS (1997). *Preparing for the 21st century: The education imperative*. Washington, DC: National Academy of Sciences.

Nicolay, J. A. (2002). Group assessment in the on-line learning environment. *New Directions for Teaching and Learning, 91*, 43–52.

Palou, E., Welti-Chanes, J., Ramírez, J.M., Guerrero, L.G., López-Malo, A., Carrillo, J., Singh, R.P., Athmaram, K., (2003). Internet-assisted remote experiments in teaching food and bioprocess engineering. 2003 ASEE Annual Conference, Nashville, TN.

Rudenstine, N. L. (1997). The internet and education: A close fit. *Chronicle of Higher Education, 43*(24), A48.

Singh, R. P. (1996). Teaching food science and technology on the world wide web. *Food Technology, 50*(3), 94–99.

Singh, R. P. (1999). Conducting laboratory experiments via the internet. *Food Technology, 53*(9), 54–59.

Singh, R. P. (2002). Role of the internet in food engineering teaching. In J. Welti-Chanes, G. V. Barbosa-Canovas, & J. M. Aguilera (Eds.), *Engineering and food for the 21st century* (pp. 1013–1021). Boca Raton, Florida: CRC Press.

Speck, B. W. (2002). Learning-teaching-assessment paradigms and the on-line classroom. *New Directions for Teaching and Learning, 91*, 5–18.